Java Concepts

6th Edition

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Cay Horstmann

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Java Concepts

6th edition

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PREFACE

This book is an introductory text in computer science, focusing on the principles of programming and software engineering. Here are its key features:

- Teach objects gradually.

  In Chapter 2, students learn how to use objects and classes from the standard library. Chapter 3 shows the mechanics of implementing classes *from a given specification*. Students then use simple objects as they master branches, loops, and arrays. Object-oriented design starts in Chapter 8. This gradual approach allows students to use objects throughout their study of the core algorithmic topics, without teaching bad habits that must be un-learned later.

- Reinforce sound engineering practices.

  A focus on test-driven development encourages students to test their programs systematically. A multitude of useful tips on software quality and common errors encourage the development of good programming habits.

- Help students with guidance and worked examples.

  Beginning programmers often ask "How do I start? Now what do I do?" Of course, an activity as complex as programming cannot be reduced to cookbook-style instructions. However, step-by-step guidance is immensely helpful for building confidence and providing an outline for the task at hand. The book contains a large number of "How To" guides for common tasks, with pointers to additional worked examples on the Web.

- Focus on the essentials while being technically accurate.

  An encyclopedic coverage is not helpful for a beginning programmer, but neither is the opposite—reducing the material to a list of simplistic bullet points that give an illusion of knowledge. In this book, the essentials of each subject are presented in digestible chunks, with separate notes that go deeper into good practices or language features when the reader is ready for the additional information.

- Use standard Java.

  The book teaches the standard Java language—not a specialized "training wheels" environment. The Java language, library, and tools are presented at a depth that is sufficient to solve real-world programming problems.

- Provide an optional graphics track.

  Graphical shapes are splendid examples of objects. Many students enjoy writing programs that create drawings or use graphical user interfaces. If desired, these topics can be integrated into the course by using the materials at the end of Chapters 2, 3, 9, and 10.

New in This Edition

This is the fourth edition of *Big Java,* and the book has once again been carefully revised and updated. The new and improved features include:

More Help for Beginning Programmers

- The How To sections have been updated and expanded, and four new ones have been added. Fifteen new Worked Examples (on the companion web site and in WileyPLUS) walk students through the steps required for solving complex and interesting problems.
- The treatment of algorithm design, planning, and the use of pseudocode has been enhanced. Students learn to use pseudocode to define the solution algorithm in Chapter 1.
- Chapters have been revised to focus each section on a specific learning objective. These learning objectives also organize the chapter summary to help students assess their progress.

Annotated Examples

- Syntax diagrams now call out features of typical example code to draw student attention to the key elements of the syntax. Additional annotations point out special cases, common errors, and good practice associated with the syntax.
- New example tables clearly present a variety of typical and special cases in a compact format. Each example is accompanied by a brief note explaining the usage shown and the values that result from it.
- The gradual introduction of objects has been further improved by providing additional examples and insights in the early chapters.

Updated for Java 7

- Features introduced in Java 7 are covered as Special Topics so that students can prepare for them. In this edition, we use Java 5 or 6 for the main discussion.

More Opportunities for Practice

- The test bank has been greatly expanded and improved. (See page xi.)
- A new set of lab assignments enables students to practice solving complex problems one step at a time.
- The LabRat code evaluation feature, enhanced for this edition, gives students instant feedback on their programming assignments. (See page xvi.)

A Tour of the Book

The book can be naturally grouped into four parts, as illustrated by Figure 1. The organization of chapters offers the same flexibility as the previous edition; dependencies among the chapters are also shown in the figure.

Part A: Fundamentals (Chapters 1–7)

Chapter 1 contains a brief introduction to computer science and Java programming. Chapter 2 shows how to manipulate objects of predefined classes. In Chapter 3, you will build your own simple classes from given specifications.

Fundamental data types, branches, loops, and arrays are covered in Chapters 4–7.

Part B: Object-Oriented Design (Chapters 8–12)

Chapter 8 takes up the subject of class design in a systematic fashion, and it introduces a very simple subset of the UML notation.

The discussion of polymorphism and inheritance is split into two chapters. Chapter 9 covers interfaces and polymorphism, whereas Chapter 10 covers inheritance. Introducing interfaces before inheritance pays off in an important way: Students immediately see polymorphism before getting bogged down with technical details such as superclass construction.

Exception handling and basic file input/output are covered in Chapter 11. The exception hierarchy gives a useful example for inheritance.

Chapter 12 contains an introduction to object-oriented design, including two significant case studies.

Part C: Data Structures and Algorithms (Chapters 13–15)

Chapters 13 through 15 contain an introduction to algorithms and basic data structures, covering recursion, sorting and searching, and linked lists, stacks, and queues. These topics can be covered as desired after Chapter 7 (see Figure 1).

Recursion is introduced from an object-oriented point of view: An object that solves a problem recursively constructs another object of the same class that solves a simpler problem. The idea of having the other object do the simpler job is more intuitive than having a function call itself.

Chapter 14 covers the fundamental sorting algorithms and gives a gentle introduction to big-Oh analysis. Chapter 15 introduces linked lists, stacks, and queues, both as abstract data types and as they appear in the standard Java library.

Part D: Advanced Topics (Chapters 16–18)

Chapter 16 covers advanced data structures: hash tables, binary search trees, and heaps. Chapter 17 introduces Java generics. This chapter is suitable for advanced students who want to implement their own generic classes and methods. Chapter 18 completes the graphics track coverage of user interfaces with a discussion of layout management and Swing components. These chapters are available on the Web at `www.wiley.com/college/horstmann`, or in the WileyPLUS course for this book.

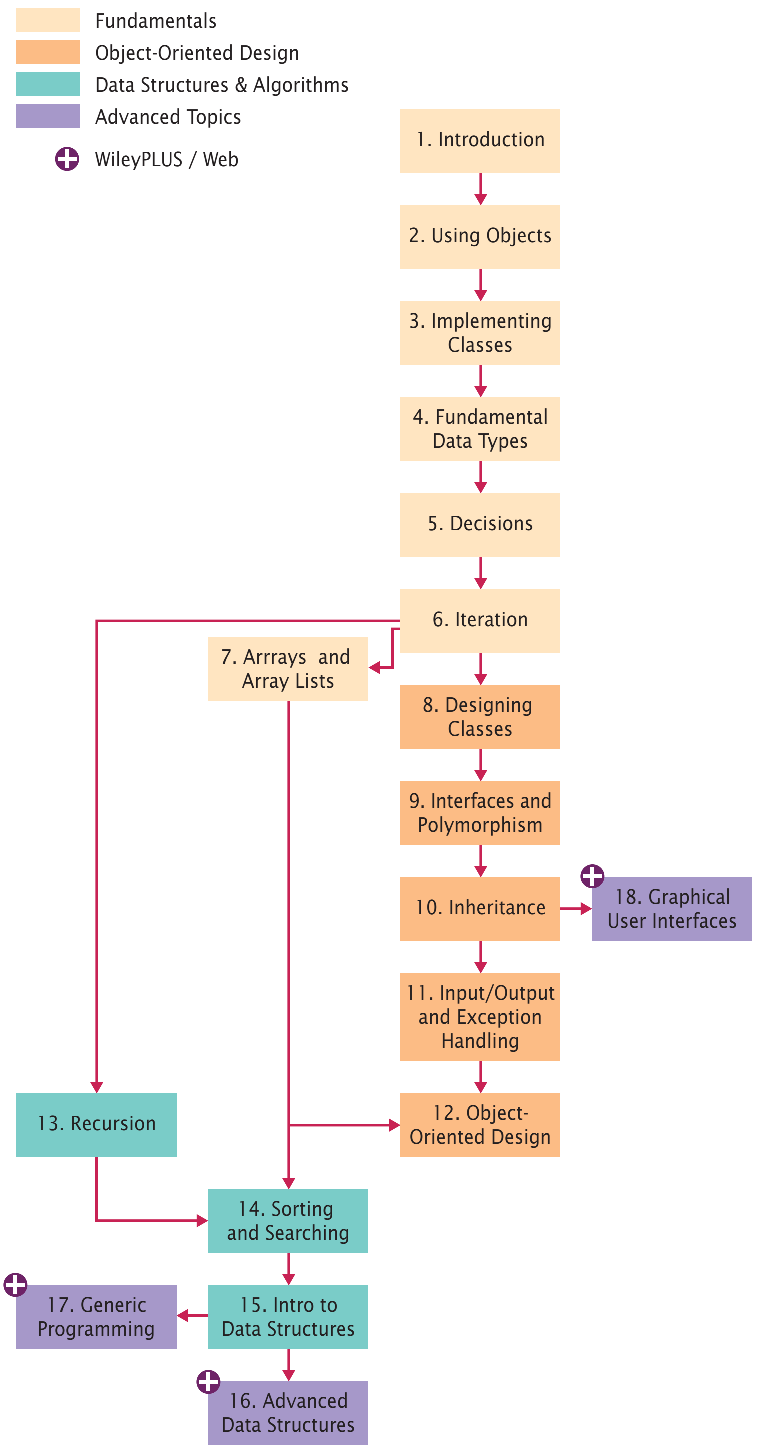

Fundamentals
Object-Oriented Design
Data Structures & Algorithms
Advanced Topics
WileyPLUS / Web
1. Introduction
2. Using Objects
3. Implementing Classes
4. Fundamental Data Types
5. Decisions
6. Iteration
7. Arrrays and Array Lists
8. Designing Classes
9. Interfaces and Polymorphism
10. Inheritance
18. Graphical User Interfaces
11. Input/Output and Exception Handling
12. Object-Oriented Design
13. Recursion
14. Sorting and Searching
15. Intro to Data Structures
17. Generic Programming
16. Advanced Data Structures

Figure 1 Chapter Dependencies

Appendices

Appendix A lists character escape sequences and the Basic Latin and Latin-1 subsets of Unicode. Appendices B and C summarize Java reserved words and operators. Appendix D documents all of the library methods and classes used in this book.

In addition, Appendices E–L are available on the Web and contain quick references on Java syntax, HTML, Java tools, binary numbers, and UML.

Appendix L contains a style guide for use with this book. Many instructors find it highly beneficial to require a consistent style for all assignments. If this style guide conflicts with instructor sentiment or local customs, however, it is available in electronic form so that it can be modified.

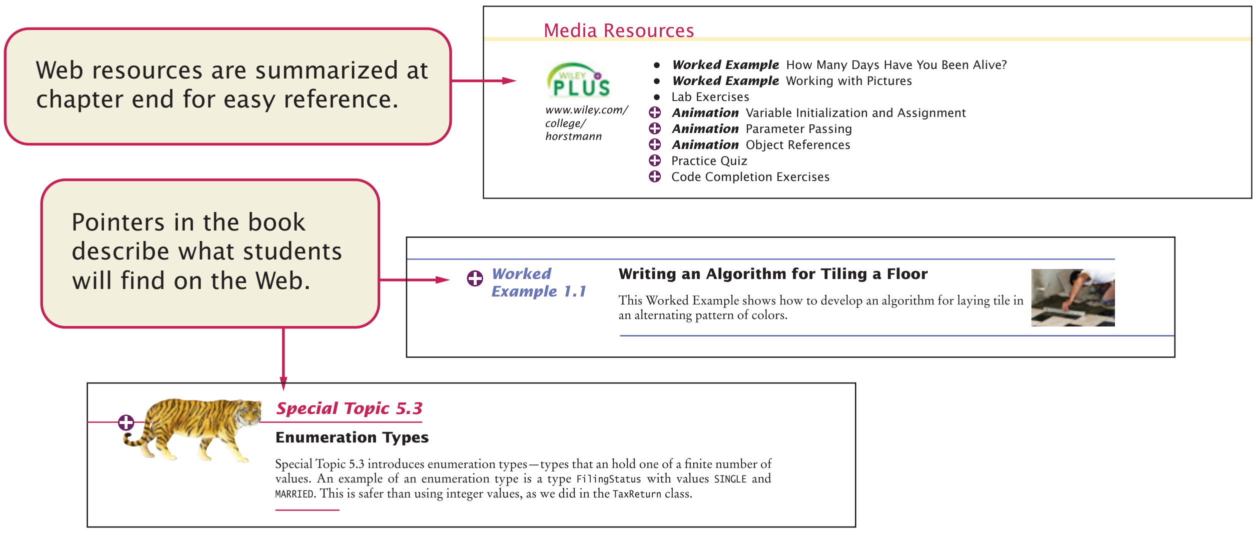
Web Resources

This book is complemented by a complete suite of online resources and a robust WileyPLUS course.

Go to `www.wiley.com/college/horstmann` to visit the online companion site, which includes

- Source code for all examples in the book.
- Worked Examples that apply the problem-solving steps in the book to other realistic examples.
- Laboratory exercises (and solutions for instructors only).
- Lecture presentation slides (in HTML and PowerPoint formats).
- Solutions to all review and programming exercises (for instructors only).
- A test bank that focuses on skills, not just terminology (for instructors only).

WileyPLUS is an online teaching and learning environment that integrates the digital textbook with instructor and student resources. See page xvi for details.



Web resources are summarized at chapter end for easy reference.

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** How Many Days Have You Been Alive?
- ***Worked Example*** Working with Pictures
- Lab Exercises
- ***Animation*** Variable Initialization and Assignment
- ***Animation*** Parameter Passing
- ***Animation*** Object References
- Practice Quiz
- Code Completion Exercises

Pointers in the book describe what students will find on the Web.

Worked Example 1.1 **Writing an Algorithm for Tiling a Floor**

This Worked Example shows how to develop an algorithm for laying tile in an alternating pattern of colors.

Special Topic 5.3

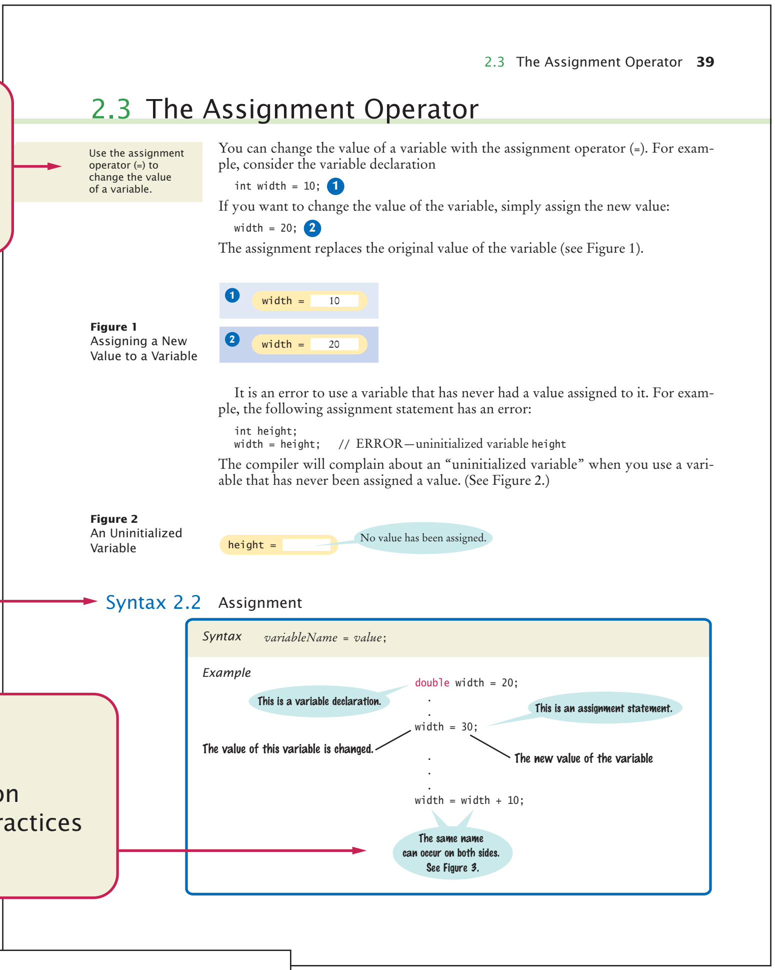
Enumeration Types

Special Topic 5.3 introduces enumeration types—types that an hold one of a finite number of values. An example of an enumeration type is a type `FilingStatus` with values `SINGLE` and `MARRIED`. This is safer than using integer values, as we did in the `TaxReturn` class.

A Walkthrough of the Learning Aids

The pedagogical elements in this book work together to make the book accessible to beginners as well as those learning Java as a second language.

Throughout each chapter, **margin notes** show where new concepts are introduced and provide an outline of key ideas.



2.3 The Assignment Operator 39

2.3 The Assignment Operator

Use the assignment operator (=) to change the value of a variable.

You can change the value of a variable with the assignment operator (=). For example, consider the variable declaration

```
int width = 10; ❶
```

If you want to change the value of the variable, simply assign the new value:

```
width = 20; ❷
```

The assignment replaces the original value of the variable (see Figure 1).

Figure 1 Assigning a New Value to a Variable

It is an error to use a variable that has never had a value assigned to it. For example, the following assignment statement has an error:

```
int height;
width = height;   // ERROR—uninitialized variable height
```

The compiler will complain about an "uninitialized variable" when you use a variable that has never been assigned a value. (See Figure 2.)

Figure 2 An Uninitialized Variable

Annotated **syntax boxes** provide a quick, visual overview of new language constructs.

Syntax 2.2 Assignment

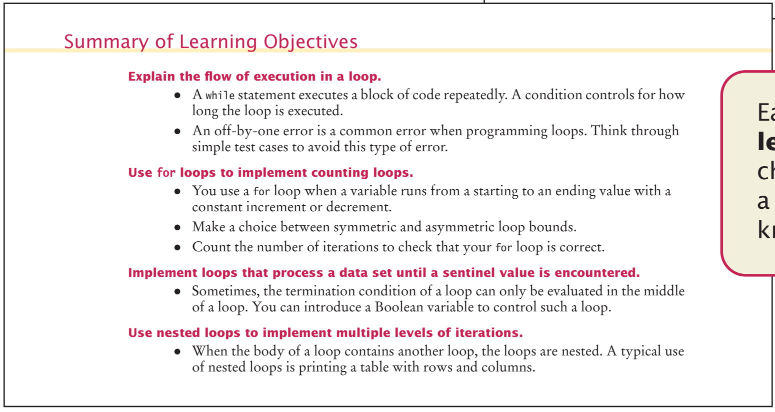
Syntax *variableName* = *value*;

Example

```
double width = 20;
   .
   .
width = 30;
   .
   .
width = width + 10;
```

This is a variable declaration.
This is an assignment statement.
The value of this variable is changed.
The new value of the variable
The same name can occur on both sides. See Figure 3.

Annotations explain required components and point to more information on common errors or best practices associated with the syntax.



Summary of Learning Objectives

Explain the flow of execution in a loop.

- A `while` statement executes a block of code repeatedly. A condition controls for how long the loop is executed.
- An off-by-one error is a common error when programming loops. Think through simple test cases to avoid this type of error.

Use `for` loops to implement counting loops.

- You use a `for` loop when a variable runs from a starting to an ending value with a constant increment or decrement.
- Make a choice between symmetric and asymmetric loop bounds.
- Count the number of iterations to check that your `for` loop is correct.

Implement loops that process a data set until a sentinel value is encountered.

- Sometimes, the termination condition of a loop can only be evaluated in the middle of a loop. You can introduce a Boolean variable to control such a loop.

Use nested loops to implement multiple levels of iterations.

- When the body of a loop contains another loop, the loops are nested. A typical use of nested loops is printing a table with rows and columns.

Each section corresponds to a **learning objective**, summarized at chapter end, giving students a roadmap for assessing what they know and what they need to review.

How To 1.1 **Developing and Describing an Algorithm**

This is the first of many "How To" sections in this book that give you step-by-step procedures for carrying out important tasks in developing computer programs.

Before you are ready to write a program in Java, you need to develop an algorithm—a method for arriving at a solution for a particular problem. Describe the algorithm in pseudocode: a sequence of precise steps formulated in English.

For example, consider this problem: You have the choice of buying two cars. One is more fuel efficient than the other, but also more expensive. You know the price and fuel efficiency (in miles per gallon, mpg) of both cars. You plan to keep the car for ten years. Assume a price of $4 per gallon of gas and usage of 15,000 miles per year. You will pay cash for the car and not worry about financing costs. Which car is the better deal?

Step 1 Determine the inputs and outputs.

In our sample problem, we have these inputs:

- purchase price1 and fuel efficiency1, the price and fuel efficiency (in mpg) of the first car.
- purchase price2 and fuel efficiency2, the price and fuel efficiency of the second car.

We simply want to know which car is the better buy. That is the desired output.

Step 2 Break down the problem into smaller tasks.

For each car, we need to know the total cost of driving it. Let's do this computation separately for each car. Once we have the total cost for each car, we can decide which car is the better deal.

The total cost for each car is purchase price + operating cost.

We assume a constant usage and gas price for ten years, so the operating cost depends on the cost of driving the car for one year.

The operating cost is 10 x annual fuel cost.
The annual fuel cost is price per gallon x annual fuel consumed.

The annual fuel consumed is annual miles driven / fuel efficiency. For example, if you drive the for 15,000 miles and the fuel efficiency is 15 miles/gallon, the car consumes 1,000 gallons

Step 3 Describe each subtask in pseudocode.

In your description, arrange the steps so that any intermediate values are computed be they are needed in other computations. For example, list the step

```
total cost = purchase price + operating cost
```

after you have computed operating cost.

Here is the algorithm for deciding which car to buy.

```
For each car, compute the total cost as follows:
    annual fuel consumed = annual miles driven / fuel efficiency
    annual fuel cost = price per gallon x annual fuel consumed
    operating cost = 10 x annual fuel cost
    total cost = purchase price + operating cost
```

How To guides give step-by-step guidance for common programming tasks, emphasizing planning and testing. They answer the beginner's question, "Now what do I do?" and integrate key concepts into a problem-solving sequence.

Worked Examples apply the steps in the How To to a different example, illustrating how they can be used to plan, implement, and test a solution to another programming problem.

Worked Example 1.1 **Writing an Algorithm for Tiling a Floor**

This Worked Example shows how to develop an algorithm for laying tile in an alternating pattern of colors.

Worked Example 6.1 **Credit Card Processing**

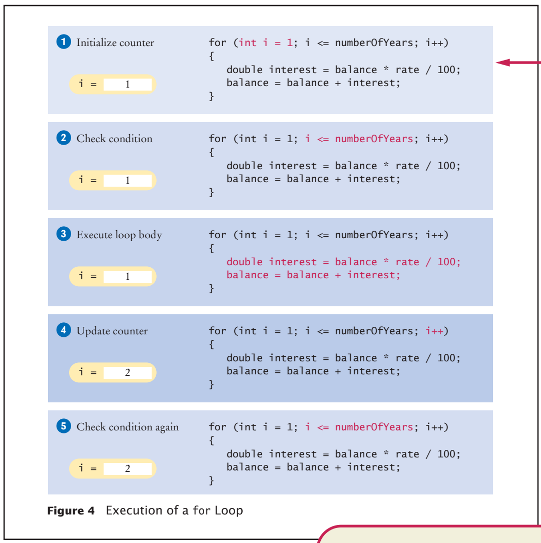
This Worked Example uses a loop to remove spaces from a credit card number.

Example tables support beginners with multiple, concrete examples. These tables point out common errors and present another quick reference to the section's topic.

Table 1 Relational Operator Examples

Expression	Value	Comment
`3 <= 4`	true	3 is less than 4; <= tests for "less than or equal".
🚫 `3 =< 4`	**Error**	The "less than or equal" operator is <=, not =<, with the "less than" symbol first.
`3 > 4`	false	> is the opposite of <=.
`4 < 4`	false	The left-hand side must be strictly smaller than the right-hand side.
`4 <= 4`	true	Both sides are equal; <= tests for "less than or equal".
`3 == 5 - 2`	true	== tests for equality.
`3 != 5 - 1`	true	!= tests for inequality. It is true that 3 is not 5 – 1.
🚫 `3 = 6 / 2`	**Error**	Use == to test for equality.
`1.0 / 3.0 == 0.333333333`	false	Although the values are very close to one another, they are not exactly equal. See Common Error 4.3.
🚫 `"10" > 5`	**Error**	You cannot compare a string to a number.
`"Tomato".substring(0, 3).equals("Tom")`	true	Always use the `equals` method to check whether two strings have the same contents.
`"Tomato".substring(0, 3) == ("Tom")`	false	Never use == to compare strings; it only checks whether the strings are stored in the same location. See Common Error 5.2 on page 180.
`"Tom".equalsIgnoreCase("TOM")`	true	Use the `equalsIgnoreCase` method if you don't want to distinguish between uppercase and lowercase letters.

Progressive figures trace code segments to help students visualize the program flow. Color is used consistently to make variables and other elements easily recognizable.



1 Initialize counter

```
i = 1

for (int i = 1; i <= numberOfYears; i++)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

2 Check condition

```
i = 1

for (int i = 1; i <= numberOfYears; i++)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

3 Execute loop body

```
i = 1

for (int i = 1; i <= numberOfYears; i++)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

4 Update counter

```
i = 2

for (int i = 1; i <= numberOfYears; i++)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

5 Check condition again

```
i = 2

for (int i = 1; i <= numberOfYears; i++)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

Figure 4 Execution of a for Loop

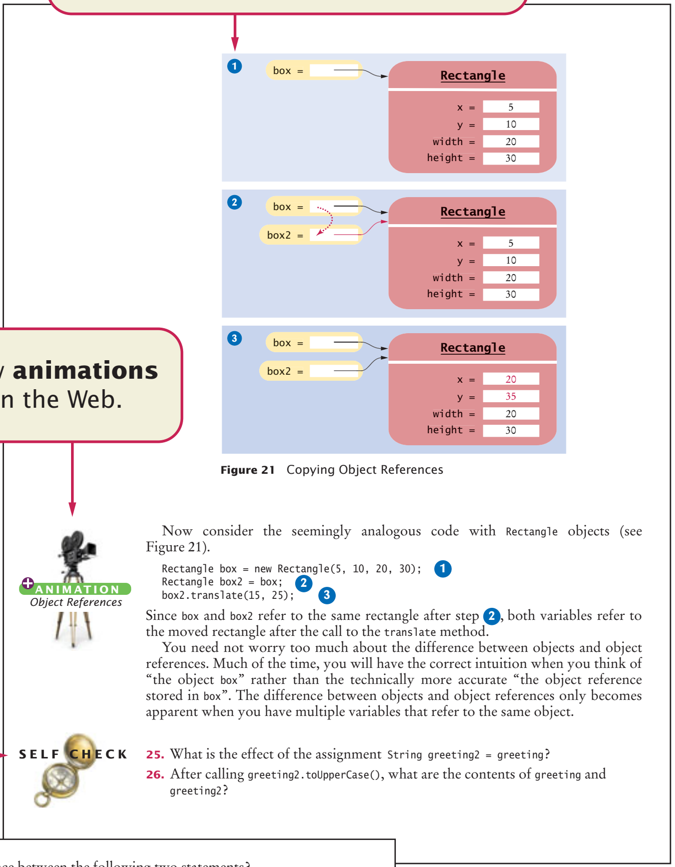


Figure 21 Copying Object References

ANIMATION
Object References

Now consider the seemingly analogous code with `Rectangle` objects (see Figure 21).

```
Rectangle box = new Rectangle(5, 10, 20, 30); 1
Rectangle box2 = box; 2
box2.translate(15, 25); 3
```

Since `box` and `box2` refer to the same rectangle after step 2, both variables refer to the moved rectangle after the call to the `translate` method.

You need not worry too much about the difference between objects and object references. Much of the time, you will have the correct intuition when you think of “the object `box`” rather than the technically more accurate “the object reference stored in `box`”. The difference between objects and object references only becomes apparent when you have multiple variables that refer to the same object.

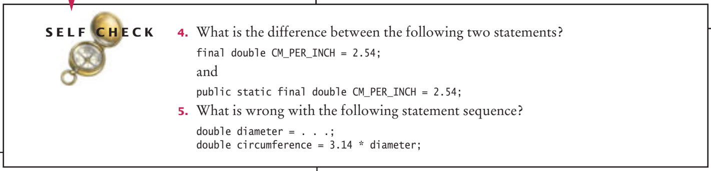
SELF CHECK

25. What is the effect of the assignment `String greeting2 = greeting`?

26. After calling `greeting2.toUpperCase()`, what are the contents of `greeting` and `greeting2`?

Students can view **animations** of key concepts on the Web.

Self-check exercises at the end of each section are designed to make students think through the new material—and can spark discussion in lecture.



SELF CHECK

4. What is the difference between the following two statements?

```
final double CM_PER_INCH = 2.54;
```

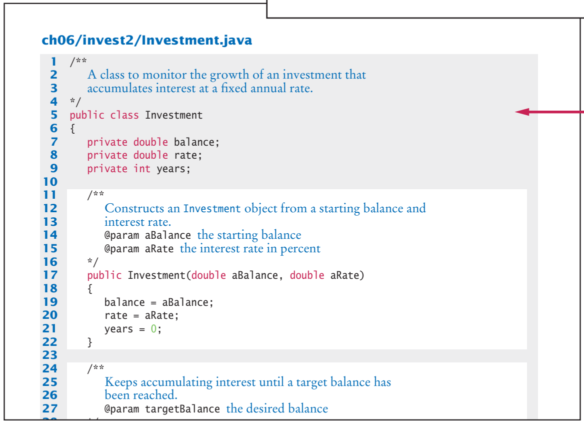
and

```
public static final double CM_PER_INCH = 2.54;
```

5. What is wrong with the following statement sequence?

```
double diameter = . . .;
double circumference = 3.14 * diameter;
```

Program listings are carefully designed for easy reading, going well beyond simple color coding. Methods are set off by a subtle outline.



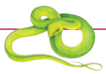
ch06/invest2/Investment.java

```
/**
   A class to monitor the growth of an investment that
   accumulates interest at a fixed annual rate.
*/
public class Investment
{
   private double balance;
   private double rate;
   private int years;

   /**
      Constructs an Investment object from a starting balance and
      interest rate.
      @param aBalance the starting balance
      @param aRate the interest rate in percent
   */
   public Investment(double aBalance, double aRate)
   {
      balance = aBalance;
      rate = aRate;
      years = 0;
   }

   /**
      Keeps accumulating interest until a target balance has
      been reached.
      @param targetBalance the desired balance
```

Common Errors describe the kinds of errors that students often make, with an explanation of why the errors occur, and what to do about them.



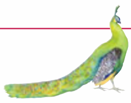
Common Error 7.3

Length and Size

Unfortunately, the Java syntax for determining the number of elements in an array, an array list, and a string is not at all consistent. It is a common error to confuse these. You just have to remember the correct syntax for every data type.

Data Type	Number of Elements
Array	`a.length`
Array list	`a.size()`
String	`a.length()`

Quality Tips explain good programming practices. These notes carefully motivate the reason behind the advice, and explain why the effort will be repaid later.



Quality Tip 4.1

Do Not Use Magic Numbers

A magic number is a numeric constant that appears in your code without explanation. For example, consider the following scary example that actually occurs in the Java library source:

```
h = 31 * h + ch;
```

Why 31? The number of days in January? One less than the number of bits in an integer? Actually, this code computes a "hash code" from a string—a number that is derived from the characters in such a way that different strings are likely to yield different hash codes. The value 31 turns out to scramble the character values nicely.

A better solution is to use a named constant:

```
final int HASH_MULTIPLIER = 31;
h = HASH_MULTIPLIER * h + ch;
```

You should never use magic numbers in your code. Any number that is not completely self-explanatory should be declared as a named constant. Even the most reasonable cosmic constant is going to change one day. You think there are 365 days in a year? Your customers on Mars are going to be pretty unhappy about your silly prejudice. Make a constant

```
final int DAYS_PER_YEAR = 365;
```

By the way, the device

```
final int THREE_HUNDRED_AND_SIXTY_FIVE = 365;
```

Productivity Hints teach students how to use their time and tools more effectively. They encourage students to be more productive with tips and techniques such as hand-tracing.

Productivity Hint 6.1

Hand-Tracing Loops

In Programming Tip 5.2, you learned about the method of hand tracing. This method is particularly effective for understanding how a loop works.

Consider this example loop. What value is displayed?

```
int n = 1729; 1
int sum = 0;
while (n > 0) 2
{
   int digit = n % 10; 3 4 5 6
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum); 7
```

1. There are three variables: `n`, `sum`, and `digit`. The first two variables are initialized with 1729 and 0 before the loop is entered.

n	sum	digit
1729	0	

Special Topics present optional topics and provide additional explanation of others. New features of Java 7 are also covered in these notes.

Special Topic 7.2

`ArrayList` Syntax Enhancements in Java 7

Java 7 introduces several convenient syntax enhancements for array lists.

When you declare and construct an array list, you need not repeat the type parameter in the constructor. That is, you can write

```
ArrayList<String> names = new ArrayList<>();
```

instead of

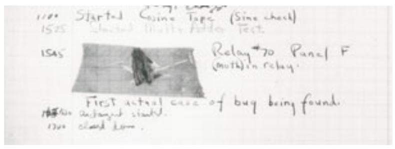
```
ArrayList<String> names = new ArrayList<String>();
```

Random Facts provide historical and social information on computing—for interest and to fulfill the "historical and social context" requirements of the ACM/IEEE curriculum guidelines.

Random Fact 6.1

The First Bug

According to legend, the first bug was one found in 1947 in the Mark II, a huge electromechanical computer at Harvard University. It really was caused by a bug—a moth trapped in a relay switch. Actually, from the note that the operator left in the log book next to the moth (see the figure), it appears as if the term "bug" had already been in active use at the time.



1100 Started Cosine Tape (Sine check)
1525 Started Multi Adder Test.
1545 Relay #70 Panel F
(moth) in relay.
First actual case of bug being found.
1700 closed down.

The First Bug

The pioneering computer scientist Maurice Wilkes wrote: "Somehow, at the Moore School and afterwards, one had always assumed there would be no particular difficulty in getting programs right. I can remember the exact instant in time at which it dawned on me

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For Students

Different learning styles, different levels of proficiency, different levels of preparation—each student is unique. WileyPLUS empowers all students to take advantage of their individual strengths.

Integrated, multi-media resources—including audio and visual exhibits and demonstration problems—encourage active learning and provide multiple study paths to fit each student's learning preferences.

- Worked Examples apply the problem-solving steps in the book to another realistic example.
- Screencast Videos present the author explaining the steps he is taking and showing his work as he solves a programming problem.
- Animations of key concepts allow students to replay dynamic explanations that instructors usually provide on a whiteboard.

Self-assessments are linked to relevant portions of the text. Students can take control of their own learning and practice until they master the material.

- Practice quizzes can reveal areas where students need to focus.
- Lab exercises can be assigned for self-study or for use in the lab.
- "Code completion" questions enable students to practice programming skills by filling in small code snippets and getting immediate feedback.
- LabRat provides instant feedback on student solutions to all programming exercises in the book.

For Instructors

WileyPLUS includes all of the instructor resources found on the companion site, and more.

WileyPLUS gives you tools for identifying those students who are falling behind, allowing you to intervene accordingly, without having to wait for them to come to office hours.

- Practice quizzes for pre-reading assessment, self-quizzing, or additional practice can be used as-is or modified for your course needs.
- Multi-step laboratory exercises can be used in lab or assigned for extra student practice.

WileyPLUS simplifies and automates student performance assessment, making assignments, and scoring student work.

- An extensive set of multiple-choice questions for quizzing and testing have been developed to focus on skills, not just terminology.
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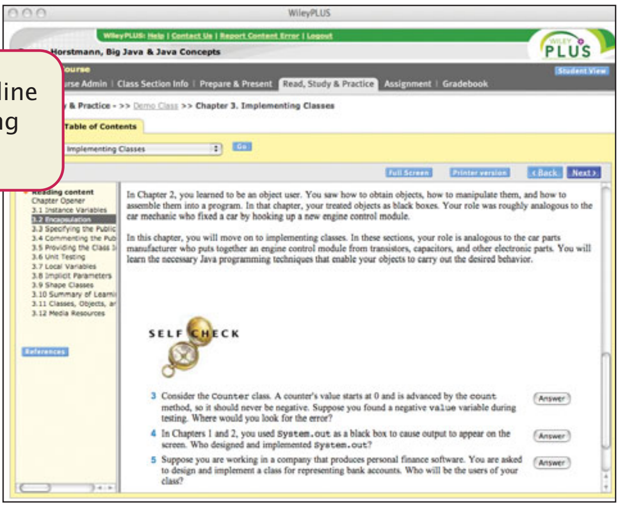
- LabRat can track student work on all programming exercises in the book, adding the student solution and a record of completion to the gradebook.
- Solutions to all review and programming exercises are provided..

With WileyPLUS ...

Students can read the book online and take advantage of searching and cross-linking.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Horstmann, Big Java & Java Concepts
Read, Study & Practice
Chapter 3. Implementing Classes
Table of Contents
Full Screen
Printer version
‹ Back
Next ›
SELF CHECK

In Chapter 2, you learned to be an object user. You saw how to obtain objects, how to manipulate them, and how to assemble them into a program. In that chapter, your treated objects as black boxes. Your role was roughly analogous to the car mechanic who fixed a car by hooking up a new engine control module.

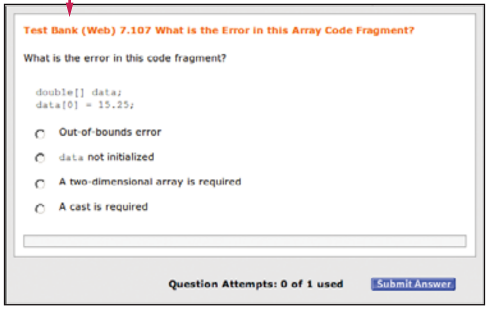
In this chapter, you will move on to implementing classes. In these sections, your role is analogous to the car parts manufacturer who puts together an engine control module from transistors, capacitors, and other electronic parts. You will learn the necessary Java programming techniques that enable your objects to carry out the desired behavior.

3 Consider the `Counter` class. A counter's value starts at 0 and is advanced by the `count` method, so it should never be negative. Suppose you found a negative `value` variable during testing. Where would you look for the error?

4 In Chapters 1 and 2, you used `System.out` as a black box to cause output to appear on the screen. Who designed and implemented `System.out`?

5 Suppose you are working in a company that produces personal finance software. You are asked to design and implement a class for representing bank accounts. Who will be the users of your class?

Instructors can assign drill-and-practice questions to check that students did their reading and grasp basic concepts.



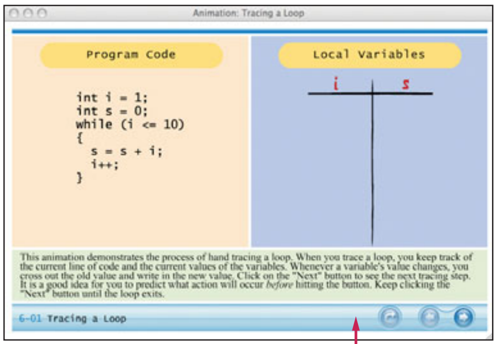
Test Bank (Web) 7.107 What is the Error in this Array Code Fragment?

What is the error in this code fragment?

```
double[] data;
data[0] = 15.25;
```

- Out-of-bounds error
- `data` not initialized
- A two-dimensional array is required
- A cast is required

Question Attempts: 0 of 1 used

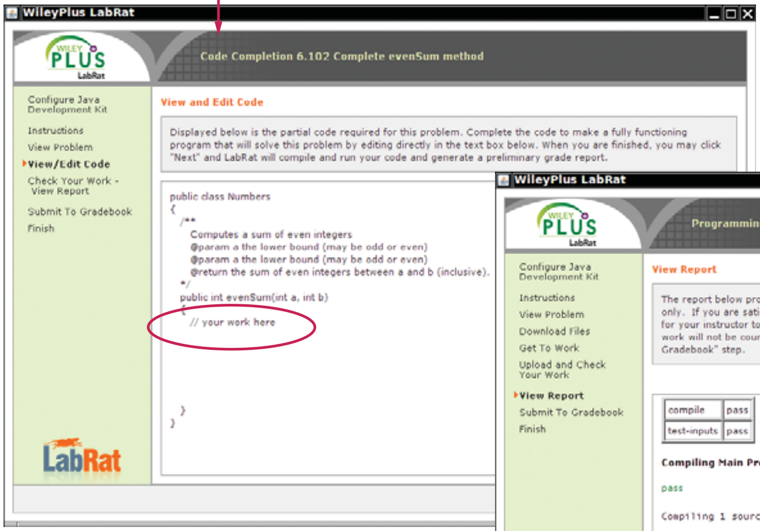


```
int i = 1;
int s = 0;
while (i <= 10)
{
  s = s + i;
  i++;
}
```

This animation demonstrates the process of hand tracing a loop. When you trace a loop, you keep track of the current line of code and the current values of the variables. Whenever a variable's value changes, you cross out the old value and write in the new value. Click on the "Next" button to see the next tracing step. It is a good idea for you to predict what action will occur *before* hitting the button. Keep clicking the "Next" button until the loop exits.

Students can practice programming by filling in small code snippets and getting immediate feedback.

Students can play and replay dynamic explanations of concepts and program flow.


WileyPlus LabRat
Code Completion 6.102 Complete evenSum method
Configure Java Development Kit
Instructions
View Problem
View/Edit Code
Check Your Work - View Report
Submit To Gradebook
Finish
LabRat

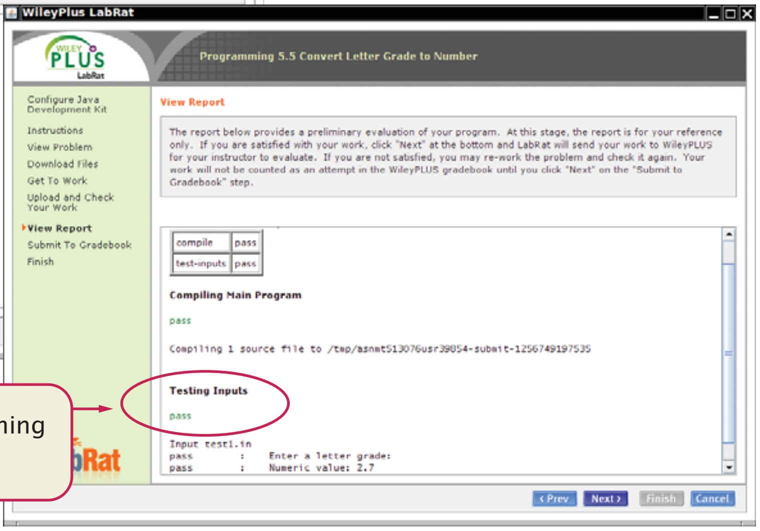
View and Edit Code

Displayed below is the partial code required for this problem. Complete the code to make a fully functioning program that will solve this problem by editing directly in the text box below. When you are finished, you may click "Next" and LabRat will compile and run your code and generate a preliminary grade report.

```
public class Numbers
{
  /**
    Computes a sum of even integers
    @param a the lower bound (may be odd or even)
    @param a the lower bound (may be odd or even)
    @return the sum of even integers between a and b (inclusive).
  */
  public int evenSum(int a, int b)
  {
    // your work here



  }
}
```



View Report

The report below provides a preliminary evaluation of your program. At this stage, the report is for your reference only. If you are satisfied with your work, click "Next" at the bottom and LabRat will send your work to WileyPLUS for your instructor to evaluate. If you are not satisfied, you may re-work the problem and check it again. Your work will not be counted as an attempt in the WileyPLUS gradebook until you click "Next" on the "Submit to Gradebook" step.

compile	pass
test-inputs	pass

```
Compiling Main Program

pass

Compiling 1 source file to /tmp/asnmt513076usr39854-submit-1256749197535

Testing Inputs

pass

Input test1.in
pass        :    Enter a letter grade:
pass        :    Numeric value: 2.7
```

Students can check that their programming assignments fulfill the specifications.

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CONTENTS

PREFACE **vii**
SPECIAL FEATURES **xxviii**

CHAPTER 1 INTRODUCTION **1**

1.1 What Is Programming? **2**
1.2 The Anatomy of a Computer **3**
1.3 Translating Human-Readable Programs to Machine Code **7**
1.4 The Java Programming Language **8**
1.5 The Structure of a Simple Program **10**
1.6 Compiling and Running a Java Program **14**
1.7 Errors **17**
1.8 Algorithms **19**

CHAPTER 2 USING OBJECTS **31**

2.1 Types **32**
2.2 Variables **34**
2.3 The Assignment Operator **37**
2.4 Objects, Classes, and Methods **39**
2.5 Method Parameters and Return Values **41**
2.6 Constructing Objects **44**
2.7 Accessor and Mutator Methods **46**
2.8 The API Documentation **47**
2.9T Implementing a Test Program **50**
2.10 Object References **52**
2.11G Graphical Applications and Frame Windows **54**
2.12G Drawing on a Component **56**
2.13G Ellipses, Lines, Text, and Color **59**

CHAPTER 3 IMPLEMENTING CLASSES **73**

3.1 Instance Variables **74**
3.2 Encapsulation **76**
3.3 Specifying the Public Interface of a Class **77**
3.4 Commenting the Public Interface **81**
3.5 Providing the Class Implementation **84**
3.6T Unit Testing **90**

3.7 Local Variables 92
3.8 Implicit Parameters 94
3.9G Shape Classes 96

CHAPTER 4 FUNDAMENTAL DATA TYPES 115

4.1 Number Types 116
4.2 Constants 118
4.3 Arithmetic Operations and Mathematical Functions 123
4.4 Calling Static Methods 131
4.5 Strings 134
4.6 Reading Input 138

CHAPTER 5 DECISIONS 151

5.1 The if Statement 152
5.2 Comparing Values 156
5.3 Multiple Alternatives 165
5.4 Using Boolean Expressions 173
5.5T Code Coverage 178

CHAPTER 6 ITERATION 193

6.1 while Loops 194
6.2 for Loops 201
6.3 Common Loop Algorithms 210
6.4 Nested Loops 218
6.5 Application: Random Numbers and Simulations 221
6.6T Using a Debugger 223

CHAPTER 7 ARRAYS AND ARRAY LISTS 241

7.1 Arrays 242
7.2 Array Lists 248
7.3 Wrappers and Auto-boxing 254
7.4 The Enhanced for Loop 255
7.5 Partially Filled Arrays 257
7.6 Common Array Algorithms 259
7.7T Regression Testing 271
7.8 Two-Dimensional Arrays 274

CHAPTER 8 DESIGNING CLASSES 289

8.1 Discovering Classes 290
8.2 Cohesion and Coupling 291
8.3 Immutable Classes 294
8.4 Side Effects 295
8.5 Preconditions and Postconditions 299
8.6 Static Methods 302
8.7 Static Variables 304
8.8 Scope 307
8.9 Packages 310
8.10T Unit Test Frameworks 316

CHAPTER 9 INTERFACES AND POLYMORPHISM 329

9.1 Using Interfaces for Algorithm Reuse 330
9.2 Converting Between Class and Interface Types 336
9.3 Polymorphism 338
9.4 Using Interfaces for Callbacks 339
9.5 Inner Classes 343
9.6T Mock Objects 345
9.7G Events, Event Sources, and Event Listeners 347
9.8G Using Inner Classes for Listeners 350
9.9G Building Applications with Buttons 352
9.10G Processing Timer Events ⊕
9.11G Mouse Events ⊕

CHAPTER 10 INHERITANCE 367

10.1 Inheritance Hierarchies 368
10.2 Implementing Subclasses 371
10.3 Overriding Methods 375
10.4 Subclass Construction 378
10.5 Converting Between Subclass and Superclass Types 381
10.6 Polymorphism and Inheritance 383
10.7 `Object`: The Cosmic Superclass 391
10.8G Using Inheritance to Customize Frames 397

CHAPTER 11 INPUT/OUTPUT AND EXCEPTION HANDLING **407**

11.1 Reading and Writing Text Files **408**
11.2 Reading Text Input **411**
11.3 Throwing Exceptions **419**
11.4 Checked and Unchecked Exceptions **421**
11.5 Catching Exceptions **423**
11.6 The `finally` Clause **426**
11.7 Designing Your Own Exception Types **428**
11.8 Case Study: A Complete Example **429**

CHAPTER 12 OBJECT-ORIENTED DESIGN **441**

12.1 The Software Life Cycle **442**
12.2 Discovering Classes **446**
12.3 Relationships Between Classes **449**
12.4 Case Study: Printing an Invoice **452**
12.5 Case Study: An Automatic Teller Machine **463**

CHAPTER 13 RECURSION **491**

13.1 Triangle Numbers **492**
13.2 Recursive Helper Methods **500**
13.3 The Efficiency of Recursion **502**
13.4 Permutations **507**
13.5 Mutual Recursions **510**

CHAPTER 14 SORTING AND SEARCHING **525**

14.1 Selection Sort **526**
14.2 Profiling the Selection Sort Algorithm **529**
14.3 Analyzing the Performance of the Selection Sort Algorithm **532**
14.4 Merge Sort **534**
14.5 Analyzing the Merge Sort Algorithm **537**
14.6 Searching **540**
14.7 Binary Search **542**
14.8 Sorting Real Data **545**

CHAPTER 15 AN INTRODUCTION TO DATA STRUCTURES **555**

15.1 Using Linked Lists **556**
15.2 Implementing Linked Lists **561**
15.3 Abstract Data Types **572**
15.4 Stacks and Queues **575**

CHAPTER 16 ADVANCED DATA STRUCTURES (ADVANCED) ⊕

16.1 Sets **666** ⊕
16.2 Maps **670** ⊕
16.3 Hash Tables **674** ⊕
16.4 Computing Hash Codes **681** ⊕
16.5 Binary Search Trees **686** ⊕
16.6 Binary Tree Traversal **696** ⊕
16.7 Priority Queues **698** ⊕
16.8 Heaps **699** ⊕
16.9 The Heapsort Algorithm **709** ⊕

CHAPTER 17 GENERIC PROGRAMMING (ADVANCED) ⊕

17.1 Generic Classes and Type Parameters **724** ⊕
17.2 Implementing Generic Types **725** ⊕
17.3 Generic Methods **728** ⊕
17.4 Constraining Type Parameters **730** ⊕
17.5 Type Erasure **732** ⊕

CHAPTER 18 GRAPHICAL USER INTERFACES (ADVANCED) ⊕

18.1G Processing Text Input **740** ⊕
18.2G Text Areas **743** ⊕
18.3G Layout Management **746** ⊕
18.4G Choices **748** ⊕
18.5G Menus **758** ⊕
18.6G Exploring the Swing Documentation **764** ⊕

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APPENDICES

APPENDIX A THE BASIC LATIN AND LATIN-1 SUBSETS OF UNICODE **589**
APPENDIX B JAVA OPERATOR SUMMARY **593**
APPENDIX C JAVA RESERVED WORD SUMMARY **595**
APPENDIX D THE JAVA LIBRARY **597**
APPENDIX E JAVA SYNTAX SUMMARY ⊕
APPENDIX F HTML SUMMARY ⊕
APPENDIX G TOOL SUMMARY ⊕
APPENDIX H JAVADOC SUMMARY ⊕
APPENDIX I NUMBER SYSTEMS ⊕
APPENDIX J BIT AND SHIFT OPERATIONS ⊕
APPENDIX K UML SUMMARY ⊕
APPENDIX L JAVA LANGUAGE CODING GUIDELINES ⊕

GLOSSARY **629**
INDEX **643**
ILLUSTRATION CREDITS **665**

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ALPHABETICAL LIST OF SYNTAX BOXES

Arrays **245**
Array Lists **250**
Assertion **301**
Assignment **37**

Calling a Superclass Constructor **379**
Calling a Superclass Method **376**
Cast **127**
Catching Exceptions **424**
Class Declaration **80**
Comparisons **158**
Constant Declaration **119**

Declaring a Generic Class ⊕
Declaring a Generic Method ⊕
Declaring an Enumeration Type ⊕
Declaring an Interface **332**

Implementing an Interface **333**
Importing a Class from a Package **49**
Inheritance **372**
Instance Variable Declaration **75**

Method Call **12**
Method Declaration **86**

Object Construction **45**

Package Specification **310**

Static Method Call **131**

The `finally` Clause **427**
The "for each" Loop **256**
The `for` Statement **204**
The `if` Statement **154**
The `instanceof` Operator **382**
The `throws` Clause **423**
The `while` Statement **194**
Throwing an Exception **419**

Variable Declaration **35**

Chapter	Common Errors		How Tos and Worked Examples		Quality Tips	
1 Introduction	Omitting Semicolons	13	Developing and Describing an Algorithm	22		
	Misspelling Words	19	Writing an Algorithm for Tiling a Floor	⊕		
2 Using Objects	Confusing Variable Declaration and Assignment Statements	38	How Many Days Have You Been Alive?	⊕	Choose Descriptive Names for Variables	36
	Trying to Invoke a Constructor Like a Method	45	Working with Pictures	⊕		
3 Implementing Classes	Declaring a Constructor as `void`	81	Implementing a Class	88		
	Forgetting to Initialize Object References in a Constructor	93	Making a Simple Menu	⊕		
			Drawing Graphical Shapes	100		
4 Fundamental Data Types	Integer Division	128	Carrying Out Computations	132	Do Not Use Magic Numbers	122
	Unbalanced Parentheses	128	Computing the Volume and Surface Area of a Pyramid	⊕	White Space	129
	Roundoff Errors	130	Extracting Initials	⊕	Factor Out Common Code	129
5 Decisions	A Semicolon After the `if` Condition	156	Implementing an `if` Statement	163	Brace Layout	154
	Using `==` to Compare Strings	160	Extracting the Middle	⊕	Avoid Conditions with Side Effects	162
	The Dangling `else` Problem	170			Calculate Sample Data Manually	179
	Multiple Relational Operators	176			Prepare Test Cases Ahead of Time	179
	Confusing `&&` and `||` Conditions	176				
6 Iteration	Infinite Loops	200	Writing a Loop	215	Use for Loops for Their Intended Purpose	206
	Off-by-One Errors	200	Credit Card Processing	⊕	Don't Use `!=` to Test the End of a Range	208
	Forgetting a Semicolon	207	Manipulating the Pixels in an Image	⊕	Symmetric and Asymmetric Bounds	208
	A Semicolon Too Many	207	Debugging	226	Count Iterations	209
			A Sample Debugging Session	⊕		

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Productivity Hints	Special Topics	Random Facts
Understand the File System 16 Have a Backup Strategy ⊕	Alternative Comment Syntax 13	The ENIAC and the Dawn of Computing ⊕
Don't Memorize—Use Online Help 49	Testing Classes in an Interactive Environment ⊕ Applets ⊕	Mainframes—When Dinosaurs Ruled the Earth ⊕ The Evolution of the Internet ⊕
The `javadoc` Utility 84	Calling One Constructor from Another ⊕	Electronic Voting Machines ⊕ Computer Graphics ⊕
Reading Exception Reports 137	Big Numbers ⊕ Binary Numbers ⊕ Combining Assignment and Arithmetic ⊕ Escape Sequences ⊕ Strings and the `char` Type ⊕ Formatting Numbers ⊕ Using Dialog Boxes for Input and Output ⊕	The Pentium Floating-Point Bug ⊕ International Alphabets ⊕
Indentation and Tabs 155 Hand-Tracing 171 Make a Schedule and Make Time for Unexpected Problems 172	The Conditional Operator ⊕ The `switch` Statement ⊕ Enumeration Types ⊕ Lazy Evaluation of Boolean Operators ⊕ De Morgan's Law ⊕ Logging 180	Artificial Intelligence ⊕
Hand-Tracing Loops 198	`do` Loops ⊕ Variables Declared in a `for` Loop Header ⊕ The "Loop and a Half" Problem ⊕ The `break` and `continue` Statements ⊕ Loop Invariants ⊕	The First Bug 228

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Chapter	Common Errors	How Tos and Worked Examples	Quality Tips
7 Arrays and Array Lists	Bounds Errors 245 Uninitialized and Unfilled Arrays 246 Length and Size 253 Underestimating the Size of a Data Set 259	Working with Arrays and Array Lists 306 Rolling the Dice ⊕ A World Population Table ⊕	Use Arrays for Sequences of Related Values 246 Make Parallel Arrays into Arrays of Objects 246
8 Designing Classes	Trying to Modify Primitive Type Parameters 296 Shadowing 309 Confusing Dots 314	Programming with Packages 315	Consistency 293 Minimize Side Effects 298 Don't Change Contents of Parameter Variables 298 Minimize the Use of Static Methods 304 Minimize Variable Scope 310
9 Interfaces and Polymorphism	Forgetting to Declare Implementing Methods as Public 335 Trying to Instantiate an Interface 337 Modifying Parameter Types in the Implementing Method 349 Forgetting to Attach a Listener 355 By Default, Components Have Zero Width and Height 356 Forgetting to Repaint 356	Investigating Number Sequences ⊕	
10 Inheritance	Confusing Super- and Subclasses 373 Shadowing Instance Variables 374 Accidental Overloading 377 Failing to Invoke the Superclass Method 378 Overriding Methods to Be Less Accessible 385 Declaring the `equals` Method with the Wrong Parameter Type 395	Developing an Inheritance Hierarchy 386 Implementing an Employee Hierarchy for Payroll Processing ⊕	Supply `toString` in All Classes 395 Clone Mutable Instance Variables in Accessor Methods ⊕

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Productivity Hints	Special Topics	Random Facts
Easy Printing of Arrays and Array Lists 268 Batch Files and Shell Scripts ⊕	Methods with a Variable Number of Parameters ⊕ ArrayList Syntax Enhancements in Java 7 253 Two-Dimensional Arrays with Variable Row Lengths ⊕ Multidimensional Arrays ⊕	An Early Internet Worm ⊕ The Therac-25 Incidents ⊕
	Call by Value and Call by Reference ⊕ Class Invariants ⊕ Static Imports ⊕ Alternative Forms of Instance and Static Variable Initialization ⊕ Package Access 314	The Explosive Growth of Personal Computers ⊕
Don’t Use a Container as a Listener 355	Constants in Interfaces 335 Anonymous Classes ⊕ Event Adapters ⊕	Operating Systems ⊕ Programming Languages ⊕
	Abstract Classes ⊕ Final Methods and Classes ⊕ Protected Access ⊕ Inheritance and the `toString` Method ⊕ Inheritance and the `equals` Method ⊕ Implementing the `clone` Method ⊕ Enumeration Types Revisited ⊕ Adding the `main` Method to the Frame Class 398	Scripting Languages ⊕

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Chapter	Common Errors	How Tos and Worked Examples	Quality Tips
11 Input/Output and Exception Handling	Backslashes in File Names 410 Constructing a Scanner with a `String` 410	Processing Text Files 416 Analyzing Baby Names ⊕	Throw Early, Catch Late 425 Do Not Squelch Exceptions 425 Do Not Use `catch` and `finally` in the Same `try` Statement 427 Do Throw Specific Exceptions 429
12 Object-Oriented Design		CRC Cards and UML Diagrams 451	
13 Recursion	Infinite Recursion 495 Tracing Through Recursive Methods 496	Thinking Recursively 497 Finding Files ⊕	
14 Sorting and Searching	The `compareTo` Method Can Return Any Integer, Not Just –1, 0, and 1 546		
15 An Introduction to Data Structures		A Reverse Polish Notation Calculator ⊕	
16 Advanced Data Structures (Advanced)	Forgetting to Provide hashCode ⊕	Choosing a Container ⊕ Word Frequency ⊕	Use Interface References to Manipulate Data Structures ⊕
17 Generic Programming	Genericity and Inheritance ⊕ Using Generic Types in a Static Context ⊕		
18 Graphical User Interfaces (Advanced)		Laying Out a User Interface ⊕ Implementing a Graphical User Interface (GUI) ⊕	

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Productivity Hints		Special Topics		Random Facts	
Regular Expressions	415	File Dialog Boxes Reading Web Pages Command Line Arguments Automatic Resource Management in Java 7	⊕ 411 ⊕ 428	The Ariane Rocket Incident	⊕
		Attributes and Methods in UML Diagrams Multiplicities Aggregation and Association	⊕ ⊕ ⊕	Programmer Productivity Software Development—Art or Science?	⊕ ⊕
				The Limits of Computation	⊕
		Insertion Sort Oh, Omega, and Theta The Quicksort Algorithm The Parameterized `Comparable` Interface The `Comparator` Interface	⊕ ⊕ ⊕ 547 ⊕	The First Programmer	⊕
		The `Iterable` Interface and the “For Each” Loop Static Inner Classes	⊕ ⊕	Standardization Reverse Polish Notation	⊕ 578
		Enhancements to Collection Classes in Java 7	⊕	Software Piracy	⊕
		Wildcard Types	⊕		
Use a GUI Builder	⊕				

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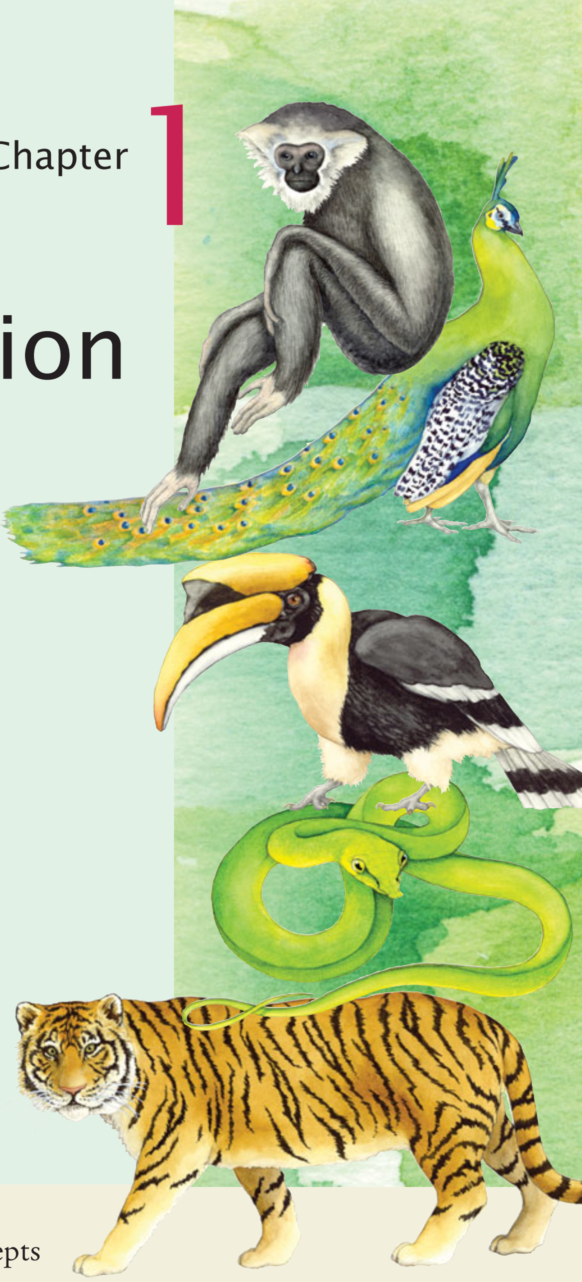
Chapter 1

Introduction



CHAPTER GOALS

- To understand the activity of programming
- To learn about the architecture of computers
- To learn about machine code and high-level programming languages
- To become familiar with the structure of simple Java programs
- To compile and run your first Java program
- To recognize compile-time and run-time errors
- To write pseudocode for simple algorithms

The purpose of this chapter is to familiarize you with the concepts of programming and program development. It reviews the architecture of a computer and discusses the difference between machine code and high-level programming languages. You will see how to compile and run your first Java program, and how to diagnose errors that may occur when a program is compiled or executed. Finally, you will learn how to formulate simple algorithms using pseudocode notation.

CHAPTER CONTENTS

1.1 What Is Programming? 2

1.2 The Anatomy of a Computer 3

RANDOM FACT 1.1: The ENIAC and the Dawn of Computing ⊕

1.3 Translating Human-Readable Programs to Machine Code 7

1.4 The Java Programming Language 8

1.5 The Structure of a Simple Program 10

SYNTAX 1.1: Method Call 12

COMMON ERROR 1.1: Omitting Semicolons 13

SPECIAL TOPIC 1.1: Alternative Comment Syntax 13

1.6 Compiling and Running a Java Program 14

PRODUCTIVITY HINT 1.1: Understand the File System 16

PRODUCTIVITY HINT 1.2: Have a Backup Strategy ⊕

1.7 Errors 17

COMMON ERROR 1.2: Misspelling Words 19

1.8 Algorithms 19

HOW TO 1.1: Developing and Describing an Algorithm 22

WORKED EXAMPLE 1.1: Writing an Algorithm for Tiling a Floor ⊕

1.1 What Is Programming?

You have probably used a computer for work or fun. Many people use computers for everyday tasks such as balancing a checkbook or writing a term paper. Computers are good for such tasks. They can handle repetitive chores, such as totaling up numbers or placing words on a page, without getting bored or exhausted. Computers also make good game machines because they can play sequences of sounds and pictures, involving the human user in the process.

The flexibility of a computer is quite an amazing phenomenon. The same machine can balance your checkbook, print your term paper, and play a game. In contrast, other machines carry out a much narrower range of tasks—a car drives and a toaster toasts.

A computer must be programmed to perform tasks. Different tasks require different programs.

To achieve this flexibility, the computer must be *programmed* to perform each task. A computer itself is a machine that stores data (numbers, words, pictures), interacts with devices (the monitor screen, the sound system, the printer), and executes programs. Programs are sequences of instructions and decisions that the computer carries out to achieve a task. One program balances checkbooks; a different program, perhaps designed and constructed by a different company, processes words; and a third program, probably from yet another company, plays a game.

A computer program executes a sequence of very basic instructions in rapid succession.

Today's computer programs are so sophisticated that it is hard to believe that they are all composed of extremely primitive instructions. A typical instruction may be one of the following:

- Put a red dot onto this screen position.
- Get a number from this location in memory.
- Add up two numbers.
- If this value is negative, continue the program at that instruction.

A computer program contains the instruction sequences for all tasks that it can execute.

A computer program tells a computer, in minute detail, the sequence of steps that are needed to complete a task. A program contains a huge number of simple instructions, and the computer executes them at great speed. The computer has no intelligence—it simply executes instruction sequences that have been prepared in advance.

To use a computer, no knowledge of programming is required. When you write a term paper with a word processor, that computer program has been developed by the manufacturer and is ready for you to use. That is only to be expected—you can drive a car without being a mechanic and toast bread without being an electrician.

A primary purpose of this book is to teach you how to design and implement computer programs. You will learn how to formulate instructions for all tasks that your programs need to execute.

Keep in mind that programming a sophisticated computer game or word processor requires a team of many highly skilled programmers, graphic artists, and other professionals. Your first programming efforts will be more mundane. The concepts and skills you learn in this book form an important foundation, but you should not expect to immediately produce professional software. A typical college degree in computer science or software engineering takes four years to complete; this book is intended as a text for an introductory course in such a program.

Many students find that there is an immense thrill even in simple programming tasks. It is an amazing experience to see the computer carry out a task precisely and quickly that would take you hours of drudgery.

SELF CHECK

1. What is required to play a music CD on a computer?
2. Why is a CD player less flexible than a computer?
3. Can a computer program develop the initiative to execute tasks in a better way than its programmers envisioned?

1.2 The Anatomy of a Computer

To understand the programming process, you need to have a rudimentary understanding of the building blocks that make up a computer. This section will describe a personal computer. Larger computers have faster, larger, or more powerful components, but they have fundamentally the same design.

At the heart of the computer lies the central processing unit (CPU).

At the heart of the computer lies the **central processing unit (CPU)** (see Figure 1). It consists of a single *chip* (integrated circuit) or a small number of chips. A computer chip is a component with a plastic or metal housing, metal connectors,

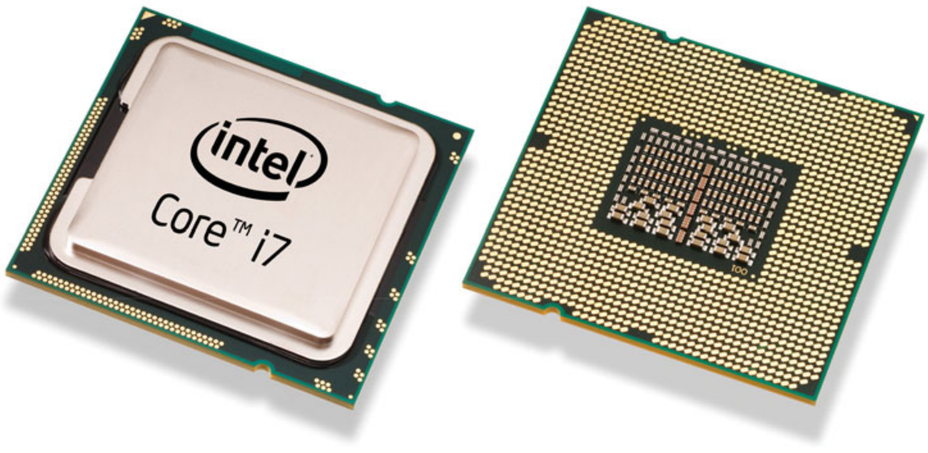
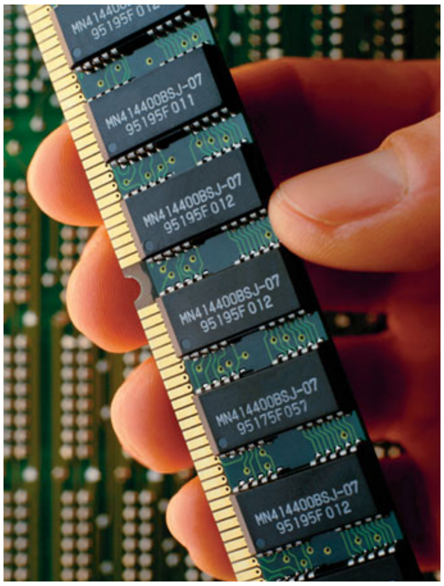


Figure 1
Central Processing Unit

Figure 2
A Memory Module with Memory Chips



and inside wiring made principally from silicon. For a CPU chip, the inside wiring is enormously complicated. For example, the Intel Core processor (a popular CPU for inexpensive laptops at the time of this writing) contains several hundred million structural elements called *transistors*—the elements that enable electrical signals to control other electrical signals, making automatic computing possible. The CPU locates and executes the program instructions; it carries out arithmetic operations such as addition, subtraction, multiplication, and division; and it fetches data from storage and input/output devices and sends data back.

Data and programs are stored in primary storage (memory) and secondary storage (such as a hard disk).

The computer keeps data and programs in *storage.* There are two kinds of storage. *Primary storage,* also called *random-access memory* (RAM) or simply *memory,* is fast but expensive; it is made from memory chips (see Figure 2). Primary storage loses all its data when the power is turned off. *Secondary storage,* usually a *hard disk* (see Figure 3), provides less expensive storage that persists without electricity. A hard disk consists of rotating platters, which are coated with a magnetic material, and read/write heads, which can detect and change the patterns of varying magnetic flux on the platters.

Some computers are self-contained units, whereas others are interconnected through *networks.* Home computers are usually intermittently connected to the Internet via a dialup or broadband connection. The computers in your computer lab are probably permanently connected to a local area network. Through the network cabling, the computer can read programs from central storage locations or send data to other computers. For the user of a networked computer, it may not even be obvious which data reside on the computer itself and which are transmitted through the network.

Most computers have *removable storage* devices that can access data or programs on media such as memory sticks or optical disks.

To interact with a human user, a computer requires other peripheral devices. The computer transmits information to the user through a display screen, loudspeakers, and printers. The user can enter information and directions to the computer by using a keyboard or a pointing device such as a mouse.

Figure 3 A Hard Disk

The CPU, the RAM, and the electronics controlling the hard disk and other devices are interconnected through a set of electrical lines called a *bus.* Data travel along the bus from the system memory and peripheral devices to the CPU and back. Figure 4 shows a *motherboard,* which contains the CPU, the RAM, and connectors to peripheral devices.

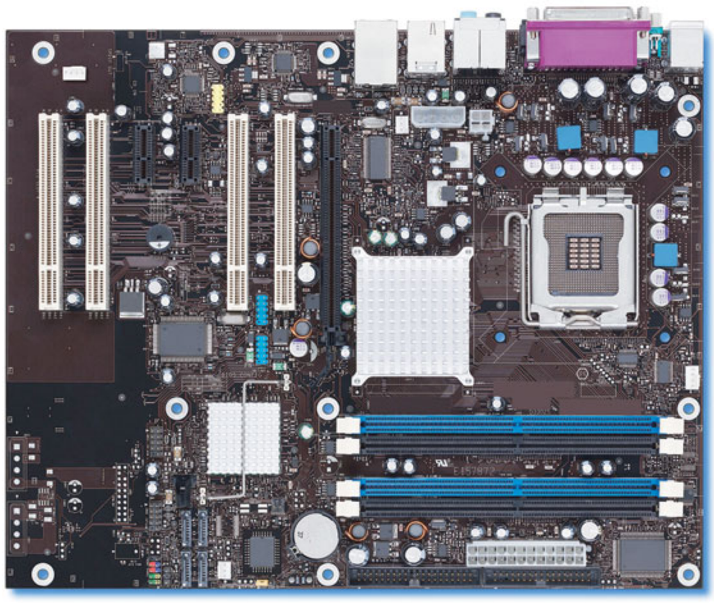


Figure 4 A Motherboard

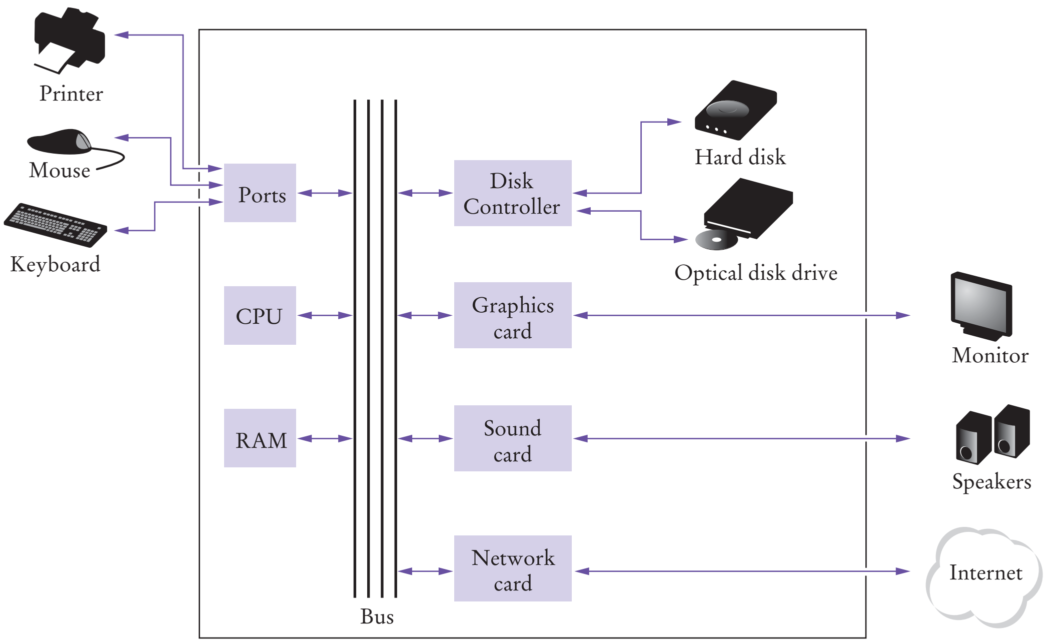


Figure 5 Schematic Diagram of a Computer

The CPU reads machine instructions from memory. The instructions direct it to communicate with memory, secondary storage, and peripheral devices.

Figure 5 gives a schematic overview of the architecture of a computer. Program instructions and data (such as text, numbers, audio, or video) are stored on the hard disk, on an optical disk (such as a DVD), or on a network. When a program is started, it is brought into memory where it can be read by the CPU. The CPU reads the program one instruction at a time. As directed by these instructions, the CPU reads data, modifies it, and writes it back to RAM or to secondary storage. Some program instructions will cause the CPU to interact with the devices that control the display screen or the speaker. Because these actions happen many times over and at great speed, the human user will perceive images and sound. Similarly, the CPU can send instructions to a printer to mark the paper with patterns of closely spaced dots, which a human recognizes as text characters and pictures. Some program instructions read user input from the keyboard or mouse. The program analyzes these inputs and then executes the next appropriate instructions.

SELF CHECK

4. Where is a program stored when it is not currently running?
5. Which part of the computer carries out arithmetic operations, such as addition and multiplication?

Random Fact 1.1

The ENIAC and the Dawn of Computing

Random Fact 1.1 tells the story of the ENIAC, the first usable electronic computer. The ENIAC was completed in 1946, contained about 18,000 vacuum tubes, and filled a large room.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

1.3 Translating Human-Readable Programs to Machine Code

Generally, machine code depends on the CPU type. However, the instruction set of the Java virtual machine (JVM) can be executed on different CPUs.

On the most basic level, computer instructions are extremely primitive. The processor executes *machine instructions*. CPUs from different vendors, such as the Intel Pentium or the Sun SPARC, have different sets of machine instructions. To enable Java applications to run on different CPUs without modification, Java programs contain machine instructions for a so-called "Java virtual machine" (JVM), an idealized CPU that is simulated by a program run on the actual CPU.

Instructions for actual and virtual machines are very simple and can be executed very quickly. A typical sequence of machine instructions is

1. Load the contents of memory location 40.
2. Load the value 100.
3. If the first value is greater than the second value, continue with the instruction that is stored in memory location 240.

Actually, machine instructions are encoded as numbers so that they can be stored in memory. On the Java virtual machine, this sequence of instructions is encoded as the sequence of numbers

```
21 40
16 100
163 240
```

When the virtual machine fetches this sequence of numbers, it decodes them and executes the associated sequence of commands.

Because machine instructions are encoded as numbers, it is difficult to write programs in machine code.

How can you communicate the command sequence to the computer? The most direct method is to place the actual numbers into the computer memory. This is, in fact, how the very earliest computers worked. However, a long program is composed of thousands of individual commands, and it is tedious and error-prone to look up the numeric codes for all commands and manually place the codes into memory. As we said before, computers are really good at automating tedious and error-prone activities, and it did not take long for computer programmers to realize that computers could be harnessed to help in the programming process.

High-level languages allow you to describe tasks at a higher conceptual level than machine code.

In the mid-1950s, *high-level* programming languages began to appear. In these languages, the programmer expresses the idea behind the task that needs to be performed, and a special computer program, called a **compiler**, translates the high-level description into machine instructions for a particular processor.

For example, in Java, the high-level programming language that you will use in this book, you might give the following instruction:

```
if (intRate > 100)
   System.out.println("Interest rate error");
```

A compiler translates programs written in a high-level language into machine code.

This means, "If the interest rate is over 100, display the message *Interest rate error*". It is then the job of the compiler program to look at the sequence of characters `if (intRate > 100) . . .` and translate that into

```
21 40 16 100 163 240 . . .
```

Compilers are quite sophisticated programs. They translate logical statements, such as the `if` statement, into sequences of computations, tests, and jumps. They assign memory locations for **variables**—items of information identified by symbolic names—like `intRate`. In this course, we will generally take the existence of a compiler for granted. If you decide to become a professional computer scientist, you may well learn more about compiler-writing techniques later in your studies.

SELF CHECK

6. What is the code for the Java virtual machine instruction "Load the contents of memory location 100"?
7. Does a person who uses a computer for office work ever run a compiler?

1.4 The Java Programming Language

Java was originally designed for programming consumer devices, but it was first used successfully to write Internet applets.

In 1991, a group led by James Gosling and Patrick Naughton at Sun Microsystems designed a programming language that they code-named "Green" for use in consumer devices, such as intelligent television "set-top" boxes. The language was designed to be simple and architecture neutral, so that it could be executed on a variety of hardware. No customer was ever found for this technology.

Gosling recounts that in 1994 the team realized, "We could write a really cool browser. It was one of the few things in the client/server mainstream that needed some of the weird things we'd done: architecture neutral, real-time, reliable, secure." Java was introduced to an enthusiastic crowd at the SunWorld exhibition in 1995.

Java was designed to be safe and portable, benefiting both Internet users and students.

Since then, Java has grown at a phenomenal rate. Programmers have embraced the language because it is simpler than its closest rival, C++. In addition, Java has a rich *library* that makes it possible to write portable programs that can bypass proprietary operating systems—a feature that was eagerly sought by those who wanted to be independent of those proprietary systems and was bitterly fought by their vendors. A "micro edition" and an "enterprise edition" of the Java library make Java programmers at home on hardware ranging from smart cards and cell phones to the largest Internet servers.

Because Java was designed for the Internet, it has two attributes that make it very suitable for beginners: safety and portability. If you visit a web page that contains Java code (so-called *applets*—see Figure 6 for an example), the code automatically starts running. It is important that you can trust that applets are inherently safe. If an applet could do something evil, such as damaging data or reading personal information on your computer, then you would be in real danger every time you browsed the Web—an unscrupulous designer might put up a web page containing dangerous code that would execute on your machine as soon as you visited the page. The Java language has an assortment of security features that guarantees that no malicious applets can run on your computer. As an added benefit, these features also help you to learn the language faster. The Java virtual machine can catch many kinds of beginners' mistakes and report them accurately. (In contrast, many beginners' mistakes in the C++ language merely produce programs that act in random and confusing ways.) The other benefit of Java is portability. The same Java program will run, without change, on Windows, UNIX, Linux, or the Macintosh. This too is a requirement for applets. When you visit a web page, the web server that serves up the page contents has no idea what computer you are using to browse the Web. It simply returns the portable code that was generated by the Java compiler.

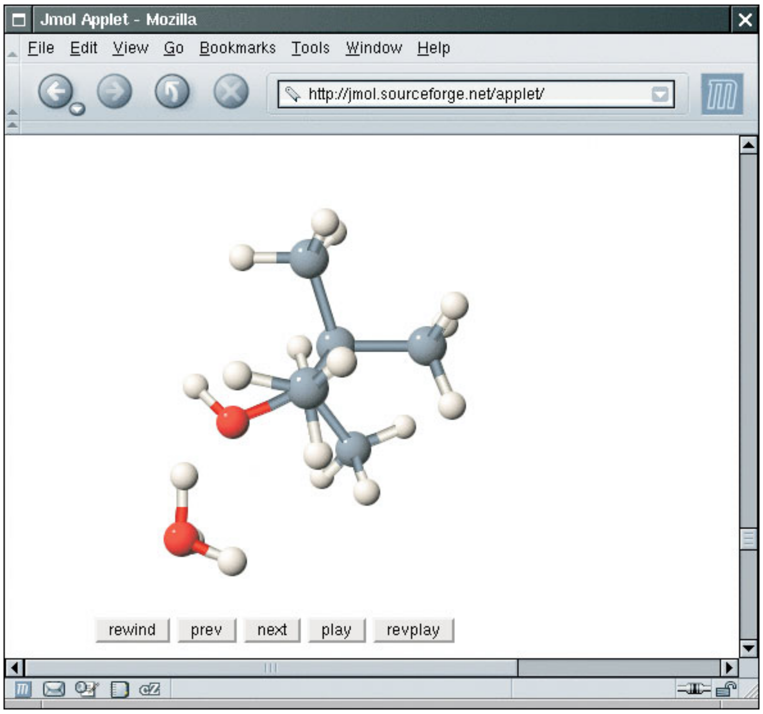

Jmol Applet - Mozilla
File Edit View Go Bookmarks Tools Window Help
http://jmol.sourceforge.net/applet/
rewind
prev
next
play
revplay

Figure 6 An Applet for Visualizing Molecules Running in a Browser (*http://jmol.sourceforge.net/applet/*)

The virtual machine on your computer executes that portable code. Again, there is a benefit for the student. You do not have to learn how to write programs for different platforms.

At this time, Java is firmly established as one of the most important languages for general-purpose programming as well as for computer science instruction. However, although Java is a good language for beginners, it is not perfect, for three reasons.

Because Java was not specifically designed for students, no thought was given to making it really simple to write basic programs. You must master a certain amount of technical detail to write even the simplest Java program. This is not a problem for professional programmers, but it is a drawback for beginning students. As you learn how to program in Java, there will be times when you will be asked to be satisfied with a preliminary explanation and wait for complete information in a later chapter.

Java was revised and extended many times during its life—see Table 1 on page 10. In this book, we assume that you have Java version 5 or later.

Java has a very large library. Focus on learning those parts of the library that you need for your programming projects.

Finally, you cannot hope to learn all of Java in one term. The Java language itself is relatively simple, but Java has a vast library with support for graphics, user interface design, cryptography, networking, sound, database storage, and many other purposes. Even expert Java programmers cannot hope to know the contents of the entire library—they just use those parts that they need for particular projects.

Using this book, you should expect to learn a good deal about the Java language and about the most important parts of the Java library. Keep in mind that the central

Table 1 Java Versions

Version	Year	Important New Features
1.0	1996	
1.1	1997	Inner classes
1.2	1998	Swing, Collections framework
1.3	2000	Performance enhancements
1.4	2002	Assertions, XML support
5	2004	Generic classes, enhanced `for` loop, auto-boxing, enumerations, annotations
6	2006	Library improvements
7	2010	Small language changes and library improvements

goal of this book is not to make you memorize Java minutiae, but to teach you how to think about programming.

SELF CHECK

8. What are the two most important benefits of the Java language?
9. How long does it take to learn the entire Java library?

1.5 The Structure of a Simple Program

When learning a new programming language, it is traditional to start with a "Hello, World!" program—a program that displays a greeting. Here is this program in Java:

ch01/hello/HelloPrinter.java

```java
public class HelloPrinter
{
   public static void main(String[] args)
   {
      // Display a greeting in the console window

      System.out.println("Hello, World!");
   }
}
```

Program Run

```
Hello, World!
```

In the next section, you will see how to compile and run this program. But let us first understand how it is structured.

The line,

```
public class HelloPrinter
```

Classes are the fundamental building blocks of Java programs.

starts a new **class**. Classes are a fundamental concept in Java, and you will begin to study them in Chapter 2. In Java, every program consists of one or more classes.

The word `public` denotes that the class is usable by the "public", that is, everywhere in your program. You will later encounter `private` features.

In Java, every source file can contain at most one public class, and the name of the public class must match the name of the file containing the class. For example, the class `HelloPrinter` *must* be contained in a file named `HelloPrinter.java`.

Every Java application contains a class with a `main` method. When the application starts, the instructions in the `main` method are executed.

The construction

```
public static void main(String[] args)
{
   . . .
}
```

declares a **method** called `main`. A method contains a collection of programming instructions that describe how to carry out a particular task. Every Java application must have a `main` method. Most Java programs contain other methods besides `main`, and you will see in Chapter 3 how to write other methods.

We will fully explain the word `static` and the declaration `String[] args` in Chapters 8 and 11. At this time, you should simply consider

```
public class ClassName
{
   public static void main(String[] args)
   {
      . . .
   }
}
```

as a part of the "plumbing" that is required to write any Java program.

The first line inside the `main` method is a **comment**:

```
// Display a greeting in the console window
```

Use comments to help human readers understand your program.

This comment is purely for the benefit of the human reader, to explain in more detail what the next statement does. Any text enclosed between `//` and the end of the line is completely ignored by the compiler. Comments are used to explain the program to other programmers or to yourself.

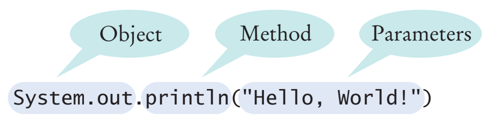
The instructions or **statements** in the *body* of the `main` method—that is, the statements inside the curly brackets (`{}`)—are executed one by one. Each statement ends in a semicolon (`;`). Our method has a single statement:

```
System.out.println("Hello, World!");
```

This statement prints a line of text, namely "Hello, World!". However, there are many places where a program can send that text: to a window, to a file, or to a networked computer on the other side of the world. You need to specify that the destination is the *system output*—that is, a console window. The console window is represented in Java by an object called `System.out`. An **object** is an entity that you manipulate in your programs.

In Java, each object belongs to a class, and the class declares methods that specify what you can do with the objects. The `System.out` object belongs to the `PrintStream` class. The `PrintStream` class has a method called `println` for printing a line of text.

Figure 7
Calling a Method



You do not have to implement this method—the programmers who wrote the Java library already did that for us—but you do need to *call* the method.

A method is called by specifying an object, the method name, and the method parameters.

Whenever you call a method in Java, you need to specify three items (see Figure 7):

1. The object that you want to use (in this case, `System.out`).
2. The name of the method you want to use (in this case, `println`).
3. A pair of parentheses, containing any other information the method needs (in this case, `"Hello, World!"`). The technical term for this information is a **parameter**.

A sequence of characters enclosed in double quotation marks

```
"Hello, World!"
```

A string is a sequence of characters enclosed in quotation marks.

is called a **string**. You must enclose the contents of the string inside quotation marks so that the compiler knows you literally mean `"Hello, World!"`. There is a reason for this requirement. Suppose you need to print the word *main*. By enclosing it in quotation marks, `"main"`, the compiler knows you mean the sequence of characters `m a i n`, not the method named `main`. The rule is simply that you must enclose all text strings in quotation marks, so that the compiler considers them plain text and does not try to interpret them as program instructions.

You can also print numerical values. For example, the statement

```
System.out.println(3 + 4);
```

displays the number 7.

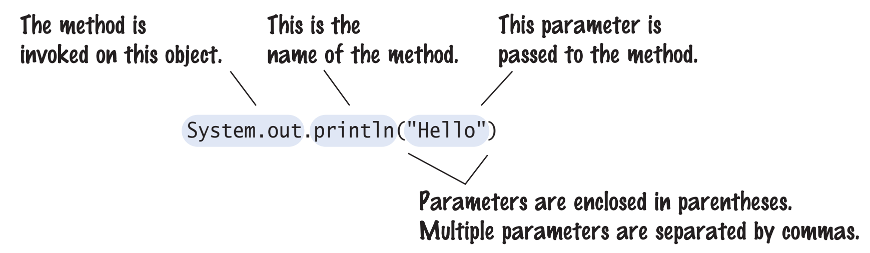
The `println` method prints a string or a number and then starts a new line. For example, the sequence of statements

```
System.out.println("Hello");
System.out.println("World!");
```

Syntax 1.1 Method Call

Syntax *object.methodName(parameters)*

Example


The method is invoked on this object.
This is the name of the method.
This parameter is passed to the method.
System.out.println("Hello")
Parameters are enclosed in parentheses. Multiple parameters are separated by commas.

prints two lines of text:

```
Hello
World!
```

There is a second method, called `print`, that you can use to print an item without starting a new line. For example, the output of the two statements

```
System.out.print("00");
System.out.println(3 + 4);
```

is the single line

```
007
```

SELF CHECK

10. How would you modify the `HelloPrinter` program to print the words "Hello," and "World!" on two lines?

11. Would the program continue to work if you omitted the line starting with `//`?

12. What does the following set of statements print?

```
System.out.print("My lucky number is");
System.out.println(3 + 4 + 5);
```

Common Error 1.1

Omitting Semicolons

In Java every statement must end in a semicolon. Forgetting to type a semicolon is a common error. It confuses the compiler, because the compiler uses the semicolon to find where one statement ends and the next one starts. The compiler does not use line breaks or closing braces to recognize the end of statements. For example, the compiler considers

```
System.out.println("Hello")
System.out.println("World!");
```

a single statement, as if you had written

```
System.out.println("Hello") System.out.println("World!");
```

Then it doesn't understand that statement, because it does not expect the word `System` following the closing parenthesis after `"Hello"`. The remedy is simple. Scan every statement for a terminating semicolon, just as a writer would check that every English sentence ends in a period.

Special Topic 1.1

Alternative Comment Syntax

In Java there are two methods for writing comments. You already learned that the compiler ignores anything that you type between `//` and the end of the current line. The compiler also ignores any text between a `/*` and `*/`.

```
/* A simple Java program */
```

The `//` comment is easier to type if the comment is only a single line long. If you have a comment that is longer than a line, then the `/* . . . */` comment is simpler:

```
/*
   This is a simple Java program that you can use to try out
   your compiler and virtual machine.
*/
```

It would be somewhat tedious to add the // at the beginning of each line and to move them around whenever the text of the comment changes.

In this book, we use // for comments that will never grow beyond a line, and /* . . . */ for longer comments. If you prefer, you can always use the // style. The readers of your code will be grateful for *any* comments, no matter which style you use.

1.6 Compiling and Running a Java Program

Set aside some time to become familiar with the computer system and the Java compiler that you will use for your class work.

Many students find that the tools that they need as programmers are very different from the software with which they familiar. You should spend some time making yourself familiar with your programming environment. Instructions for several popular environments are available in WileyPLUS.

Some Java development environments are very convenient to use. Enter the code in one window, click on a button to compile, and click on another button to execute your program. Error messages show up in a second window, and the program runs in a third window. With such an environment you are completely shielded from the details of the compilation process. On other systems you must carry out every step manually, by typing commands into a console window.

An editor is a program for entering and modifying text, such as a Java program.

No matter which development environment you use, you begin your activity by typing in the program statements. The program that you use for entering and modifying the program text is called an *editor*. The first step for creating a Java program, such as the `HelloPrinter` program of the preceding section, is to start your editor. Make a new program file and call it `HelloPrinter.java`. (If your environment requires that you supply a project name in addition to the file name, use the name `hello` for the project.) Enter the program instructions exactly as they are given above. Alternatively, locate an electronic copy and paste it into your editor.

Java is case sensitive. You must be careful about distinguishing between upper- and lowercase letters.

Java is **case sensitive**. You must enter upper- and lowercase letters in the same way as they appear in the program listing. You cannot type `MAIN` or `PrintLn`. If you are not careful, you will run into problems—see Common Error 1.2 on page 19. On the other hand, Java has *free-form layout*. You can use any number of spaces and line breaks to separate words. You can cram as many words as possible into each line,

```
public class HelloPrinter{public static void main(String[]
args){// Display a greeting in the console window
System.out.println("Hello, World!");}}
```

Lay out your programs so that they are easy to read.

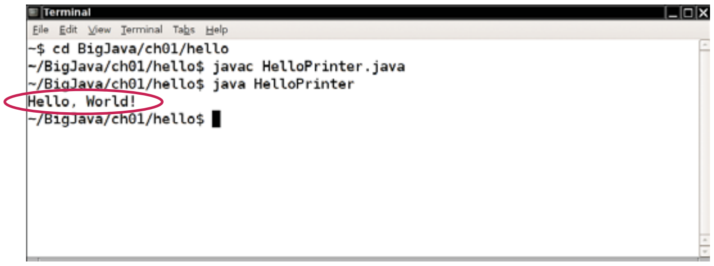
Of course, this is not a good idea. It is important to format your programs neatly so that you and other programmers can read them easily. We will give you recommendations for good layout throughout this book. Appendix L contains a summary of our recommendations.

Now find out how to run the test program. The message

```
Hello, World!
```

will appear somewhere on the screen (see Figures 8 and 9). The exact location depends on your programming environment.

Figure 8 Running the `HelloPrinter` Program in a Console Window



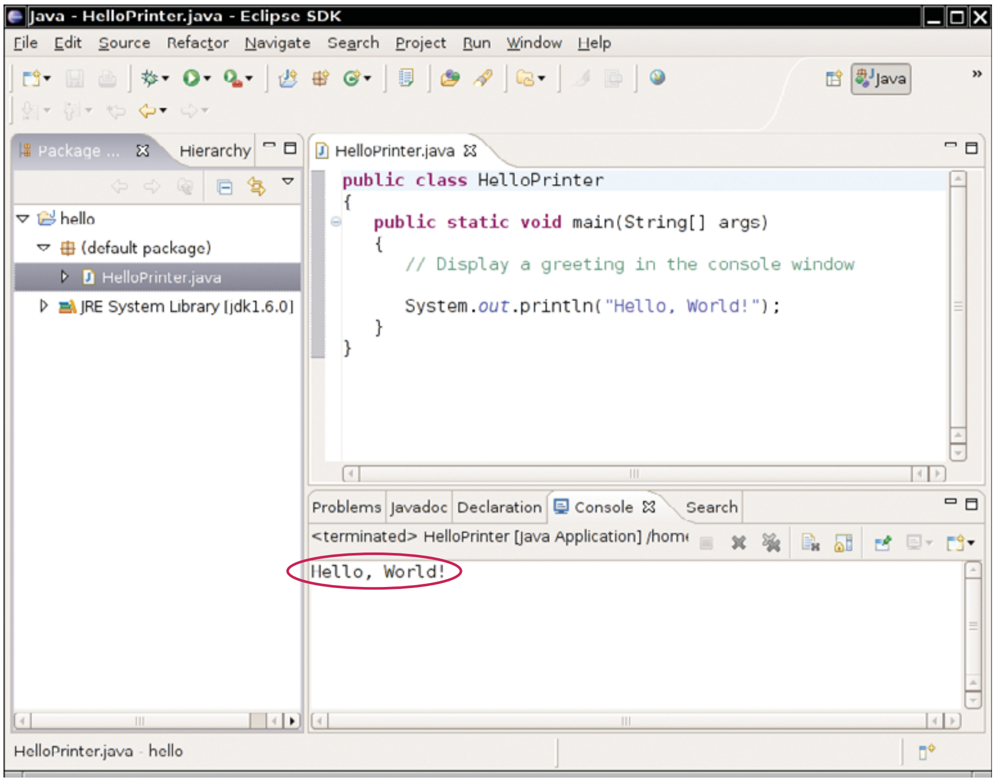
```
~$ cd BigJava/ch01/hello
~/BigJava/ch01/hello$ javac HelloPrinter.java
~/BigJava/ch01/hello$ java HelloPrinter
Hello, World!
~/BigJava/ch01/hello$
```

The Java compiler translates source code into class files that contain instructions for the Java virtual machine.

Running your program takes two steps. (Some development environments automatically carry out both steps when you ask to run a program.)

The first step is to *compile* your program. The compiler translates the Java **source code** (that is, the statements that you wrote) into *class files*, which consist of virtual machine instructions and other information that is required for execution. The class files have the extension `.class`. For example, the virtual machine instructions for the `HelloPrinter` program are stored in a file `HelloPrinter.class`. Note that the compiler does not produce a class file if it has found errors in your program.

The class file contains merely the translation of the instructions that you wrote. That is not enough to actually run the program. To display a string in a window, quite a bit of low-level activity is necessary. The authors of the `System` and


Java - HelloPrinter.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Java
Package ...
Hierarchy
hello
(default package)
HelloPrinter.java
JRE System Library [jdk1.6.0]
HelloPrinter.java
Problems
Javadoc
Declaration
Console
Search
HelloPrinter.java - hello

```
public class HelloPrinter
{
   public static void main(String[] args)
   {
      // Display a greeting in the console window

      System.out.println("Hello, World!");
   }
}
```

```
<terminated> HelloPrinter [Java Application] /home
Hello, World!
```

Figure 9 Running the `HelloPrinter` Program in an Integrated Development Environment

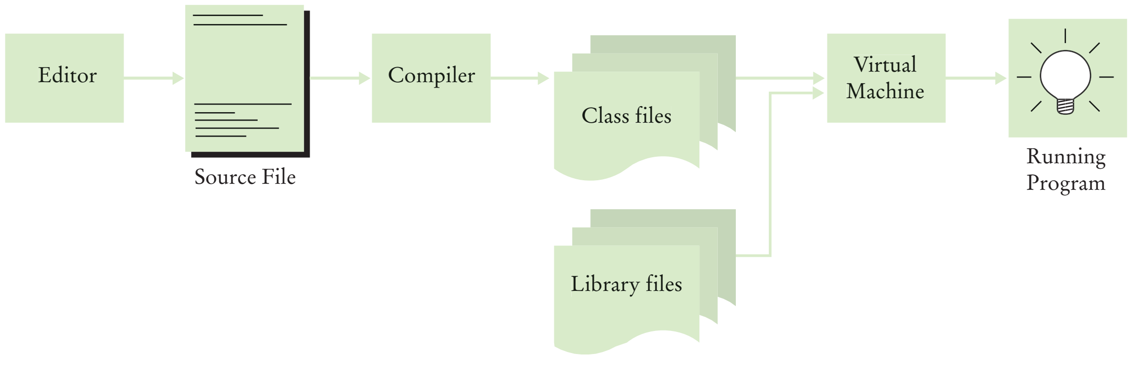


Figure 10 From Source Code to Running Program

The Java virtual machine loads program instructions from class files and library files.

PrintStream classes (which declare the out object and the println method) have implemented all necessary actions and placed the required class files into a **library**. A library is a collection of code that has been programmed and translated by someone else, ready for you to use in your program.

The Java virtual machine loads the instructions for the program that you wrote, starts your program, and loads the necessary library files as they are required.

The steps of compiling and running your program are outlined in Figure 10.

SELF CHECK

13. Can you use a word processor for writing Java programs?

14. What do you expect to see when you load a class file into your text editor?

Productivity Hint 1.1

Understand the File System

In recent years, computers have become easier to use for home or office users. Many inessential details are now hidden from casual users. For example, many users simply place all their work inside a default folder (such as "Home" or "My Documents") and are blissfully ignorant about details of the file system.

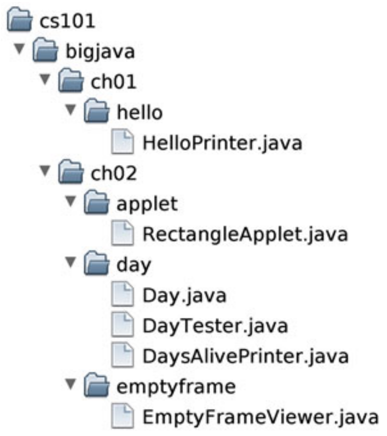
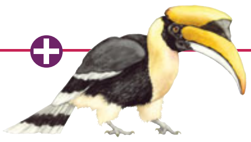

```
cs101
▼ bigjava
  ▼ ch01
    ▼ hello
        HelloPrinter.java
  ▼ ch02
    ▼ applet
        RectangleApplet.java
    ▼ day
        Day.java
        DayTester.java
        DaysAlivePrinter.java
    ▼ emptyframe
        EmptyFrameViewer.java
```

Figure 11
A Folder Hierarchy

For your programming work, you need to understand that files are stored in *folders* or **directories**, and that these file containers can be *nested.* That is, a folder can contain not only files but also other folders, which themselves can contain more files and folders (see Figure 11).

You need to know how to impose an organization on the data that you create. You also need to be able to locate files and inspect their contents.

If you are not comfortable with files and folders, be sure to set aside some time to learn about these concepts.



Productivity Hint 1.2

Have a Backup Strategy

Productivity Hint 1.2 discusses strategies for backing up your programming work so that you won't lose data if your computer malfunctions.

1.7 Errors

Experiment a little with the `HelloPrinter` program. What happens if you make a typing error such as

```
System.ou.println("Hello, World!);
System.out.println("Hello, Word!");
```

A compile-time error is a violation of the programming language rules that is detected by the compiler.

In the first case, the compiler will complain. It will say that it has no clue what you mean by `ou`. The exact wording of the error message is dependent on the compiler, but it might be something like "Cannot find symbol *ou*". This is a **compile-time error**, also called a *syntax error.* Something is wrong according to the language rules and the compiler finds it. When the compiler finds one or more errors, it refuses to translate the program to Java virtual machine instructions, and as a consequence you have no program that you can run. You must fix the error and compile again. In fact, the compiler is quite picky, and it is common to go through several rounds of fixing compile-time errors before compilation succeeds for the first time.

If the compiler finds an error, it will not simply stop and give up. It will try to report as many errors as it can find, so you can fix them all at once.

Sometimes, an error throws the compiler off track. Suppose, for example, you forget the quotation marks around a string: `System.out.println(Hello, World!)`. The compiler will not complain about the missing quotation marks. Instead, it will report "Cannot find symbol Hello". It is up to you to realize that you need to enclose strings in quotation marks.

The error in the second line is of a different kind. The program will compile and run, but its output will be wrong. It will print

```
Hello, Word!
```

This is a **run-time error**, also called a *logic error.* The program is syntactically correct and does something, but it doesn't do what it is supposed to do.

A run-time error causes a program to take an action that the programmer did not intend.

This particular run-time error did not include an error message. It simply produced the wrong output. Some kinds of run-time errors are so severe that they generate an *exception*: an error message from the Java virtual machine. For example, if your program includes the statement

```
System.out.println(1/0);
```

you will get a run-time error message “Division by zero”.

During program development, errors are unavoidable. Once a program is longer than a few lines, it requires superhuman concentration to enter it correctly without slipping up once. You will find yourself omitting semicolons or quotes more often than you would like, but the compiler will track down these problems for you.

Run-time errors are more troublesome. The compiler will not find them—in fact, the compiler will cheerfully translate any program as long as its syntax is correct—but the resulting program will do something wrong. It is the responsibility of the program author to test the program and find any run-time errors. Testing programs is an important topic that you will encounter many times in this book. Another important aspect of good craftsmanship is *defensive programming:* structuring programs and development processes in such a way that an error in one part of a program does not trigger a disastrous response.

The error examples that you saw so far were not difficult to diagnose or fix, but as you learn more sophisticated programming techniques, there will also be much more room for error. It is an uncomfortable fact that locating all errors in a program is very difficult. Even if you can observe that a program exhibits faulty behavior, it may not at all be obvious what part of the program caused it and how you can fix it. Special software tools (so-called **debuggers**) let you trace through a program to find *bugs*—that is, run-time errors. In Chapter 6 you will learn how to use a debugger effectively.

Note that these errors are different from the types of errors that you are likely to make in calculations. If you total up a column of numbers, you may miss a minus sign or accidentally drop a carry, perhaps because you are bored or tired. Computers do not make these kinds of errors.

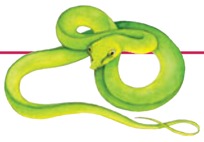
This book uses a three-part error management strategy. First, you will learn about common errors and how to avoid them. Then you will learn defensive programming strategies to minimize the likelihood and impact of errors. Finally, you will learn testing and debugging strategies to flush out those errors that remain.

SELF CHECK

15. Suppose you omit the `//` characters fro m the `HelloPrinter.java` program but not the remainder of the comment. Will you get a compile-time error or a run-time error?

16. When you used your computer, you may have experienced a program that “crashed” (quit spontaneously) or “hung” (failed to respond to your input). Is that behavior a compile-time error or a run-time error?

17. Why can’t you test a program for run-time errors when it has compiler errors?



Common Error 1.2

Misspelling Words

If you accidentally misspell a word, then strange things may happen, and it may not always be completely obvious from the error messages what went wrong. Here is a good example of how simple spelling errors can cause trouble:

```
public class HelloPrinter
{
   public static void Main(String[] args)
   {
      System.out.println("Hello, World!");
   }
}
```

This class declares a method called `Main`. The compiler will not consider this to be the same as the `main` method, because `Main` starts with an uppercase letter and the Java language is case sensitive. Upper- and lowercase letters are considered to be completely different from each other, and to the compiler `Main` is no better match for `main` than `rain`. The compiler will cheerfully compile your `Main` method, but when the Java virtual machine executes the compiled file, it will complain about the missing `main` method and refuse to run the program. Of course, the message "missing main method" should give you a clue where to look for the error.

If you get an error message that seems to indicate that the compiler is on the wrong track, it is a good idea to check for spelling and capitalization. If you misspell the name of a symbol (for example, `ou` instead of `out`), the compiler will produce an error message such as "Cannot find symbol ou". That error message is usually a good clue that you made a spelling error.

1.8 Algorithms

You will soon learn how to program calculations and decision making in Java. But before we look at the mechanics of implementing computations in the next chapter, let's consider the planning process that precedes implementation.

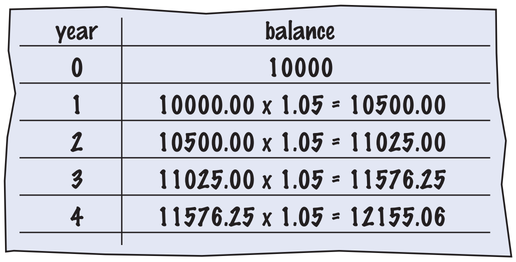
You may have run across advertisements that encourage you to pay for a computerized service that matches you up with a love partner. Think how this might work. You fill out a form and send it in. Others do the same. The data are processed by a computer program. Is it reasonable to assume that the computer can perform the task of finding the best match for you? Suppose your younger brother, not the computer, had all the forms on his desk. What instructions could you give him? You can't say, "Find the best-looking person who likes inline skating and browsing the Internet". There is no objective standard for good looks, and your brother's opinion (or that of a computer program analyzing the digitized photo) will likely be different from yours. If you can't give written instructions for someone to solve the problem, there is no way the computer can magically find the right solution. The computer can only do what you tell it to do. It just does it faster, without getting bored or exhausted.

For that reason, a computerized match-making service cannot guarantee to find the optimal match for you. Instead, it may present a set of potential partners who share common interests with you. That is a task that a computer program can solve.

Now consider the following investment problem:

> You put $10,000 into a bank account that earns 5 percent interest per year. How many years does it take for the account balance to be double the original?

Could you solve this problem by hand? Sure, you could. You figure out the balance as follows:

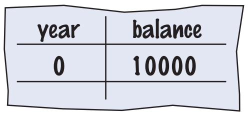


year	balance
0	10000
1	10000.00 x 1.05 = 10500.00
2	10500.00 x 1.05 = 11025.00
3	11025.00 x 1.05 = 11576.25
4	11576.25 x 1.05 = 12155.06

You keep going until the balance is at least $20,000. Then the last number in the year column is the answer.

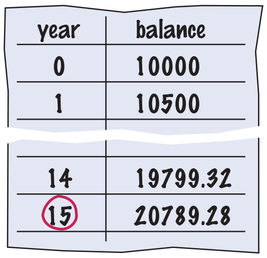
Of course, carrying out this computation is intensely boring to you or your younger brother. But computers are very good at carrying out repetitive calculations quickly and flawlessly. What is important to the computer is a description of the steps for finding the solution. Each step must be clear and unambiguous, requiring no guesswork. Here is such a description:

```
Start with a year value of 0 and a balance of $10,000.
```



year	balance
0	10000

```
Repeat the following steps while the balance is less than $20,000.
    Add 1 to the year value.
    Multiply the balance value by 1.05 (a 5 percent increase).
```



year	balance
0	10000
1	10500
14	19799.32
15	20789.28

```
Report the final year value as the answer.
```

Pseudocode is an informal description of a sequence of steps for solving a problem.

Of course, these steps are not yet in a language that a computer can understand, but you will soon learn how to formulate them in Java. This informal description is called **pseudocode**.

There are no strict requirements for pseudocode because it is read by human readers, not a computer program. Here are the kinds of pseudocode statements that we will use in this book:

- Use statements such as the following to describe how a value is set or changed:

  ```
  total cost = purchase price + operating cost
  ```

  or

  ```
  Multiply the balance value by 1.05.
  ```

  or

  ```
  Remove the first and last character from the word.
  ```

- Describe decisions and repetitions as follows:

  ```
  If total cost 1 < total cost 2
  ```

  or

  ```
  While the balance is less than $20,000
  ```

  or

  ```
  For each picture in the sequence
  ```

  Use indentation to indicate which statements should be selected or repeated.

  ```
  For each car
      operating cost = 10 x annual fuel cost
      total cost = purchase price + operating cost
  ```

  Here, the indentation indicates that both statements should be executed for each car.

- Indicate results with statements such as

  ```
  Choose car1.
  Report the final year value as the answer.
  ```

The exact wording is not important. What is important is that the pseudocode describes a sequence of steps that is

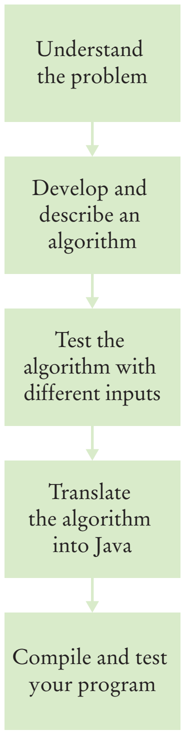
- Unambiguous
- Executable
- Terminating

The step sequence is *unambiguous* when there are precise instructions for what to do at each step and where to go next. There is no room for guesswork or personal opinion. A step is *executable* when it can be carried out in practice. Had we asked to use the actual interest rate that will be charged in years to come, and not a fixed rate of 5 percent per year, that step would not have been executable, because there is no way for anyone to know what that interest rate will be. A sequence of steps is *terminating* if it will eventually come to an end. In our example, it requires a bit of thought to see that the sequence will not go on forever: With every step, the balance goes up by at least $500, so eventually it must reach $20,000.

An algorithm for solving a problem is a sequence of steps that is unambiguous, executable, and terminating.

A sequence of steps that is unambiguous, executable, and terminating is called an **algorithm**. We have found an algorithm to solve our investment problem, and thus we can find the solution by programming a computer. The existence of an algorithm is an essential prerequisite for programming a task. You need to first discover and describe an algorithm for the task that you want to solve before you start programming (see Figure 12).

Figure 12
The Program Development Process


Understand the problem
Develop and describe an algorithm
Test the algorithm with different inputs
Translate the algorithm into Java
Compile and test your program

SELF CHECK

18. Suppose the interest rate was 20 percent. How long would it take for the investment to double?

19. Suppose your cell phone carrier charges you $29.95 for up to 300 minutes of calls, and $0.45 for each additional minute, plus 12.5 percent taxes and fees. Give an algorithm to compute the monthly charge for a given number of minutes.

How To 1.1 Developing and Describing an Algorithm

This is the first of many "How To" sections in this book that give you step-by-step procedures for carrying out important tasks in developing computer programs.

Before you are ready to write a program in Java, you need to develop an algorithm—a method for arriving at a solution for a particular problem. Describe the algorithm in pseudocode: a sequence of precise steps formulated in English.

For example, consider this problem: You have the choice of buying two cars. One is more fuel efficient than the other, but also more expensive. You know the price and fuel efficiency (in miles per gallon, mpg) of both cars. You plan to keep the car for ten years. Assume a price of $4 per gallon of gas and usage of 15,000 miles per year. You will pay cash for the car and not worry about financing costs. Which car is the better deal?

Step 1 Determine the inputs and outputs.

In our sample problem, we have these inputs:

- **purchase price1** and **fuel efficiency1**, the price and fuel efficiency (in mpg) of the first car.
- **purchase price2** and **fuel efficiency2**, the price and fuel efficiency of the second car.

We simply want to know which car is the better buy. That is the desired output.

Step 2 Break down the problem into smaller tasks.

For each car, we need to know the total cost of driving it. Let's do this computation separately for each car. Once we have the total cost for each car, we can decide which car is the better deal.

The total cost for each car is `purchase price + operating cost`.

We assume a constant usage and gas price for ten years, so the operating cost depends on the cost of driving the car for one year.

The operating cost is `10 x annual fuel cost`.

The annual fuel cost is `price per gallon x annual fuel consumed`.

The annual fuel consumed is `annual miles driven / fuel efficiency`. For example, if you drive the car for 15,000 miles and the fuel efficiency is 15 miles/gallon, the car consumes 1,000 gallons.

Step 3 Describe each subtask in pseudocode.

In your description, arrange the steps so that any intermediate values are computed before they are needed in other computations. For example, list the step

```
total cost = purchase price + operating cost
```

after you have computed `operating cost`.

Here is the algorithm for deciding which car to buy.

```
For each car, compute the total cost as follows:
    annual fuel consumed = annual miles driven / fuel efficiency
    annual fuel cost = price per gallon x annual fuel consumed
    operating cost = 10 x annual fuel cost
    total cost = purchase price + operating cost
If total cost1 < total cost2
    Choose car1.
Else
    Choose car2.
```

Step 4 Test your pseudocode by working problems.

We will use these sample values:

Car 1: $25,000, 50 miles/gallon
Car 2: $20,000, 30 miles/gallon

Here is the calculation for the cost of the first car.

```
annual fuel consumed = annual miles driven / fuel efficiency = 15000 / 50 = 300
annual fuel cost = price per gallon x annual fuel consumed = 4 x 300 = 1200
operating cost = 10 x annual fuel cost = 10 x 1200 = 12000
total cost = purchase price + operating cost = 25000 + 12000 = 37000
```

Similarly, the total cost for the second car is $40,000. Therefore, the output of the algorithm is to choose car 1.

Worked Example 1.1

Writing an Algorithm for Tiling a Floor

This Worked Example shows how to develop an algorithm for laying tile in an alternating pattern of colors.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Summary of Learning Objectives

Define "computer program" and "programming".

- A computer must be programmed to perform tasks. Different tasks require different programs.
- A computer program executes a sequence of very basic instructions in rapid succession.
- A computer program contains the instruction sequences for all tasks that it can execute.

Describe the components of a computer.

- At the heart of the computer lies the central processing unit (CPU).
- Data and programs are stored in primary storage (memory) and secondary storage (such as a hard disk).
- The CPU reads machine instructions from memory. The instructions direct it to communicate with memory, secondary storage, and peripheral devices.

Describe the process of translating high-level languages to machine code.

- Generally, machine code depends on the CPU type. However, the instruction set of the Java virtual machine (JVM) can be executed on different CPUs.
- Because machine instructions are encoded as numbers, it is difficult to write programs in machine code.
- High-level languages allow you to describe tasks at a higher conceptual level than machine code.
- A compiler translates programs written in a high-level language into machine code.

Describe the history and design principles of the Java programming language.

- Java was originally designed for programming consumer devices, but it was first used successfully to write Internet applets.
- Java was designed to be safe and portable, benefiting both Internet users and students.
- Java has a very large library. Focus on learning those parts of the library that you need for your programming projects.

Describe the building blocks of a simple program and the structure of a method call.

- Classes are the fundamental building blocks of Java programs.
- Every Java application contains a class with a `main` method. When the application starts, the instructions in the `main` method are executed.
- Use comments to help human readers understand your program.
- A method is called by specifying an object, the method name, and the method parameters.
- A string is a sequence of characters enclosed in quotation marks.

Use your programming environment to write and run Java programs.

- Set aside some time to become familiar with the computer system and the Java compiler that you will use for your class work.
- An editor is a program for entering and modifying text, such as a Java program.

- Java is case sensitive. You must be careful about distinguishing between upper- and lowercase letters.
- Lay out your programs so that they are easy to read.
- The Java compiler translates source code into class files that contain instructions for the Java virtual machine.
- The Java virtual machine loads program instructions from class files and library files.
- Develop a strategy for keeping backup copies of your work before disaster strikes.

Classify program errors as compile-time and run-time errors.

- A compile-time error is a violation of the programming language rules that is detected by the compiler.
- A run-time error causes a program to take an action that the programmer did not intend.

Write pseudocode for simple algorithms.

- Pseudocode is an informal description of a sequence of steps for solving a problem.
- An algorithm for solving a problem is a sequence of steps that is unambiguous, executable, and terminating.

Classes, Objects, and Methods Introduced in this Chapter

Here is a list of all classes, objects, and methods introduced in this chapter. Turn to the documentation in Appendix D for more information.

```
java.io.PrintStream                    java.lang.System
   print                                  out
   println
```

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** Writing an Algorithm for Tiling a Floor
- Practice Quiz
- Code Completion Exercises

Review Exercises

★ **R1.1** Explain the difference between using a computer program and programming a computer.

★ **R1.2** What distinguishes a computer from a typical household appliance?

★★ **R1.3** Describe *exactly* what steps you would take to back up your work after you have typed in the `HelloPrinter.java` program.

★★ **R1.4** On your own computer or on a lab computer, find the exact location (folder or directory name) of

a. The sample file `HelloPrinter.java`, which you wrote with the editor.
b. The Java program launcher `java.exe` or `java`.
c. The library file `rt.jar` that contains the run-time library.

★ **R1.5** How do you discover syntax errors? How do you discover logic errors?

★★ **R1.6** Write three versions of the `HelloPrinter.java` program that have different compile-time errors. Write a version that has a run-time error.

★★★ **R1.7** What do the following statements print? Don't guess; write programs to find out.

a. `System.out.println("3 + 4");`
b. `System.out.println(3 + 4);`
c. `System.out.println(3 + "4");`

★★ **R1.8** Write an algorithm to settle the following question: A bank account starts out with $10,000. Interest is compounded monthly at 6 percent per year (0.5 percent per month). Every month, $500 is withdrawn to meet college expenses. After how many years is the account depleted?

★★★ **R1.9** Consider the question in Exercise R1.8. Suppose the numbers ($10,000, 6 percent, $500) were user selectable. Are there values for which the algorithm you developed would not terminate? If so, change the algorithm to make sure it always terminates.

★★★ **R1.10** In order to estimate the cost of painting a house, a painter needs to know the surface area of the exterior. Develop an algorithm for computing that value. Your inputs are the width, length, and height of the house, the number of windows and doors, and their dimensions. (Assume the windows and doors have a uniform size.)

★★ **R1.11** You want to decide whether you should drive your car to work or take the train. You know the one-way distance from your home to your place of work, and the fuel efficiency of your car (in miles per gallon). You also know the one-way price of a train ticket. You assume the cost of gas at $4 per gallon, and car maintenance at 5 cents per mile. Write an algorithm to decide which commute is cheaper.

★★ **R1.12** You want to find out which fraction of your car use is for commuting to work, and which is for personal use. You know the one-way distance from your home to your place of work. For a particular period, you recorded the beginning and ending mileage on the odometer and the number of work days. Write an algorithm to settle this question.

★ **R1.13** In the problem described in How To 1.1 on page 22, you made assumptions about the price of gas and the annual usage. Ideally, you would like to know which car is the better deal without making these assumptions. Why can't a computer program solve that problem?

Programming Exercises

★ **P1.1** Write a program `NamePrinter` that displays your name inside a box on the console screen, like this:

```
+----+
|Dave|
+----+
```

Do your best to approximate lines with characters, such as `|`, `-`, and `+`.

★★★ **P1.2** Write a program that prints your name in large letters, such as

```
*   *    **    ****    ****   *   *
*   *   *  *   *   *   *   *  *   *
*****  *    *  ****    ****    * *
*   *  ******  *   *   *   *    *
*   *  *    *  *    *  *    *   *
```

★ **P1.3** Write a program `FacePrinter` that prints a face, using text characters, hopefully better looking than this one:

```
  /////
 | o o |
(|  ^  |)
 | [_] |
  -----
```

Use *comments* to indicate the statements that print the hair, ears, mouth, and so on.

★★★ **P1.4** Write a program that prints an animal speaking a greeting, similar to (but different from) the following

```
 /\_/\     -----
( ‘ ’ )  / Hello \
(  -  ) <  Junior |
 | | |   \ Coder!/
(__|__)    -----
```

★ **P1.5** Write a program `TicTacToeBoardPrinter` that prints a tic-tac-toe board:

```
+---+---+---+
|   |   |   |
+---+---+---+
|   |   |   |
+---+---+---+
|   |   |   |
+---+---+---+
```

★ **P1.6** Write a program `StaircasePrinter` that prints a staircase:

```
            +---+
            |   |
        +---+---+
        |   |   |
    +---+---+---+
    |   |   |   |
+---+---+---+---+
|   |   |   |   |
+---+---+---+---+
```

★ **P1.7** Write a program that prints three items, such as the names of your three best friends or favorite movies, on three separate lines.

★★ **P1.8** Write a program that computes the sum of the first ten positive integers, 1 + 2 + · · · + 10. *Hint:* Write a program of the form

```
public class Sum10
{
   public static void main(String[] args)
   {
      System.out.println(          );
   }
}
```

★★ **P1.9** Type in and run the following program:

```
import javax.swing.JOptionPane;

public class DialogViewer
{
   public static void main(String[] args)
   {
      JOptionPane.showMessageDialog(null, "Hello, World!");
      System.exit(0);
   }
}
```

Then modify the program to show the message “Hello, *your name*!”.

★★ **P1.10** Type in and run the following program:

```
import javax.swing.JOptionPane;

public class DialogViewer
{
   public static void main(String[] args)
   {
      String name = JOptionPane.showInputDialog("What is your name?");
      System.out.println(name);
      System.exit(0);
   }
}
```

Then modify the program to print “Hello, *name*!”, displaying the name that the user typed in.

★★ **P1.11** Run the following program:

```
import java.net.URL;
import javax.swing.ImageIcon;
import javax.swing.JOptionPane;

public class Test
{
   public static void main(String[] args) throws Exception
   {
      URL imageLocation = new URL(
         "http://horstmann.com/bigjava/duke.gif");
      JOptionPane.showMessageDialog(null, "Hello", "Title",
         JOptionPane.PLAIN_MESSAGE, new ImageIcon(imageLocation));
      System.exit(0);
   }
}
```

Then modify it to show a different greeting and image.

Programming Projects

Project 1.1 This project builds on Exercises P1.9 and P1.10. Your program should read the user's name, then show a sequence of two dialog boxes:

- First, an input dialog box that asks: "What would you like me to do?"
- Then a message dialog box that says: "I'm sorry, *your name*. I'm afraid I can't do that."

Answers to Self-Check Questions

1. A program that reads the data on the CD and sends output to the speakers and the screen.
2. A CD player can do one thing—play music CDs. It cannot execute programs.
3. No—the program simply executes the instruction sequences that the programmers have prepared in advance.
4. In secondary storage, typically a hard disk.
5. The central processing unit.
6. 21 100
7. No—a compiler is intended for programmers, to translate high-level programming instructions into machine code.
8. Safety and portability.
9. No one person can learn the entire library—it is too large.
10. `System.out.println("Hello,"); System.out.println("World!");`
11. Yes—the line starting with `//` is a comment, intended for human readers. The compiler ignores comments.
12. The printout is `My lucky number is12`. It would be a good idea to add a space after the `is`.
13. Yes, but you must remember to save your file as "plain text."
14. A sequence of random characters, some funny-looking. Class files contain virtual machine instructions that are encoded as binary numbers.
15. A compile-time error. The compiler will not know what to do with the word `Display`.
16. It is a run-time error. After all, the program had been compiled in order for you to run it.
17. When a program has compiler errors, no class file is produced, and there is nothing to run.
18. 4 years:

0	10,000
1	12,000
2	14,400
3	17,280
4	20,736

19. Is the number of minutes at most 300?

a. If so, the answer is $29.95 × 1.125 = $33.70.

b. If not,

1. Compute the difference: (number of minutes) – 300.
2. Multiply that difference by 0.45.
3. Add $29.95.
4. Multiply the total by 1.125. That is the answer.

Chapter 2

Using Objects

CHAPTER GOALS

- To learn about variables
- To understand the concepts of classes and objects
- To be able to call methods
- To learn about parameters and return values
- To be able to browse the API documentation

T To implement test programs

- To understand the difference between objects and object references

G To write programs that display simple shapes

Most useful programs don't just manipulate numbers and strings. Instead, they deal with data items that are more complex and that more closely represent entities in the real world. Examples of these data items include bank accounts, employee records, and graphical shapes.

The Java language is ideally suited for designing and manipulating such data items, or **objects**. In Java, you implement **classes** that describe the behavior of these objects. In this chapter, you will learn how to manipulate objects that belong to classes that have already been implemented. This knowledge will prepare you for the next chapter in which you will learn how to implement your own classes.

CHAPTER CONTENTS

2.1 Types 32

2.2 Variables 34

Syntax 2.1: Variable Declaration 35

Quality Tip 2.1: Choose Descriptive Names for Variables 36

2.3 The Assignment Operator 37

Syntax 2.2: Assignment 37

Common Error 2.1: Confusing Variable Declarations and Assignment Statements 38

2.4 Objects, Classes, and Methods 39

2.5 Method Parameters and Return Values 41

2.6 Constructing Objects 44

Syntax 2.3: Object Construction 45

Common Error 2.2: Trying to Invoke a Constructor Like a Method 45

2.7 Accessor and Mutator Methods 46

2.8 The API Documentation 47

Syntax 2.4: Importing a Class from a Package 49

Productivity Hint 2.1: Don't Memorize—Use Online Help 49

2.9T Implementing a Test Program 50

Special Topic 2.1: Testing Classes in an Interactive Environment ⊕

Worked Example 2.1: How Many Days Have You Been Alive? ⊕

Worked Example 2.2: Working with Pictures ⊕

2.10 Object References 52

Random Fact 2.1: Mainframes—When Dinosaurs Ruled the Earth ⊕

2.11G Graphical Applications and Frame Windows 54

2.12G Drawing on a Component 56

Special Topic 2.2: Applets ⊕

2.13G Ellipses, Lines, Text, and Color 59

Random Fact 2.2: The Evolution of the Internet ⊕

2.1 Types

Before we start with the main topic of this chapter, we need to go over some basic programming terminology. In the first three sections of this chapter, you will learn about the concepts of types, variables, and assignment.

A type specifies a set of values and the operations that can be carried out with the values.

A computer program processes values: numbers, strings, and more complex data items. In Java, every value has a **type**. For example, the number 13 has the type `int` (an abbreviation for "integer"), `"Hello, World"` has the type `String`, and the object `System.out` has the type `PrintStream`. The type tells you what operations you can carry out with the values. For example, you can compute the sum or product of any two integers. You can call `println` on any object of type `PrintStream`.

Java has separate types for **integers** and **floating-point numbers**. Integers are whole numbers; floating-point numbers can have fractional parts. For example, 13 is an integer and 1.3 is a floating-point number.

The name "floating-point" describes the representation of the number in the computer as a sequence of the significant digits and an indication of the position of the decimal point. For example, the numbers 13000.0, 1.3, 0.00013 all have the same decimal digits: 13. When a floating-point number is multiplied or divided by 10, only the position of the decimal point changes; it "floats". This representation is related to the "scientific" notation 1.3×10^{-4}. (Actually, the computer represents numbers in base 2, not base 10, but the principle is the same.)

The `double` type denotes floating-point numbers that can have fractional parts.

If you need to process numbers with a fractional part, you should use the type called `double`, which stands for "double precision floating-point number". Think of a number in `double` format as any number that can appear in the display panel of a calculator, such as 1.3 or –0.333333333.

Table 1 Number Literals in Java

Number	Type	Comment
6	`int`	An integer has no fractional part.
–6	`int`	Integers can be negative.
0	`int`	Zero is an integer.
0.5	`double`	A number with a fractional part has type `double`.
1.0	`double`	An integer with a fractional part .0 has type `double`.
`1E6`	`double`	A number in exponential notation: 1×10^6 or 1000000. Numbers in exponential notation always have type `double`.
`2.96E-2`	`double`	Negative exponent: $2.96 \times 10^{-2} = 2.96 / 100 = 0.0296$
🚫 100,000		**Error:** Do not use a comma as a decimal separator.
🚫 3 1/2		**Error:** Do not use fractions; use decimal notation: 3.5.

When a value such as `13` or `1.3` occurs in a Java program, it is called a **number literal**. Do not use commas when you write number literals in Java. For example, 13,000 must be written as `13000`. To write numbers in exponential notation in Java, use the notation `E`*n* instead of "$\times 10^n$". For example, 1.3×10^{-4} is written as `1.3E-4`. Table 1 shows how to write integer and floating-point literals in Java.

You may wonder why Java has separate integer and floating-point number types. Pocket calculators don't need a separate integer type; they use floating-point numbers for all calculations. However, integers have several advantages over floating-point numbers. They take less storage space, are processed faster, and don't cause rounding errors. You will want to use the `int` type for quantities that can never have fractional parts, such as the length of a string. Use the `double` type for quantities that can have fractional parts, such as a grade point average.

In Java, the number types are primitive types, and numbers are not objects.

There are several other number types in Java that are not as commonly used. We will discuss these types in Chapter 4. For most programs in this book, however, the `int` and `double` types are all you need for processing numbers.

In Java, the number types (`int`, `double`, and the less commonly used types) are **primitive types**. Numbers are not objects. The number types have no methods.

However, you can combine numbers with operators such as `+` and `-`, as in `10 + n` or `n - 1`. To multiply two numbers, use the `*` operator. For example, $10 \times n$ is written as `10 * n`.

A combination of variables, literals, operators, and/or methods (which you will see in Section 2.4) is called an *expression*. A typical example of an expression is

```
x + y * 2
```

Numbers can be combined by arithmetic operators such as +, -, and *.

As in mathematics, the `*` operator binds more strongly than the `+` operator. That is, `x + y * 2` means the sum of `x` and `y * 2`. If you want to multiply the sum of `x` and `y` by 2, use parentheses:

```
(x + y) * 2
```

SELF CHECK

1. What are the types of the values `0` and `"0"`?
2. Which number type would you use for storing the area of a circle?
3. Why is the expression `13.println()` an error?
4. Write an expression to compute the average of the values `x` and `y`.

2.2 Variables

You often want to store values so that you can use them at a later time. To remember a value, you need to hold it in a **variable**. A variable is a storage location in the computer's memory that has a type, name, and contents. For example, here we declare three variables:

```
String greeting = "Hello, World!";
PrintStream printer = System.out;
int width = 20;
```

You use variables to store values that you want to use at a later time. A variable has a type, a name, and a value.

The first variable is called `greeting`. It can be used to store `String` values, and it is set to the value `"Hello, World!"`. The second variable, `printer`, stores a `PrintStream` value, and the third stores an integer.

Variables can be used in place of the values that they store:

```
printer.println(greeting); // Same as System.out.println("Hello, World!")
printer.println(width); // Same as System.out.println(20)
```

When you declare your own variables, you need to make two decisions.

- What type should you use for the variable?
- What name should you give the variable?

The type depends on the intended use. If you need to store a string, use the `String` type for your variable. If you need a number, choose the `int` or `double` type.

It is an error to store a value whose type does not match the type of the variable. For example, the following is an error:

```
String greeting = 20; // ERROR: Types don't match
```

Table 2 Variable Declarations in Java

Variable Name	Comment
`int width = 10;`	Declares an integer variable and initializes it with 10.
`int area = width * height;`	The initial value can depend on other variables. (Of course, `width` and `height` must have been previously declared.)
🚫 `height = 5;`	**Error:** The type is missing. This statement is not a declaration but an assignment of a new value to an existing variable—see Section 2.3.
🚫 `int height = "5";`	**Error:** You cannot initialize a number with a string.
`int width, height;`	Declares two integer variables in a single statement. In this book, we will declare each variable in a separate statement.

You cannot use a `String` variable to store an integer. The compiler checks type mismatches to protect you from errors.

When deciding on a name for a variable, you should make a choice that describes the purpose of the variable. For example, the variable name `greeting` is a better choice than the name `g`.

Identifiers for variables, methods, and classes are composed of letters, digits, and the underscore character.

An *identifier* is the name of a variable, method, or class. Java imposes the following rules for identifiers:

- Identifiers can be made up of letters, digits, and the underscore (_) and dollar sign (`$`) characters. They cannot start with a digit, though.
- You cannot use spaces or symbols such as `?` or `%`.
- Furthermore, you cannot use **reserved words**, such as `public`, as names; these words are reserved exclusively for their special Java meanings. (See Appendix C for all reserved words in Java.)

By convention, variable names should start with a lowercase letter.

These are firm rules of the Java language. If you violate one of them, the compiler will report an error. Moreover, there are a couple of *conventions* that you should follow so that other programmers will find your programs easy to read:

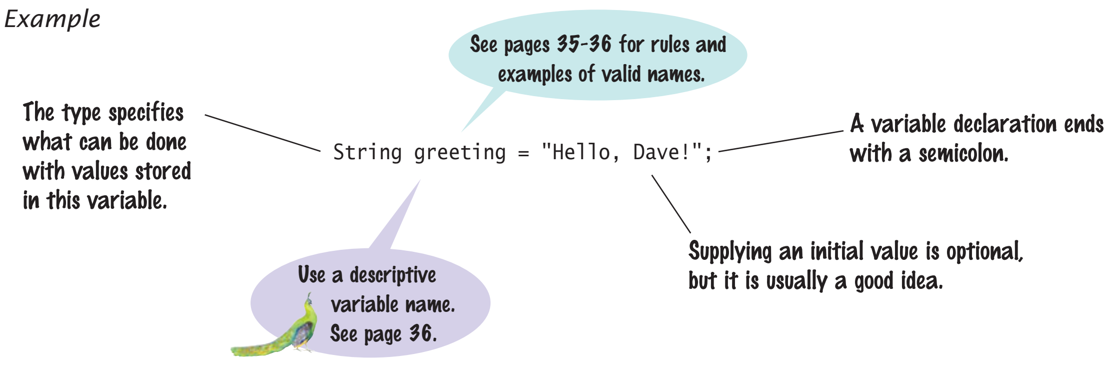
- Variable and method names should start with a lowercase letter. It is OK to use an occasional uppercase letter, such as `farewellMessage`. This mixture of lowercase and uppercase letters is sometimes called "camel case" because the uppercase letters stick out like the humps of a camel.
- Class names should start with an uppercase letter. For example, `Greeting` would be an appropriate name for a class, but not for a variable.
- You should not use the `$` symbol in names. It is intended for names that are automatically generated by tools.

If you violate these conventions, the compiler won't complain, but you will confuse other programmers who read your code.

Syntax 2.1 Variable Declaration

Syntax *typeName variableName* = *value*;
or
typeName variableName;

Example


See pages 35–36 for rules and examples of valid names.
The type specifies what can be done with values stored in this variable.
A variable declaration ends with a semicolon.
Supplying an initial value is optional, but it is usually a good idea.
Use a descriptive variable name. See page 36.

```
String greeting = "Hello, Dave!";
```

Table 3 Variable Names in Java

Variable Name	Comment
`farewellMessage`	Use “camel case” for variable names consisting of multiple words.
`x`	In mathematics, you use short variable names such as *x* or *y*. This is legal in Java, but not very common, because it can make programs harder to understand.
⚠ `Greeting`	**Caution:** Variable names are case-sensitive. This variable name is different from `greeting`.
🚫 `6pack`	**Error:** Variable names cannot start with a number.
🚫 `farewell message`	**Error:** Variable names cannot contain spaces.
🚫 `public`	**Error:** You cannot use a reserved word as a variable name.

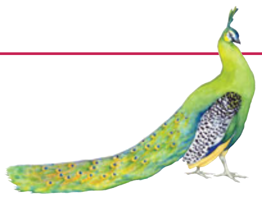
Table 3 shows examples of legal and illegal variable names in Java.

SELF CHECK

5. Which of the following are legal identifiers?

```
Greeting1
g
void
101dalmatians
Hello, World
<greeting>
```

6. Declare a variable to hold your name. Use camel case in the variable name.



Quality Tip 2.1

Choose Descriptive Names for Variables

In algebra, variable names are usually just one letter long, such as *p* or *A*, maybe with a subscript such as p_1. You might be tempted to save yourself a lot of typing by using short variable names in your Java programs:

```
int A = w * h;
```

Compare this with the following statement:

```
int area = width * height;
```

The advantage is obvious. Reading `width` is much easier than reading `w` and then figuring out that it must mean “width”.

In practical programming, descriptive variable names are particularly important when programs are written by more than one person. It may be obvious to you that `w` stands for width, but is it obvious to the person who needs to update your code years later? For that matter, will you yourself remember what `w` means when you look at the code a month from now?

2.3 The Assignment Operator

Use the assignment operator (=) to change the value of a variable.

You can change the value of a variable with the assignment operator (=). For example, consider the variable declaration

```
int width = 10; ❶
```

If you want to change the value of the variable, simply assign the new value:

```
width = 20; ❷
```

The assignment replaces the original value of the variable (see Figure 1).

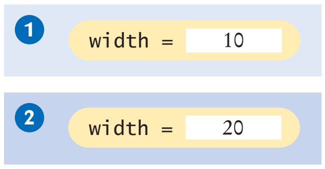


Figure 1
Assigning a New Value to a Variable

It is an error to use a variable that has never had a value assigned to it. For example, the following assignment statement has an error:

```
int height;
width = height;    // ERROR—uninitialized variable height
```

The compiler will complain about an "uninitialized variable" when you use a variable that has never been assigned a value. (See Figure 2.)

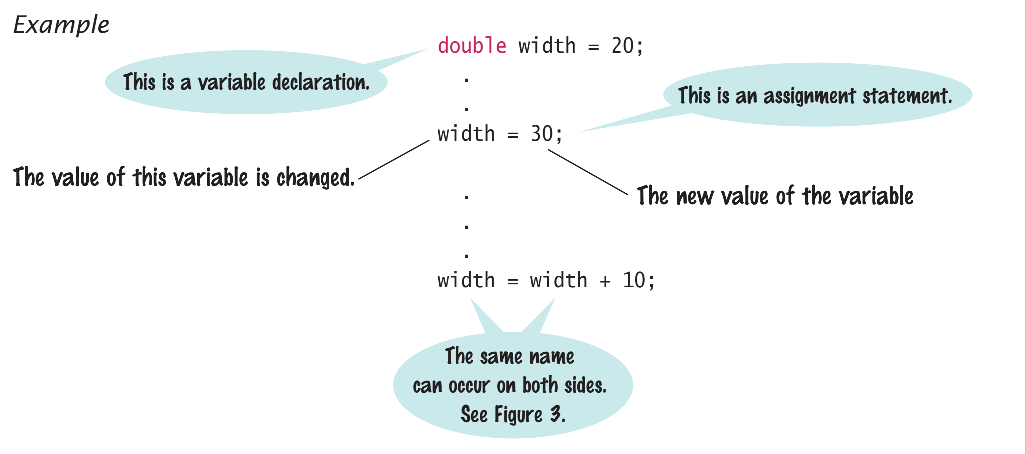
height =
No value has been assigned.

Figure 2
An Uninitialized Variable

Syntax 2.2 Assignment

Syntax *variableName* = *value*;

Example



```
double width = 20;
      .
      .
width = 30;
      .
      .
      .
width = width + 10;
```

This is a variable declaration.
This is an assignment statement.
The value of this variable is changed.
The new value of the variable
The same name can occur on both sides. See Figure 3.

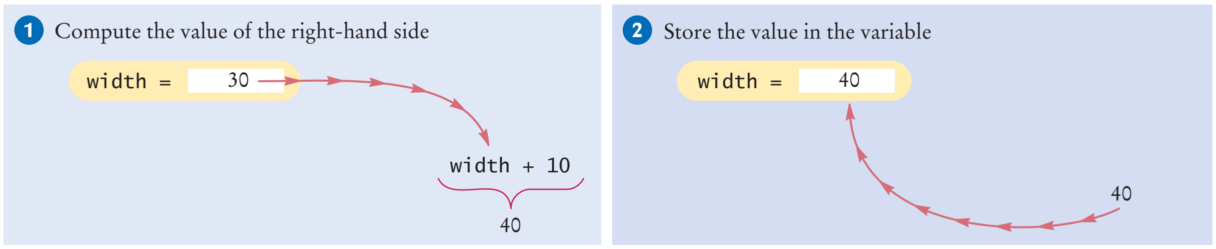

1 Compute the value of the right-hand side
width = 30
width + 10
40
2 Store the value in the variable
width = 40
40

Figure 3 Executing the Statement `width = width + 10`

All variables must be initialized before you access them.

The remedy is to assign a value to the variable before you use it:

```
int height = 30;
width = height; // OK
```

Or, even better, initialize the variable when you declare it.

```
int height = 30;
int width = height; // OK
```

ANIMATION *Variable Initialization and Assignment*

The right-hand side of the = symbol can be a mathematical expression. For example,

```
width = height + 10;
```

This means "compute the value of `height + 10` and store that value in the variable `width`".

In the Java programming language, the = operator denotes an *action*, to replace the value of a variable. This usage differs from the mathematical usage of the = symbol, as a statement about equality. For example, in Java, the following statement is entirely legal:

```
width = width + 10;
```

This means "compute the value of `width + 10` 1 and store that value in the variable `width` 2" (see Figure 3).

In Java, it is not a problem that the variable `width` is used on both sides of the = symbol. Of course, in mathematics, the equation $width = width + 10$ has no solution.

SELF CHECK

7. Is `12 = 12` a valid expression in the Java language?
8. How do you change the value of the `greeting` variable to `"Hello, Nina!"`?

Common Error 2.1

Confusing Variable Declarations and Assignment Statements

Suppose your program declares a variable as follows:

```
int width = 20;
```

If you want to change the value of the variable, you use an assignment statement:

```
width = 30;
```

It is a common error to accidentally use another variable declaration:

```
int width = 30; // ERROR—starts with int and is therefore a declaration
```

But there is already a variable named `width`. The compiler will complain that you are trying to declare another variable with the same name.

2.4 Objects, Classes, and Methods

Objects are entities in your program that you manipulate by calling methods.

A method is a sequence of instructions that accesses the data of an object.

We now come to the main purpose of this chapter: a closer understanding of objects. An **object** is a value that you can manipulate by calling one or more of its **methods**. A method consists of a sequence of instructions that can access the internal data of an object. When you call the method, you do not know exactly what those instructions are, or even how the object is organized internally. However, the behavior of the method is well-defined, and that is what matters to us when we use it.

For example, you saw in Chapter 1 that `System.out` refers to an object. You manipulate it by calling the `println` method. When the `println` method is called, some activities occur inside the object, and the ultimate effect is that text appears in the console window. You don't know how that happens, and that's OK. What matters is that the method carries out the work that you requested.

Figure 4 shows a representation of the `System.out` object. The internal data is symbolized by a sequence of zeroes and ones. Think of each method (symbolized by the gears) as a piece of machinery that carries out its assigned task.

In Chapter 1, you encountered two objects:

- `System.out`
- `"Hello, World!"`

A class declares the methods that you can apply to its objects.

The type of an object is a **class**. The `System.out` object belongs to the class `PrintStream`. The `"Hello, World!"` object belongs to the class `String`. A class specifies the methods that you can apply to its objects.

You can use the `println` method with any object that belongs to the `PrintStream` class. `System.out` is one such object. It is possible to obtain other objects of the `PrintStream` class. For example, you can construct a `PrintStream` object to send output to a file. However, we won't discuss files until Chapter 11.

Just as the `PrintStream` class provides methods such as `println` and `print` for its objects, the `String` class provides methods that you can apply to `String` objects. One of them is the `length` method. The `length` method counts the number of characters in

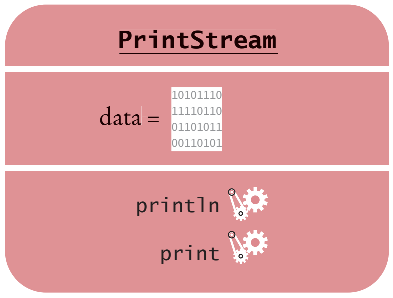


Figure 4 Representation of the `System.out` Object

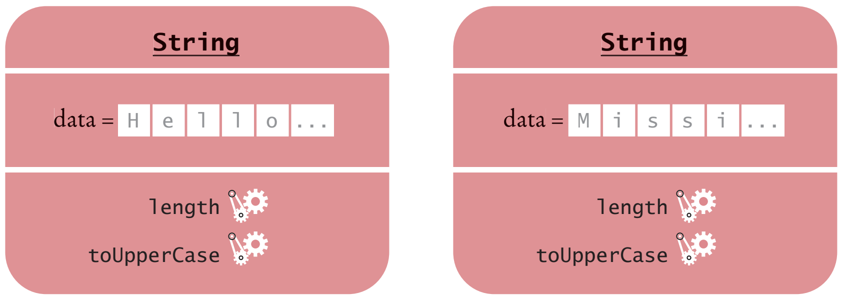


Figure 5 A Representation of Two `String` Objects

a string. You can apply that method to any object of type `String`. For example, the sequence of statements

```
String greeting = "Hello, World!";
int n = greeting.length();
```

sets `n` to the number of characters in the `String` object `"Hello, World!"`. After the instructions in the `length` method are executed, `n` is set to 13. (The quotation marks are not part of the string, and the `length` method does not count them.)

The `length` method—unlike the `println` method—requires no input inside the parentheses. However, the `length` method yields an output, namely the character count.

In the next section, you will see in greater detail how to supply method inputs and obtain method outputs.

Let us look at another method of the `String` class. When you apply the `toUpperCase` method to a `String` object, the method creates another `String` object that contains the characters of the original string, with lowercase letters converted to uppercase. For example, the sequence of statements

```
String river = "Mississippi";
String bigRiver = river.toUpperCase();
```

sets `bigRiver` to the `String` object `"MISSISSIPPI"`.

When you apply a method to an object, you must make sure that the method is declared in the appropriate class. For example, it is an error to call

```
System.out.length(); // This method call is an error
```

The `PrintStream` class (to which `System.out` belongs) has no `length` method.

The public interface of a class specifies what you can do with its objects. The hidden implementation describes how these actions are carried out.

Let us summarize. In Java, *every object belongs to a class. The class declares the methods for the objects*. For example, the `String` class declares the `length` and `toUpperCase` methods (as well as other methods—you will learn about most of them in Chapter 4). The methods form the *public interface* of the class, telling you what you can do with the objects of the class. A class also declares a *private implementation*, describing the data inside its objects and the instructions for its methods. Those details are hidden from the programmers who use objects and call methods.

Figure 5 shows two objects of the `String` class. Each object stores its own data (drawn as boxes that contain characters). Both objects support the same set of methods—the interface that is specified by the `String` class.

Occasionally, a class declares two methods with the same name and different parameter types. For example, the `PrintStream` class declares a second method, also called `println`, as

```
public void println(int output)
```

That method is used to print an integer value. We say that the `println` name is **overloaded** because it refers to more than one method.

SELF CHECK

9. How can you compute the length of the string `"Mississippi"`?
10. How can you print out the uppercase version of `"Hello, World!"`?
11. Is it legal to call `river.println()`? Why or why not?

2.5 Method Parameters and Return Values

Methods are fundamental building blocks of Java programs. A program performs useful work by calling methods. In this section, we will examine how to provide inputs into a method, and how to obtain the result of the method.

A parameter is an input to a method.

Most methods require inputs that give details about the work that the method needs to do. For example, the `println` method has an input: the string that should be printed. Computer scientists use the technical term parameter for method inputs. We say that the string `greeting` is a parameter of the method call

```
System.out.println(greeting);
```

Figure 6 illustrates passing of the parameter to the method.

The implicit parameter of a method call is the object on which the method is invoked. All other parameters are explicit parameters.

Technically speaking, the `greeting` parameter is an **explicit parameter** of the `println` method. The object on which you invoke the method is also considered a parameter of the method call; it is called the **implicit parameter**. For example, `System.out` is the implicit parameter of the method call

```
System.out.println(greeting);
```

Some methods require multiple explicit parameters, others don't require any explicit parameters at all. An example of the latter is the `length` method of the `String` class (see Figure 7). All the information that the `length` method requires to do its job—namely, the character sequence of the string—is stored in the implicit parameter object.

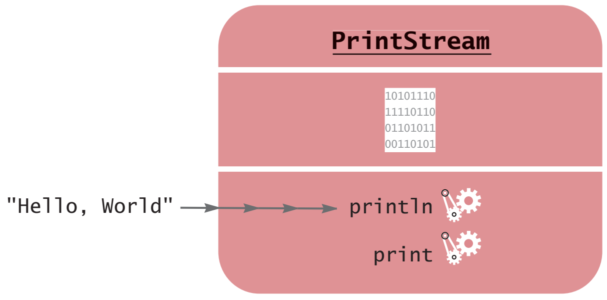


Figure 6 Passing a Parameter to the `println` Method

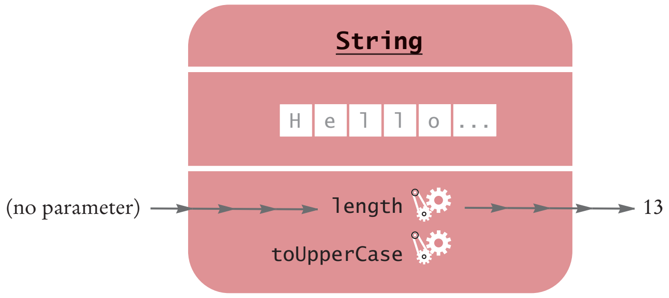


Figure 7 Invoking the `length` Method on a `String` Object

The return value of a method is a result that the method has computed for use by the code that called it.

The `length` method differs from the `println` method in another way: it has an output. We say that the method *returns a value*, namely the number of characters in the string. You can store the return value in a variable:

```
int n = greeting.length();
```

You can also use the return value as a parameter of another method:

```
System.out.println(greeting.length());
```

The method call `greeting.length()` returns a value—the integer 13. The return value becomes a parameter of the `println` method. Figure 8 shows the process.

ANIMATION *Parameter Passing*

Not all methods return values. One example is the `println` method. The `println` method interacts with the operating system, causing characters to appear in a window. But it does not return a value to the code that calls it.

Let us analyze a more complex method call. Here, we will call the `replace` method of the `String` class. The `replace` method carries out a search-and-replace operation, similar to that of a word processor. For example, the call

```
river.replace("issipp", "our")
```

constructs a new string that is obtained by replacing all occurrences of `"issipp"` in `"Mississippi"` with `"our"`. (In this situation, there was only one replacement.) The method returns the `String` object `"Missouri"`. You can save that string in a variable:

```
river = river.replace("issipp", "our");
```

Or you can pass it to another method:

```
System.out.println(river.replace("issipp", "our"));
```

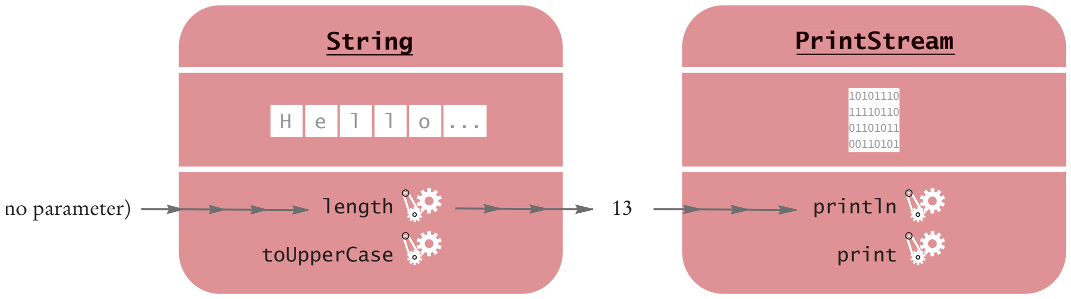


Figure 8 Passing the Result of a Method Call to Another Method

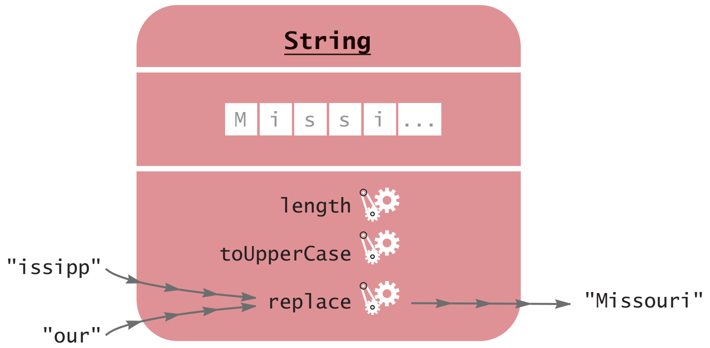


Figure 9 Calling the `replace` Method

As Figure 9 shows, this method call has

- one implicit parameter: the string `"Mississippi"`
- two explicit parameters: the strings `"issipp"` and `"our"`
- a return value: the string `"Missouri"`

When a method is declared in a class, the declaration specifies the types of the explicit parameters and the return value. For example, the `String` class declares the `length` method as

```
public int length()
```

That is, there are no explicit parameters, and the return value has the type int. (For now, all the methods that we consider will be "public" methods—see Chapter 10 for more restricted methods.)

The type of the implicit parameter is the class that declares the method—`String` in our case. It is not mentioned in the method declaration—hence the term "implicit".

The `replace` method is declared as

```
public String replace(String target, String replacement)
```

To call the `replace` method, you supply two explicit parameters, `target` and `replacement`, which both have type `String`. The returned value is another string.

When a method returns no value, the return type is declared with the reserved word `void`. For example, the `PrintStream` class declares the `println` method as

```
public void println(String output)
```

SELF CHECK

12. What are the implicit parameters, explicit parameters, and return values in the method call `river.length()`?
13. What is the result of the call `river.replace("p", "s")`?
14. What is the result of the call `greeting.replace("World", "Dave").length()`?
15. How is the `toUpperCase` method declared in the `String` class?

2.6 Constructing Objects

Most Java programs need to work on a variety of objects. In this section, you will see how to *construct* new objects. This allows you to go beyond `String` objects and the `System.out` object.

To learn about object construction, let us turn to another class: the `Rectangle` class in the Java class library. Objects of type `Rectangle` describe rectangular shapes—see Figure 10. These objects are useful for a variety of purposes. You can assemble rectangles into bar charts, and you can program simple games by moving rectangles inside a window.

Note that a `Rectangle` object isn't a rectangular shape—it's an object that contains a set of numbers. The numbers *describe* the rectangle (see Figure 11). Each rectangle is described by the *x*- and *y*-coordinates of its top-left corner, its width, and its height.

It is very important that you understand this distinction. In the computer, a `Rectangle` object is a block of memory that holds four numbers, for example $x = 5$, $y = 10$, $width = 20$, $height = 30$. In the imagination of the programmer who uses a `Rectangle` object, the object describes a geometric figure.

Use the `new` operator, followed by a class name and parameters, to construct new objects.

To make a new rectangle, you need to specify the *x*, *y*, *width*, and *height* values. Then *invoke the* `new` *operator*, specifying the name of the class and the parameters that are required for constructing a new object. For example, you can make a new rectangle with its top-left corner at (5, 10), width 20, and height 30 as follows:

```
new Rectangle(5, 10, 20, 30)
```

Here is what happens in detail:

1. The `new` operator makes a `Rectangle` object.
2. It uses the parameters (in this case, 5, 10, 20, and 30) to initialize the data of the object.
3. It returns the object.

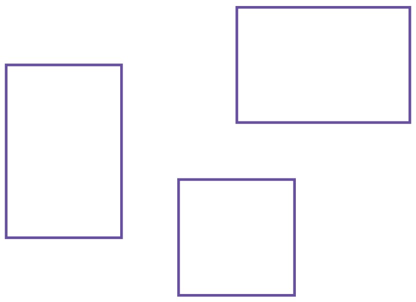


Figure 10 Rectangular Shapes

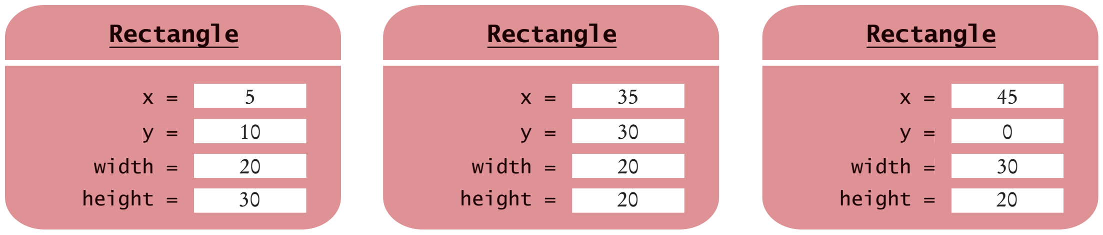
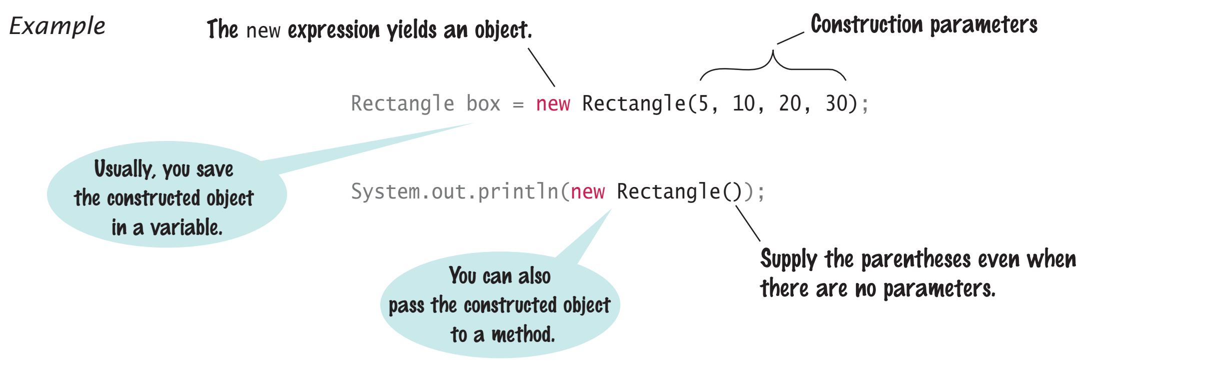


Figure 11 Rectangle Objects

Syntax 2.3 Object Construction

Syntax new *ClassName*(*parameters*)

Example



```
Rectangle box = new Rectangle(5, 10, 20, 30);

System.out.println(new Rectangle());
```

The new expression yields an object.
Construction parameters
Usually, you save the constructed object in a variable.
You can also pass the constructed object to a method.
Supply the parentheses even when there are no parameters.

The process of creating a new object is called **construction**. The four values 5, 10, 20, and 30 are called the *construction parameters*.

The `new` expression yields an object, and you need to store the object if you want to use it later. Usually you assign the output of the `new` operator to a variable. For example,

```
Rectangle box = new Rectangle(5, 10, 20, 30);
```

Some classes let you construct objects in multiple ways. For example, you can also obtain a `Rectangle` object by supplying no construction parameters at all (but you must still supply the parentheses):

```
new Rectangle()
```

This expression constructs a (rather useless) rectangle with its top-left corner at the origin (0, 0), width 0, and height 0.

SELF CHECK

16. How do you construct a square with center (100, 100) and side length 20?

17. The `getWidth` method returns the width of a `Rectangle` object. What does the following statement print?

```
System.out.println(new Rectangle().getWidth());
```

Common Error 2.2

Trying to Invoke a Constructor Like a Method

Constructors are not methods. You can only use a constructor with the `new` operator, not to reinitialize an existing object:

```
box.Rectangle(20, 35, 20, 30); // Error—can't reinitialize object
```

The remedy is simple: Make a new object and overwrite the current one stored by `box`.

```
box = new Rectangle(20, 35, 20, 30); // OK
```

2.7 Accessor and Mutator Methods

An accessor method does not change the internal data of its implicit parameter. A mutator method changes the data.

In this section we introduce a useful terminology for the methods of a class. A method that accesses an object and returns some information about it, without changing the object, is called an **accessor method**. In contrast, a method whose purpose is to modify the internal data of an object is called a **mutator method**.

For example, the `length` method of the `String` class is an accessor method. It returns information about a string, namely its length. But it doesn't modify the string at all when counting the characters.

The `Rectangle` class has a number of accessor methods. The `getX`, `getY`, `getWidth`, and `getHeight` methods return the *x*- and *y*-coordinates of the top-left corner, the width, and the height values. For example,

```
double width = box.getWidth();
```

Now let us consider a mutator method. Programs that manipulate rectangles frequently need to move them around, for example, to display animations. The `Rectangle` class has a method for that purpose, called `translate`. (Mathematicians use the term "translation" for a rigid motion of the plane.) This method moves a rectangle by a certain distance in the *x*- and *y*-directions. The method call,

```
box.translate(15, 25);
```

moves the rectangle by 15 units in the *x*-direction and 25 units in the *y*-direction (see Figure 12). Moving a rectangle doesn't change its width or height, but it changes the top-left corner. Afterward, the rectangle that had its top-left corner at (5, 10) now has it at (20, 35).

This method is a mutator because it modifies the implicit parameter object.

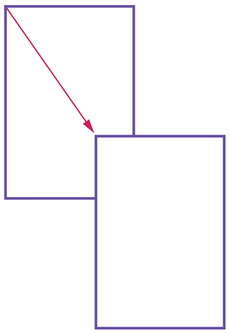


Figure 12
Using the `translate` Method to Move a Rectangle

SELF CHECK

18. Is the `toUpperCase` method of the `String` class an accessor or a mutator?

19. Which call to `translate` is needed to move the rectangle declared by `Rectangle box = new Rectangle(5, 10, 20, 30)` so that its top-left corner is the origin (0, 0)?

2.8 The API Documentation

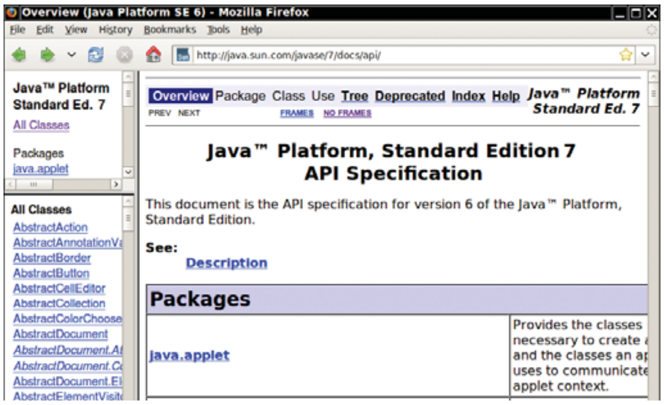
The API (Application Programming Interface) documentation lists the classes and methods of the Java library.

The classes and methods of the Java library are listed in the **API documentation**. The API is the "application programming interface". A programmer who uses the Java classes to put together a computer program (or *application*) is an *application programmer*. That's you. In contrast, the programmers who designed and implemented the library classes such as `PrintStream` and `Rectangle` are *system programmers*.

You can find the API documentation on the Web. Point your web browser to `http://java.sun.com/javase/7/docs/api/index.html`. Appendix D contains an abbreviated version of the API documentation that may be easier to use at first. It is fine if you rely on the abbreviated documentation for your first programs, but you should eventually move on to the real thing.

The API documentation documents all classes in the Java library—there are thousands of them (see Figure 13). Most of the classes are rather specialized, and only a few are of interest to the beginning programmer.

Locate the `Rectangle` link in the left pane, preferably by using the search function of your browser. Click on the link, and the right pane shows all the features of the `Rectangle` class (see Figure 14).

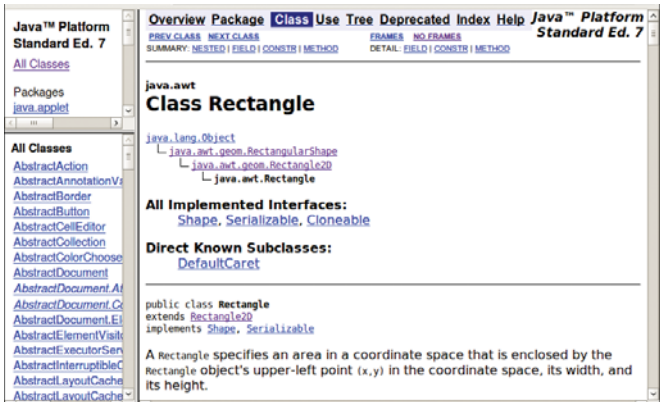


Java™ Platform, Standard Edition 7
API Specification

This document is the API specification for version 6 of the Java™ Platform, Standard Edition.

Provides the classes necessary to create and the classes an a uses to communicate applet context.

Figure 13 The API Documentation of the Standard Java Library



java.awt
Class Rectangle

```
java.lang.Object
  └ java.awt.geom.RectangularShape
      └ java.awt.geom.Rectangle2D
          └ java.awt.Rectangle
```

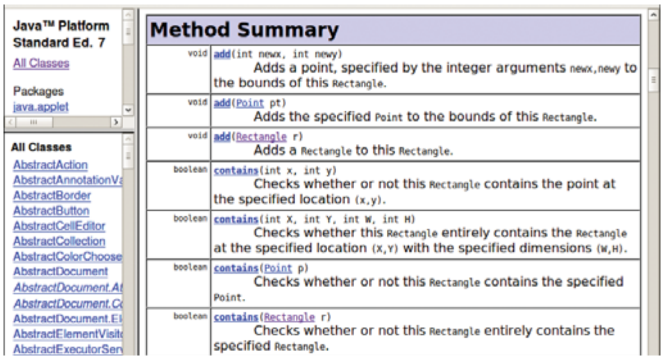
All Implemented Interfaces:
Shape, Serializable, Cloneable

Direct Known Subclasses:
DefaultCaret

```
public class Rectangle
extends Rectangle2D
implements Shape, Serializable
```

A `Rectangle` specifies an area in a coordinate space that is enclosed by the `Rectangle` object's upper-left point `(x,y)` in the coordinate space, its width, and its height.

Figure 14 The API Documentation for the `Rectangle` Class



Java™ Platform
Standard Ed. 7
All Classes

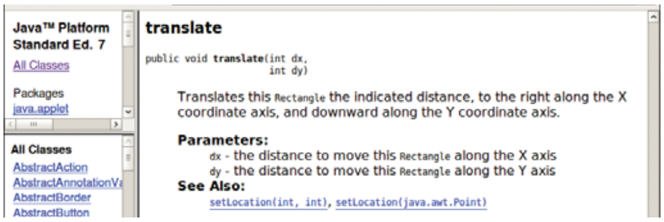
Packages
java.applet

All Classes
AbstractAction
AbstractAnnotationV
AbstractBorder
AbstractButton
AbstractCellEditor
AbstractCollection
AbstractColorChoose
AbstractDocument
AbstractDocument.At
AbstractDocument.C
AbstractDocument.El
AbstractElementVisit
AbstractExecutorSen

Method Summary

void	add(int newx, int newy) Adds a point, specified by the integer arguments newx,newy to the bounds of this Rectangle.
void	add(Point pt) Adds the specified Point to the bounds of this Rectangle.
void	add(Rectangle r) Adds a Rectangle to this Rectangle.
boolean	contains(int x, int y) Checks whether or not this Rectangle contains the point at the specified location (x,y).
boolean	contains(int X, int Y, int W, int H) Checks whether this Rectangle entirely contains the Rectangle at the specified location (X,Y) with the specified dimensions (W,H).
boolean	contains(Point p) Checks whether or not this Rectangle contains the specified Point.
boolean	contains(Rectangle r) Checks whether or not this Rectangle entirely contains the specified Rectangle.

Figure 15 The Method Summary for the Rectangle Class



Java™ Platform
Standard Ed. 7
All Classes

Packages
java.applet

All Classes
AbstractAction
AbstractAnnotationV
AbstractBorder
AbstractButton

translate

```
public void translate(int dx,
                      int dy)
```

Translates this Rectangle the indicated distance, to the right along the X coordinate axis, and downward along the Y coordinate axis.

Parameters:
dx - the distance to move this Rectangle along the X axis
dy - the distance to move this Rectangle along the Y axis
See Also:
setLocation(int, int), setLocation(java.awt.Point)

Figure 16 The API Documentation of the translate Method

The API documentation for each class starts out with a section that describes the purpose of the class. Then come summary tables for the constructors and methods (see Figure 15). Click on the link of a method to get a detailed description (see Figure 16).

The detailed description of a method shows

- The action that the method carries out.
- The parameters that the method receives.
- The value that it returns (or the reserved word void if the method doesn't return any value).

As you can see, the Rectangle class has quite a few methods. While occasionally intimidating for the beginning programmer, this is a strength of the standard library. If you ever need to do a computation involving rectangles, chances are that there is a method that does all the work for you.

For example, suppose you want to change the width or height of a rectangle. If you browse through the API documentation, you will find a setSize method with the description "Sets the size of this Rectangle to the specified width and height." The method has two parameters, described as

- width - the new width for this Rectangle
- height - the new height for this Rectangle

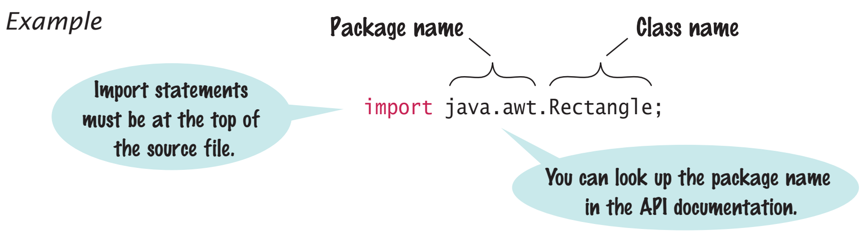
Now let us use this information to change the box object so that it is a square of side length 40. The name of the method is setSize, and we supply two parameters: the new width and height:

```
box.setSize(40, 40);
```

Syntax 2.4 Importing a Class from a Package

Syntax `import` *packageName.ClassName*;

Example



```
import java.awt.Rectangle;
```

Package name
Class name
Import statements must be at the top of the source file.
You can look up the package name in the API documentation.

The API documentation contains another important piece of information about each class. The classes in the standard library are organized into **packages**. A package is a collection of classes with a related purpose. The `Rectangle` class belongs to the package `java.awt` (where `awt` is an abbreviation for "Abstract Windowing Toolkit"), which contains many classes for drawing windows and graphical shapes. You can see the package name `java.awt` in Figure 14, just above the class name.

Java classes are grouped into packages. Use the `import` statement to use classes that are declared in other packages.

To use the `Rectangle` class from the `java.awt` package, you must *import* the package. Simply place the following line at the top of your program:

```
import java.awt.Rectangle;
```

Why don't you have to import the `System` and `String` classes? Because the `System` and `String` classes are in the `java.lang` package, and all classes from this package are automatically imported, so you never need to import them yourself.

SELF CHECK

20. Look at the API documentation of the `String` class. Which method would you use to obtain the string `"hello, world!"` from the string `"Hello, World!"`?

21. In the API documentation of the `String` class, look at the description of the `trim` method. What is the result of applying `trim` to the string `" Hello, Space ! "`? (Note the spaces in the string.)

22. The `Random` class is declared in the `java.util` package. What do you need to do in order to use that class in your program?

Productivity Hint 2.1

Don't Memorize—Use Online Help

The Java library has thousands of classes and methods. It is neither necessary nor useful trying to memorize them. Instead, you should become familiar with using the API documentation. Because you will need to use the API documentation all the time, it is best to download and install it onto your computer, particularly if your computer is not always connected to the Internet. You can download the documentation from `http://java.sun.com/javase/downloads/index.html`.

2.9 Implementing a Test Program

In this section, we discuss the steps that are necessary to implement a test program. The purpose of a test program is to verify that one or more methods have been implemented correctly. A test program calls methods and checks that they return the expected results. Writing test programs is a very important skill.

In this section, we will develop a simple program that tests a method in the Rectangle class. The program performs the following steps:

1. Provide a tester class.
2. Supply a main method.
3. Inside the main method, construct one or more objects.
4. Apply methods to the objects.
5. Display the results of the method calls.
6. Display the values that you expect to get.

A test program verifies that methods behave as expected.

Our sample test program tests the behavior of the translate method. Here are the key steps (which have been placed inside the main method of the MoveTester class).

```
Rectangle box = new Rectangle(5, 10, 20, 30);

// Move the rectangle
box.translate(15, 25);

// Print information about the moved rectangle
System.out.print("x: ");
System.out.println(box.getX());
System.out.println("Expected: 20");
```

We print the value that is returned by the getX method, and then we print a message that describes the value we expect to see.

Determining the expected result in advance is an important part of testing.

This is a very important step. You want to spend some time thinking about the expected result before you run a test program. This thought process will help you understand how your program should behave, and it can help you track down errors at an early stage. Finding and fixing errors early is a very effective strategy that can save you a great deal of time.

In our case, the rectangle has been constructed with the top-left corner at (5, 10). The x-direction is moved by 15, so we expect an x-value of 5 + 15 = 20 after the move.

Here is a complete program that tests the moving of a rectangle.

ch02/rectangle/MoveTester.java

```
import java.awt.Rectangle;

public class MoveTester
{
   public static void main(String[] args)
   {
      Rectangle box = new Rectangle(5, 10, 20, 30);

      // Move the rectangle
      box.translate(15, 25);

      // Print information about the moved rectangle
      System.out.print("x: ");
      System.out.println(box.getX());
      System.out.println("Expected: 20");

      System.out.print("y: ");
      System.out.println(box.getY());
      System.out.println("Expected: 35");
   }
}
```

Program Run

```
x: 20
Expected: 20
y: 35
Expected: 35
```

23. Suppose we had called `box.translate(25, 15)` instead of `box.translate(15, 25)`. What are the expected outputs?

24. Why doesn't the `MoveTester` program need to print the width and height of the rectangle?

Special Topic 2.1

Testing Classes in an Interactive Environment

Special Topic 2.1 describes how classes can be tested easily in the BlueJ environment, without having to write a separate tester class.

Worked Example 2.1

How Many Days Have You Been Alive?

In this Worked Example, you explore the API of a class `Day` that represents a calendar day, and you write a program that computes how many days have elapsed since the day you were born.

Worked Example 2.2

Working with Pictures

In this Worked Example, you use the API of a `Picture` class to edit photos.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

2.10 Object References

In Java, a variable whose type is a class does not actually hold an object. It merely holds the memory *location* of an object. The object itself is stored elsewhere—see Figure 17.

There is a reason for this behavior. Objects can be very large. It is more efficient to store only the memory location instead of the entire object.

An object reference describes the location of an object.

We use the technical term **object reference** to denote the memory location of an object. When a variable contains the memory location of an object, we say that it *refers* to an object. For example, after the statement

```
Rectangle box = new Rectangle(5, 10, 20, 30);
```

the variable box refers to the Rectangle object that the new operator constructed. Technically speaking, the new operator returned a reference to the new object, and that reference is stored in the box variable.

Multiple object variables can contain references to the same object.

It is very important that you remember that the box variable *does not contain* the object. It *refers* to the object. Two object variables can refer to the same object:

```
Rectangle box2 = box;
```

Now you can access the same Rectangle object both as box and as box2, as shown in Figure 18.

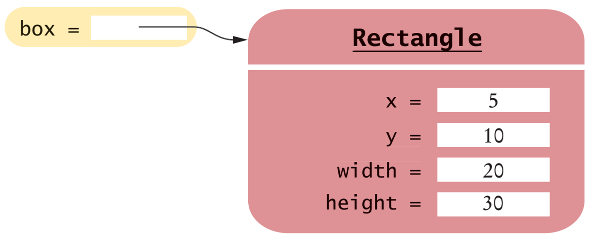


Figure 17
An Object Variable Containing an Object Reference

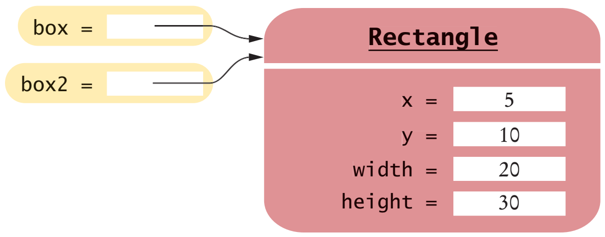


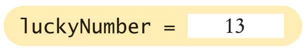
Figure 18
Two Object Variables Referring to the Same Object

However, number variables actually store numbers. When you declare

```
int luckyNumber = 13;
```

then the luckyNumber variable holds the number 13, not a reference to the number (see Figure 19). The reason is again efficiency. Because numbers require little storage, it is more efficient to store them directly in a variable.

Figure 19
A Number Variable Stores a Number

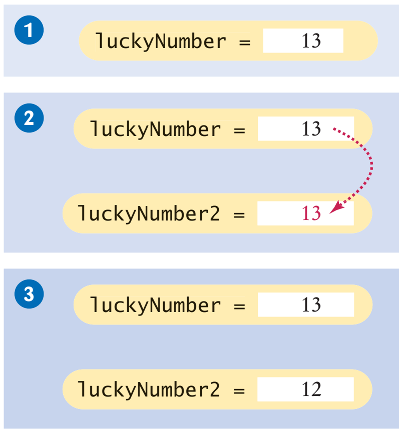


Number variables store numbers. Object variables store references.

You can see the difference between number variables and object variables when you make a copy of a variable. When you copy a number, the original and the copy of the number are independent values. But when you copy an object reference, both the original and the copy are references to the same object.

Consider the following code, which copies a number and then changes the copy (see Figure 20):

Figure 20
Copying Numbers



```
int luckyNumber = 13; ①
int luckyNumber2 = luckyNumber; ②
luckyNumber2 = 12; ③
```

Now the variable `luckyNumber` contains the value 13, and `luckyNumber2` contains 12.

Now consider the seemingly analogous code with `Rectangle` objects (see Figure 21).

```
Rectangle box = new Rectangle(5, 10, 20, 30); ①
Rectangle box2 = box; ②
box2.translate(15, 25); ③
```

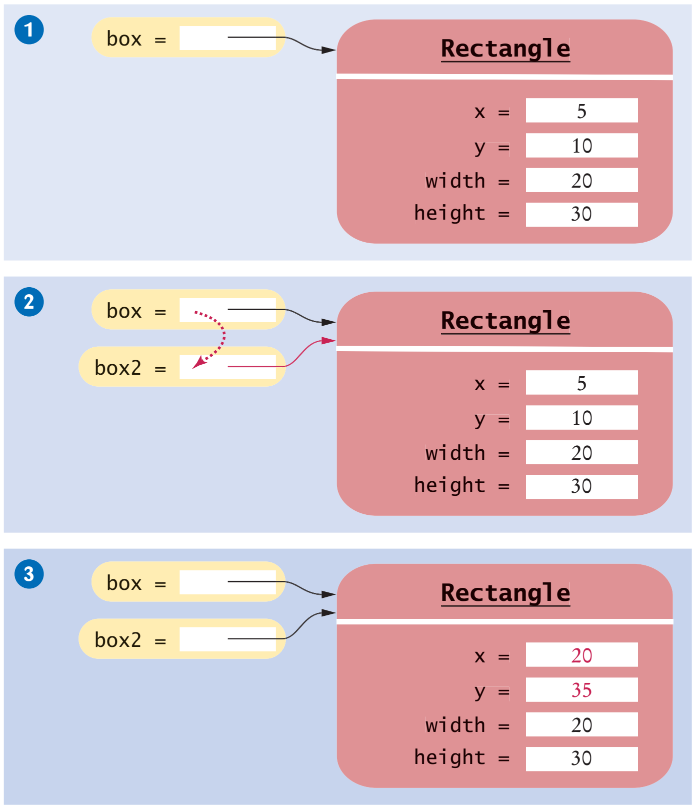


Figure 21
Copying Object References

Since `box` and `box2` refer to the same rectangle after step 2, both variables refer to the moved rectangle after the call to the `translate` method.

You need not worry too much about the difference between objects and object references. Much of the time, you will have the correct intuition when you think of "the object `box`" rather than the technically more accurate "the object reference stored in `box`". The difference between objects and object references only becomes apparent when you have multiple variables that refer to the same object.

SELF CHECK

25. What is the effect of the assignment `String greeting2 = greeting`?

26. After calling `greeting2.toUpperCase()`, what are the contents of `greeting` and `greeting2`?

Random Fact 2.1

Mainframes—When Dinosaurs Ruled the Earth

Random Fact 2.1 describes the history of mainframe computers, extremely expensive computers that filled entire rooms and were the mainstay of computing from 1950–1980.

2.11 Graphical Applications and Frame Windows

This is the first of several optional sections that teach you how to write *graphical applications:* applications that display drawings inside a window. Graphical applications look more attractive than the console applications that show plain text in a console window.

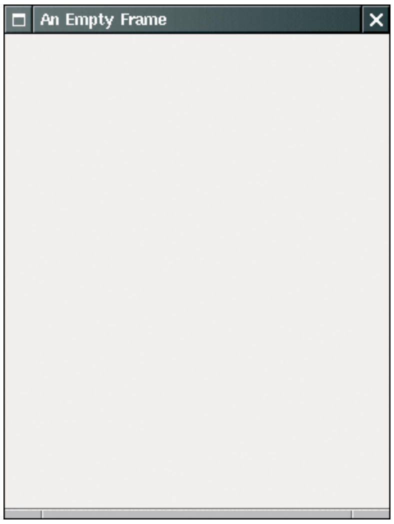


Figure 22
A Frame Window

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

To show a frame, construct a JFrame object, set its size, and make it visible.

A graphical application shows information inside a **frame**: a window with a title bar, as shown in Figure 22. In this section, you will learn how to display a frame. In Section 3.9, you will learn how to create a drawing inside the frame.

To show a frame, carry out the following steps:

1. Construct an object of the JFrame class:

   ```
   JFrame frame = new JFrame();
   ```

2. Set the size of the frame:

   ```
   frame.setSize(300, 400);
   ```

   This frame will be 300 pixels wide and 400 pixels tall. If you omit this step the frame will be 0 by 0 pixels, and you won't be able to see it. (Pixels are the tiny dots from which digital images are composed.)

3. If you'd like, set the title of the frame:

   ```
   frame.setTitle("An Empty Frame");
   ```

   If you omit this step, the title bar is simply left blank.

4. Set the "default close operation":

   ```
   frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
   ```

   When the user closes the frame, the program automatically exits. Don't omit this step. If you do, the program continues running even after the frame is closed.

5. Make the frame visible:

   ```
   frame.setVisible(true);
   ```

The simple program below shows all of these steps. It produces the empty frame shown in Figure 22.

The JFrame class is a part of the javax.swing package. Swing is the nickname for the graphical user interface library in Java. The "x" in javax denotes the fact that Swing started out as a Java *extension* before it was added to the standard library.

We will go into much greater detail about Swing programming in Chapters 3, 9, 10, and 18. For now, consider this program to be the essential plumbing that is required to show a frame.

ch02/emptyframe/EmptyFrameViewer.java

```
import javax.swing.JFrame;

public class EmptyFrameViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();

      frame.setSize(300, 400);
      frame.setTitle("An Empty Frame");
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

      frame.setVisible(true);
   }
}
```

SELF CHECK

27. How do you display a square frame with a title bar that reads “Hello, World!”?
28. How can a program display two frames at once?

2.12 Drawing on a Component

This section continues the optional graphics track. You will learn how to make shapes appear inside a frame window. The first drawing will be exceedingly modest: just two rectangles (see Figure 23). You’ll soon see how to produce more interesting drawings. The purpose of this example is to show you the basic outline of a program that creates a drawing. You cannot draw directly onto a frame. Whenever you want to show anything inside a frame, be it a button or a drawing, you have to construct a **component** object and add it to the frame. In the Swing toolkit, the `JComponent` class represents a blank component.

In order to display a drawing in a frame, declare a class that extends the `JComponent` class.

Since we don’t want to add a blank component, we have to modify the `JComponent` class and specify how the component should be painted. The solution is to declare a new class that extends the `JComponent` class. You will learn about the process of extending classes in Chapter 10. For now, simply use the following code as a template.

```
public class RectangleComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Drawing instructions
   }
}
```

The `extends` reserved word indicates that our component class, `RectangleComponent`, can be used like a `JComponent`. However, the `RectangleComponent` class will be different from the plain `JComponent` class in one respect: Its `paintComponent` method will contain instructions to draw the rectangles.

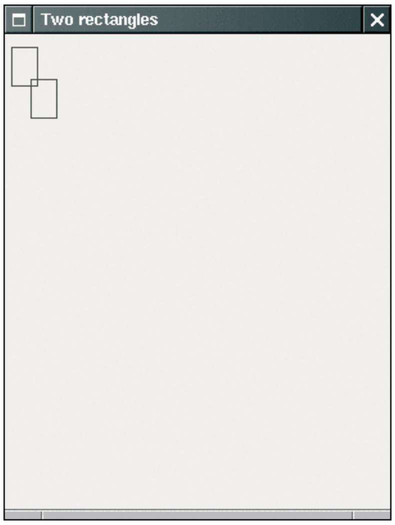


Figure 23
Drawing Rectangles

Place drawing instructions inside the paintComponent method. That method is called whenever the component needs to be repainted.

When the component is shown for the first time, the paintComponent method is called automatically. The method is also called when the window is resized, or when it is shown again after it was hidden.

The paintComponent method receives an object of type Graphics. The Graphics object stores the graphics state—the current color, font, and so on, that are used for drawing operations. However, the Graphics class is primitive. When programmers clamored for a more object-oriented approach for drawing graphics, the designers of Java created the Graphics2D class, which extends the Graphics class. Whenever the Swing toolkit calls the paintComponent method, it actually passes a parameter of type Graphics2D. Because we want to use the more sophisticated methods to draw two-dimensional graphics objects, we need to use the Graphics2D class. This is accomplished by using a **cast**:

Use a cast to recover the Graphics2D object from the Graphics parameter of the paintComponent method.

```
public class RectangleComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      // Recover Graphics2D
      Graphics2D g2 = (Graphics2D) g;
      . . .
   }
}
```

We cover the concepts of extending classes and of casting in Chapter 10. For now, you should simply include the cast at the top of your paintComponent methods.

Now you are ready to draw shapes. The draw method of the Graphics2D class can draw shapes, such as rectangles, ellipses, line segments, polygons, and arcs. Here we draw a rectangle:

```
public class RectangleComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      . . .
      Rectangle box = new Rectangle(5, 10, 20, 30);
      g2.draw(box);
      . . .
   }
}
```

Following is the source code for the RectangleComponent class. Note that the paintComponent method of the RectangleComponent class draws two rectangles.

As you can see from the import statements, the Graphics and Graphics2D classes are part of the java.awt package.

ch02/rectangles/RectangleComponent.java

```
import java.awt.Graphics;
import java.awt.Graphics2D;
import java.awt.Rectangle;
import javax.swing.JComponent;

/*
   A component that draws two rectangles.
*/
public class RectangleComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      // Recover Graphics2D
      Graphics2D g2 = (Graphics2D) g;

      // Construct a rectangle and draw it
      Rectangle box = new Rectangle(5, 10, 20, 30);
      g2.draw(box);

      // Move rectangle 15 units to the right and 25 units down
      box.translate(15, 25);

      // Draw moved rectangle
      g2.draw(box);
   }
}
```

In order to see the drawing, one task remains. You need to display the frame into which you added a component object. Follow these steps:

1. Construct a frame as described in the preceding section.
2. Construct an object of your component class:

   ```
   RectangleComponent component = new RectangleComponent();
   ```
3. Add the component to the frame:

   ```
   frame.add(component);
   ```
4. Make the frame visible, as described in the preceding section.

The following listing shows the complete process.

ch02/rectangles/RectangleViewer.java

```
import javax.swing.JFrame;

public class RectangleViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();

      frame.setSize(300, 400);
      frame.setTitle("Two rectangles");
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

      RectangleComponent component = new RectangleComponent();
      frame.add(component);

      frame.setVisible(true);
   }
}
```

Note that the rectangle drawing program consists of two classes:

- The `RectangleComponent` class, whose `paintComponent` method produces the drawing.
- The `RectangleViewer` class, whose `main` method constructs a frame and a `RectangleComponent`, adds the component to the frame, and makes the frame visible.

SELF CHECK

29. How do you modify the program to draw two squares?

30. How do you modify the program to draw one rectangle and one square?

31. What happens if you call `g.draw(box)` instead of `g2.draw(box)`?

Special Topic 2.2

Applets

Special Topic 2.2 shows how you can implement programs that show drawings as applets, programs that run inside a web browser.

2.13 Ellipses, Lines, Text, and Color

In Section 2.12 you learned how to write a program that draws rectangles. In this section you will learn how to draw other shapes: ellipses and lines. With these graphical elements, you can draw quite a few interesting pictures.

2.13.1 Ellipses and Circles

To draw an ellipse, you specify its bounding box (see Figure 24) in the same way that you would specify a rectangle, namely by the *x*- and *y*-coordinates of the top-left corner and the width and height of the box.

However, there is no simple `Ellipse` class that you can use. Instead, you must use one of the two classes `Ellipse2D.Float` and `Ellipse2D.Double`, depending on whether you want to store the ellipse coordinates as single- or double-precision floating-point values. Because the latter are more convenient to use in Java, we will always use the `Ellipse2D.Double` class. Here is how you construct an ellipse:

```
Ellipse2D.Double ellipse = new Ellipse2D.Double(x, y, width, height);
```

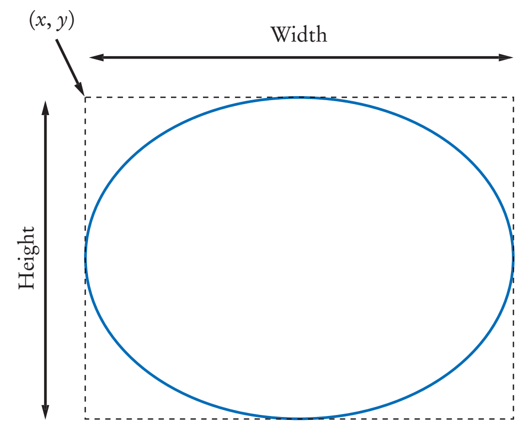


Figure 24 An Ellipse and Its Bounding Box

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

The Ellipse2D.Double and Line2D.Double classes describe graphical shapes.

The class name Ellipse2D.Double looks different from the class names that you have encountered up to now. It consists of two class names Ellipse2D and Double separated by a period (.). This indicates that Ellipse2D.Double is a so-called **inner class** inside Ellipse2D. When constructing and using ellipses, you don't actually need to worry about the fact that Ellipse2D.Double is an inner class—just think of it as a class with a long name. However, in the import statement at the top of your program, you must be careful that you import only the outer class:

```
import java.awt.geom.Ellipse2D;
```

Drawing an ellipse is easy: Use exactly the same draw method of the Graphics2D class that you used for drawing rectangles.

```
g2.draw(ellipse);
```

To draw a circle, simply set the width and height to the same values:

```
Ellipse2D.Double circle = new Ellipse2D.Double(x, y, diameter, diameter);
g2.draw(circle);
```

Notice that (x, y) is the top-left corner of the bounding box, not the center of the circle.

2.13.2 Lines

To draw a line, use an object of the Line2D.Double class. A line is constructed by specifying its two end points. You can do this in two ways. Simply give the *x*- and *y*-coordinates of both end points:

```
Line2D.Double segment = new Line2D.Double(x1, y1, x2, y2);
```

Or specify each end point as an object of the Point2D.Double class:

```
Point2D.Double from = new Point2D.Double(x1, y1);
Point2D.Double to = new Point2D.Double(x2, y2);

Line2D.Double segment = new Line2D.Double(from, to);
```

The second option is more object-oriented and is often more useful, particularly if the point objects can be reused elsewhere in the same drawing.

2.13.3 Drawing Text

The drawString method draws a string, starting at its basepoint.

You often want to put text inside a drawing, for example, to label some of the parts. Use the drawString method of the Graphics2D class to draw a string anywhere in a window. You must specify the string and the *x*- and *y*-coordinates of the basepoint of the first character in the string (see Figure 25). For example,

```
g2.drawString("Message", 50, 100);
```

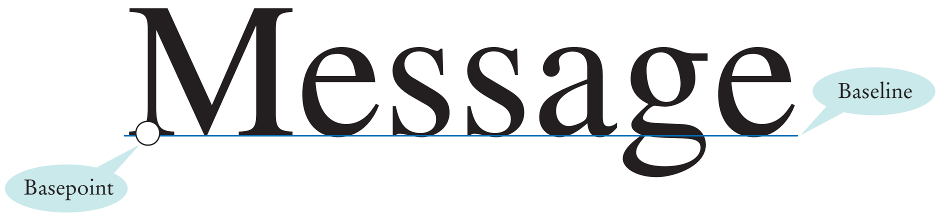


Figure 25 Basepoint and Baseline

2.13.4 Colors

When you first start drawing, all shapes and strings are drawn with a black pen. To change the color, you need to supply an object of type `Color`. Java uses the RGB color model. That is, you specify a color by the amounts of the primary colors—red, green, and blue—that make up the color. The amounts are given as integers between `0` (primary color not present) and 255 (maximum amount present). For example,

```
Color magenta = new Color(255, 0, 255);
```

constructs a `Color` object with maximum red, no green, and maximum blue, yielding a bright purple color called magenta.

When you set a new color in the graphics context, it is used for subsequent drawing operations.

For your convenience, a variety of colors have been declared in the `Color` class. Table 4 shows those colors and their RGB values. For example, `Color.PINK` has been declared to be the same color as `new Color(255, 175, 175)`.
To draw a shape in a different color, first set the color of the `Graphics2D` object, then call the draw method:

```
g2.setColor(Color.RED);
g2.draw(circle); // Draws the shape in red
```

If you want to color the inside of the shape, use the `fill` method instead of the `draw` method. For example,

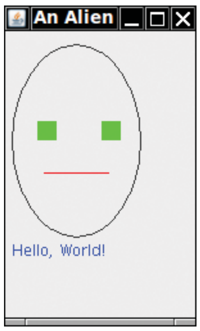
```
g2.fill(circle);
```

fills the inside of the circle with the current color.

Table 4 Predefined Colors

Color		RGB Value
`Color.BLACK`	⬛	0, 0, 0
`Color.BLUE`	🟦	0, 0, 255
`Color.CYAN`	🟦	0, 255, 255
`Color.GRAY`	⬛	128, 128, 128
`Color.DARKGRAY`	⬛	64, 64, 64
`Color.LIGHTGRAY`	⬜	192, 192, 192
`Color.GREEN`	🟩	0, 255, 0
`Color.MAGENTA`	🟪	255, 0, 255
`Color.ORANGE`	🟧	255, 200, 0
`Color.PINK`	🟥	255, 175, 175
`Color.RED`	🟥	255, 0, 0
`Color.WHITE`	⬜	255, 255, 255
`Color.YELLOW`	🟨	255, 255, 0

Figure 26
An Alien Face



Hello, World!

The following program puts all these shapes to work, creating a simple drawing (see Figure 26).

ch02/face/FaceComponent.java

```java
import java.awt.Color;
import java.awt.Graphics;
import java.awt.Graphics2D;
import java.awt.Rectangle;
import java.awt.geom.Ellipse2D;
import java.awt.geom.Line2D;
import javax.swing.JComponent;

/*
   A component that draws an alien face.
*/
public class FaceComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      // Recover Graphics2D
      Graphics2D g2 = (Graphics2D) g;

      // Draw the head
      Ellipse2D.Double head = new Ellipse2D.Double(5, 10, 100, 150);
      g2.draw(head);

      // Draw the eyes
      g2.setColor(Color.GREEN);
      Rectangle eye = new Rectangle(25, 70, 15, 15);
      g2.fill(eye);
      eye.translate(50, 0);
      g2.fill(eye);

      // Draw the mouth
      Line2D.Double mouth = new Line2D.Double(30, 110, 80, 110);
      g2.setColor(Color.RED);
      g2.draw(mouth);

      // Draw the greeting
      g2.setColor(Color.BLUE);
      g2.drawString("Hello, World!", 5, 175);
   }
}
```

ch02/face/FaceViewer.java

```
import javax.swing.JFrame;

public class FaceViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();
      frame.setSize(150, 250);
      frame.setTitle("An Alien Face");
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

      FaceComponent component = new FaceComponent();
      frame.add(component);

      frame.setVisible(true);
   }
}
```

SELF CHECK

32. Give instructions to draw a circle with center (100, 100) and radius 25.

33. Give instructions to draw a letter “V” by drawing two line segments.

34. Give instructions to draw a string consisting of the letter “V”.

35. What are the RGB color values of `Color.BLUE`?

36. How do you draw a yellow square on a red background?

Random Fact 2.2

The Evolution of the Internet

Random Fact 2.2 traces the evolution of the Internet from its humble beginnings as a research network through its explosive growth that started when graduate student Marc Andreesen released the first web browser.

Summary of Learning Objectives

Use integers and floating-point numbers.

- A type specifies a set of values and the operations that can be carried out with the values.
- The `double` type denotes floating-point numbers that can have fractional parts.
- In Java, the number types are primitive types, and numbers are not objects.
- Numbers can be combined by arithmetic operators such as `+`, `-`, and `*`.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Write variable declarations in Java.

- You use variables to store values that you want to use at a later time. A variable has a type, a name, and a value.
- Identifiers for variables, methods, and classes are composed of letters, digits, and the underscore character.
- By convention, variable names should start with a lowercase letter.

Explain the processes of variable assignment and initialization.

- Use the assignment operator (`=`) to change the value of a variable.
- All variables must be initialized before you access them.

Declare objects, classes, and methods.

- Objects are entities in your program that you manipulate by calling methods.
- A method is a sequence of instructions that accesses the data of an object.
- A class declares the methods that you can apply to its objects.
- The public interface of a class specifies what you can do with its objects. The hidden implementation describes how these actions are carried out.

Recognize implicit parameters, explicit parameters, and return values of methods.

- A parameter is an input to a method.
- The implicit parameter of a method call is the object on which the method is invoked. All other parameters are explicit parameters.
- The return value of a method is a result that the method has computed for use by the code that called it.

Use constructors to construct new objects.

- Use the `new` operator, followed by a class name and parameters, to construct new objects.

Classify methods as accessor and mutator methods.

- An accessor method does not change the internal data of its implicit parameter. A mutator method changes the data.

Use the API documentation for finding method descriptions and packages.

- The API (Application Programming Interface) documentation lists the classes and methods of the Java library.
- Java classes are grouped into packages. Use the `import` statement to use classes that are declared in other packages.

Write programs that test behavior of methods.

- A test program verifies that methods behave as expected.
- Determining the expected result in advance is an important part of testing.

Describe how multiple object references can refer to the same object.

- An object reference describes the location of an object.
- Multiple object variables can contain references to the same object.
- Number variables store numbers. Object variables store references.

Write programs that display frame windows.

- To show a frame, construct a `JFrame` object, set its size, and make it visible.
- In order to display a drawing in a frame, declare a class that extends the `JComponent` class.
- Place drawing instructions inside the `paintComponent` method. That method is called whenever the component needs to be repainted.
- Use a cast to recover the `Graphics2D` object from the `Graphics` parameter of the `paintComponent` method.

Use the Java API for drawing simple figures.

- The `Ellipse2D.Double` and `Line2D.Double` classes describe graphical shapes.
- The `drawString` method draws a string, starting at its basepoint.
- When you set a new color in the graphics context, it is used for subsequent drawing operations.

Classes, Objects, and Methods Introduced in this Chapter

```
java.awt.Color
java.awt.Component
   getHeight
   getWidth
   setSize
   setVisible
java.awt.Frame
   setTitle
java.awt.geom.Ellipse2D.Double
java.awt.geom.Line2D.Double
java.awt.geom.Point2D.Double
java.awt.Graphics
   setColor
java.awt.Graphics2D
   draw
   drawString
   fill
java.awt.Rectangle
   getX
   getY
   getHeight
   getWidth
   setSize
   translate
java.lang.String
   length
   replace
   toLowerCase
   toUpperCase
javax.swing.JComponent
   paintComponent
javax.swing.JFrame
   setDefaultCloseOperation
```

Media Resources

www.wiley.com/ college/ horstmann

- ***Worked Example*** How Many Days Have You Been Alive?
- ***Worked Example*** Working with Pictures
- Lab Exercises
- ⊕ ***Animation*** Variable Initialization and Assignment
- ⊕ ***Animation*** Parameter Passing
- ⊕ ***Animation*** Object References
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★ **R2.1** Explain the difference between an object and an object reference.

★ **R2.2** Explain the difference between an object and an object variable.

★ **R2.3** Explain the difference between an object and a class.

★★ **R2.4** Give the Java code for constructing an *object* of class `Rectangle`, and for declaring an *object variable* of class `Rectangle`.

★★ **R2.5** Explain the difference between the `=` symbol in Java and in mathematics.

★★ **R2.6** Give Java code for objects with the following descriptions:

a. A rectangle with center (100, 100) and all side lengths equal to 50

b. A string with the contents “Hello, Dave”

Create objects, not object variables.

★★ **R2.7** Repeat Exercise R2.6, but now declare object variables that are initialized with the required objects.

★★ **R2.8** Write a Java statement to initialize a variable `square` with a rectangle object whose top left corner is (10, 20) and whose sides all have length 40. Then write a statement that replaces `square` with a rectangle of the same size and top left corner (20, 20).

★★ **R2.9** Write Java statements that initialize two variables `square1` and `square2` to refer to the same square with center (20, 20) and side length 40.

★★ **R2.10** Write Java statements that initialize a string `message` with `"Hello"` and then change it to `"HELLO"`. Use the `toUpperCase` method.

★★ **R2.11** Write Java statements that initialize a string `message` with `"Hello"` and then change it to `"hello"`. Use the `replace` method.

★★ **R2.12** Find the errors in the following statements:

a.
```
Rectangle r = (5, 10, 15, 20);
```
b.
```
double width = Rectangle(5, 10, 15, 20).getWidth();
```
c.
```
Rectangle r;
r.translate(15, 25);
```
d.
```
r = new Rectangle();
r.translate("far, far away!");
```

★ **R2.13** Name two accessor methods and two mutator methods of the `Rectangle` class.

★★ **R2.14** Look into the API documentation of the `Rectangle` class and locate the method

```
void add(int newx, int newy)
```

Read through the method documentation. Then determine the result of the following statements:

```
Rectangle box = new Rectangle(5, 10, 20, 30);
box.add(0, 0);
```

If you are not sure, write a small test program.

★G **R2.15** What is the difference between a console application and a graphical application?

★★G **R2.16** Who calls the `paintComponent` method of a component? When does the call to the `paintComponent` method occur?

★★G **R2.17** Why does the parameter of the `paintComponent` method have type `Graphics` and not `Graphics2D`?

★★G **R2.18** What is the purpose of a graphics context?

★★G **R2.19** Why are separate viewer and component classes used for graphical programs?

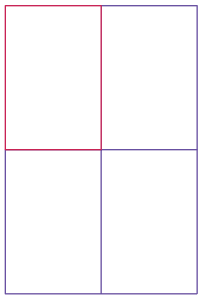
★G **R2.20** How do you specify a text color?

Programming Exercises

★T **P2.1** Write an `AreaTester` program that constructs a `Rectangle` object and then computes and prints its area. Use the `getWidth` and `getHeight` methods. Also print the expected answer.

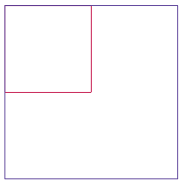
★T **P2.2** Write a `PerimeterTester` program that constructs a `Rectangle` object and then computes and prints its perimeter. Use the `getWidth` and `getHeight` methods. Also print the expected answer.

★★ **P2.3** Write a program called `FourRectanglePrinter` that constructs a `Rectangle` object, prints its location by calling `System.out.println(box)`, and then translates and prints it three more times, so that, if the rectangles were drawn, they would form one large rectangle:



Your program will not produce a drawing. It will simply print the locations of the four rectangles.

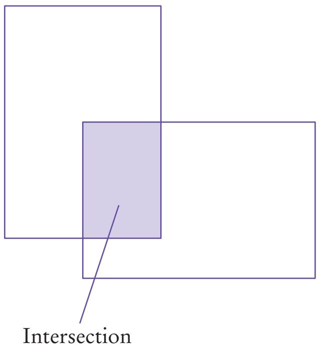
★★ **P2.4** Write a `GrowSquarePrinter` program that constructs a `Rectangle` object `square` representing a square with top-left corner (100, 100) and side length 50, prints its location by calling `System.out.println(square)`, applies the `translate` and `grow` methods and calls `System.out.println(square)` again. The calls to `translate` and `grow` should modify the square so that it has twice the size and the same top-left corner as the original. If the squares were drawn, they would look like this:



Your program will not produce a drawing. It will simply print the locations of square before and after calling the mutator methods.

Look up the description of the `grow` method in the API documentation.

★★★ **P2.5** The `intersection` method computes the *intersection* of two rectangles—that is, the rectangle that would be formed by two overlapping rectangles if they were drawn:



You call this method as follows:

```
Rectangle r3 = r1.intersection(r2);
```

Write a program `IntersectionPrinter` that constructs two rectangle objects, prints them as described in Exercise P2.3, and then prints the rectangle object that describes the intersection. Then the program should print the result of the `intersection` method when the rectangles do not overlap. Add a comment to your program that explains how you can tell whether the resulting rectangle is empty.

★★★ **P2.6** In this exercise, you will explore a simple way of visualizing a `Rectangle` object. The `setBounds` method of the `JFrame` class moves a frame window to a given rectangle. Complete the following program to visually show the `translate` method of the `Rectangle` class:

```
import java.awt.Rectangle;
import javax.swing.JFrame;
import javax.swing.JOptionPane;

public class TranslateDemo
{
   public static void main(String[] args)
   {
      // Construct a frame and show it
      JFrame frame = new JFrame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);

      // Your work goes here:
      // Construct a rectangle and set the frame bounds

      JOptionPane.showMessageDialog(frame, "Click OK to continue");

      // Your work goes here:
      // Move the rectangle and set the frame bounds again
   }
}
```

★★ **P2.7** In the Java library, a color is specified by its red, green, and blue components between 0 and 255 (see Table 4 on page 61). Write a program `BrighterDemo` that constructs a `Color` object with red, green, and blue values of 50, 100, and 150. Then apply the `brighter` method and print the red, green, and blue values of the resulting color. (You won't actually see the color—see the next exercise on how to display the color.)

★★ **P2.8** Repeat Exercise P2.7, but place your code into the following class. Then the color will be displayed.

```
import java.awt.Color;
import javax.swing.JFrame;

public class BrighterDemo
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();
      frame.setSize(200, 200);
      Color myColor = ...;
      frame.getContentPane().setBackground(myColor);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

★★ **P2.9** Repeat Exercise P2.7, but apply the `darker` method twice to the object `Color.RED`. Call your class `DarkerDemo`.

★★ **P2.10** The `Random` class implements a *random number generator*, which produces sequences of numbers that appear to be random. To generate random integers, you construct an object of the `Random` class, and then apply the `nextInt` method. For example, the call `generator.nextInt(6)` gives you a random number between 0 and 5.

Write a program `DieSimulator` that uses the `Random` class to simulate the cast of a die, printing a random number between 1 and 6 every time that the program is run.

★★★ **P2.11** Write a program `LotteryPrinter` that picks a combination in a lottery. In this lottery, players can choose 6 numbers (possibly repeated) between 1 and 49. (In a real lottery, repetitions aren't allowed, but we haven't yet discussed the programming constructs that would be required to deal with that problem.) Your program should print out a sentence such as "Play this combination—it'll make you rich!", followed by a lottery combination.

★★T **P2.12** Write a program `ReplaceTester` that encodes a string by replacing all letters `"i"` with `"!"` and all letters `"s"` with `"$"`. Use the `replace` method. Demonstrate that you can correctly encode the string `"Mississippi"`. Print both the actual and expected result.

★★★ **P2.13** Write a program `HollePrinter` that switches the letters `"e"` and `"o"` in a string. Use the `replace` method repeatedly. Demonstrate that the string `"Hello, World!"` turns into `"Holle, Werld!"`

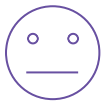
★★G **P2.14** Write a graphics program that draws your name in red, contained inside a blue rectangle. Provide a class `NameViewer` and a class `NameComponent`.

★★G **P2.15** Write a graphics program that draws 12 strings, one each for the 12 standard colors, besides `Color.WHITE`, each in its own color. Provide a class `ColorNameViewer` and a class `ColorNameComponent`.

★★G **P2.16** Write a program that draws two solid squares: one in pink and one in purple. Use a standard color for one of them and a custom color for the other. Provide a class `TwoSquareViewer` and a class `TwoSquareComponent`.

★★★G **P2.17** Write a program that fills the window with a large ellipse, with a black outline and filled with your favorite color. The ellipse should touch the window boundaries, even if the window is resized.

★★G **P2.18** Write a program to plot the following face.



Provide a class `FaceViewer` and a class `FaceComponent`.

Programming Projects

Project 2.1 The `GregorianCalendar` class describes a point in time, as measured by the Gregorian calendar, the standard calendar that is commonly used throughout the world today. You construct a `GregorianCalendar` object from a year, month, and day of the month, like this:

```
GregorianCalendar cal = new GregorianCalendar(); // Today's date
GregorianCalendar eckertsBirthday = new GregorianCalendar(1919,
      Calendar.APRIL, 9);
```

Use the values `Calendar.JANUARY . . . Calendar.DECEMBER` to specify the month.

The `add` method can be used to add a number of days to a `GregorianCalendar` object:

```
cal.add(Calendar.DAY_OF_MONTH, 10); // Now cal is ten days from today
```

This is a mutator method—it changes the `cal` object.

The `get` method can be used to query a given `GregorianCalendar` object:

```
int dayOfMonth = cal.get(Calendar.DAY_OF_MONTH);
int month = cal.get(Calendar.MONTH);
int year = cal.get(Calendar.YEAR);
int weekday = cal.get(Calendar.DAY_OF_WEEK);
   // 1 is Sunday, 2 is Monday, . . . , 7 is Saturday
```

Your task is to write a program that prints the following information:

- The date and weekday that is 100 days from today
- The weekday of your birthday
- The date that is 10,000 days from your birthday

Use the birthday of a computer scientist if you don't want to reveal your own birthday.

Project 2.2 Run the following program:

```
import java.awt.Color;
import javax.swing.JFrame;
import javax.swing.JLabel;

public class FrameViewer
{
      public static void main(String[] args)
      {
         JFrame frame = new JFrame();
         frame.setSize(200, 200);
         JLabel label = new JLabel("Hello, World!");
         label.setOpaque(true);
         label.setBackground(Color.PINK);
         frame.add(label);
         frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
         frame.setVisible(true);
      }
   }
```

Modify the program as follows:

- Double the frame size.
- Change the greeting to "Hello, *your name*!".
- Change the background color to pale green (see Exercise P2.7).
- For extra credit, add an image of yourself. (*Hint:* Construct an `ImageIcon`.)

Answers to Self-Check Questions

1. `int` and `String`

2. `double`

3. An `int` is not an object, and you cannot call a method on it.

4. `(x + y) * 0.5`

5. Only the first two are legal identifiers.

6. `String myName = "John Q. Public";`

7. No, the left-hand side of the `=` operator must be a variable.

8. `greeting = "Hello, Nina!";`

Note that

`String greeting = "Hello, Nina!";`

is not the right answer—that statement declares a new variable.

9. `river.length()` or `"Mississippi".length()`

10. `System.out.println(greeting.toUpperCase());`

or

`System.out.println("Hello, World!".toUpperCase());`

11. It is not legal. The variable `river` has type `String`. The `println` method is not a method of the `String` class.

12. The implicit parameter is `river`. There is no explicit parameter. The return value is 11.

13. `"Missississi"`

14. 12

15. As `public String toUpperCase()`, with no explicit parameter and return type `String`.

16. `new Rectangle(90, 90, 20, 20)`

17. `0`

18. An accessor—it doesn't modify the original string but returns a new string with uppercase letters.

19. `box.translate(-5, -10)`, provided the method is called immediately after storing the new rectangle into `box`.

20. `toLowerCase`

21. `"Hello, Space !"`—only the leading and trailing spaces are trimmed.

22. Add the statement `import java.util.Random;` at the top of your program.

23. `x: 30`, `y: 25`

24. Because the `translate` method doesn't modify the shape of the rectangle.

25. Now `greeting` and `greeting2` both refer to the same `String` object.

26. Both variables still refer to the same string, and the string has not been modified. Recall that the `toUpperCase` method constructs a new string that contains uppercase characters, leaving the original string unchanged.

27. Modify the `EmptyFrameViewer` program as follows:

```
frame.setSize(300, 300);
frame.setTitle("Hello, World!");
```

28. Construct two `JFrame` objects, set each of their sizes, and call `setVisible(true)` on each of them.

29. `Rectangle box = new Rectangle(5, 10, 20, 20);`

30. Replace the call to `box.translate(15, 25)` with

```
box = new Rectangle(20, 35, 20, 20);
```

31. The compiler complains that `g` doesn't have a `draw` method.

32. `g2.draw(new Ellipse2D.Double(75, 75, 50, 50));`

33.
```
Line2D.Double segment1 = new Line2D.Double(0, 0, 10, 30);
g2.draw(segment1);
Line2D.Double segment2 = new Line2D.Double(10, 30, 20, 0);
g2.draw(segment2);
```

34. `g2.drawString("V", 0, 30);`

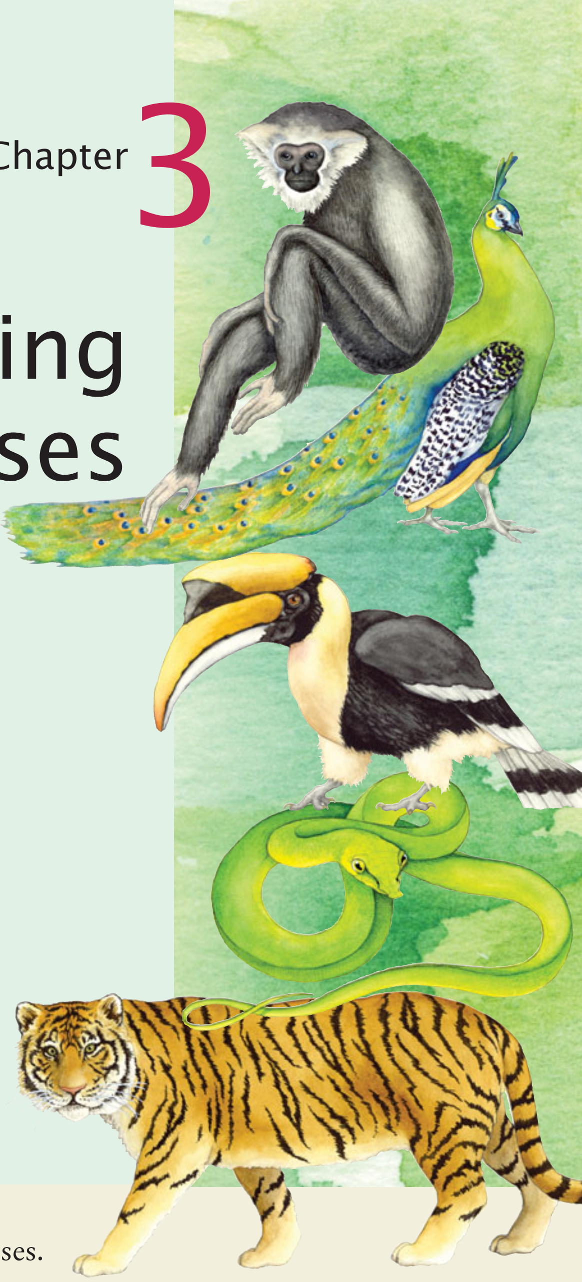
35. `0, 0, 255`

36. First fill a big red square, then fill a small yellow square inside:

```
g2.setColor(Color.RED);
g2.fill(new Rectangle(0, 0, 200, 200));
g2.setColor(Color.YELLOW);
g2.fill(new Rectangle(50, 50, 100, 100));
```

Chapter 3

Implementing Classes



CHAPTER GOALS

- To become familiar with the process of implementing classes
- To be able to implement simple methods
- To understand the purpose and use of constructors
- To understand how to access instance variables and local variables
- To be able to write javadoc comments

G To implement classes for drawing graphical shapes

In this chapter, you will learn how to implement your own classes. You will start with a given design that specifies the public interface of the class—that is, the methods through which programmers can manipulate the objects of the class. Then you will learn the steps to completing the class. You need to implement the methods, which requires that you find a data representation for the objects, and supply the instructions for each method. You need to document your efforts so that other programmers can understand and use your creation. And you need to provide a tester to validate that your class works correctly.

CHAPTER CONTENTS

3.1 Instance Variables 74

SYNTAX 3.1: Instance Variable Declaration 75

3.2 Encapsulation 76

3.3 Specifying the Public Interface of a Class 77

SYNTAX 3.2: Class Declaration 80

COMMON ERROR 3.1: Declaring a Constructor as void 81

3.4 Commenting the Public Interface 81

PRODUCTIVITY HINT 3.1: The javadoc Utility 84

3.5 Providing the Class Implementation 84

SYNTAX 3.3: Method Declaration 86

HOW TO 3.1: Implementing a Class 88

WORKED EXAMPLE 3.1: Making a Simple Menu ➕

3.6T Unit Testing 90

3.7 Local Variables 92

COMMON ERROR 3.2: Forgetting to Initialize Object References in a Constructor 93

3.8 Implicit Parameters 94

SPECIAL TOPIC 3.1: Calling One Constructor from Another ➕

RANDOM FACT 3.1: Electronic Voting Machines ➕

3.9G Shape Classes 96

HOW TO 3.2: Drawing Graphical Shapes 100

RANDOM FACT 3.2: Computer Graphics ➕

3.1 Instance Variables

In Chapter 2, you learned how to use objects from existing classes. In this chapter, you will start implementing your own classes. We begin with a very simple example that shows you how objects store their data, and how methods access the data of an object. You will then learn a systematic process for implementing classes.

Our first example is a class that models a *tally counter*, a mechanical device that is used to count people—for example, to find out how many people attend a concert or board a bus (see Figure 1).

Whenever the operator pushes a button, the counter value advances by one. We model this operation with a `count` method. A physical counter has a display to show the current value. In our simulation, we use a `getValue` method instead. For example,

```
Counter tally = new Counter();
tally.count();
tally.count();
int result = tally.getValue(); // Sets result to 2
```

When implementing the `Counter` class, we need to determine the data that each counter object contains. In this simple example, that is very straightforward. Each counter needs to store a variable that keeps track of how many times the counter has been advanced.

Figure 1 A Tally Counter

Syntax 3.1 Instance Variable Declaration

Syntax

```
accessSpecifier class ClassName
{
   accessSpecifier typeName variableName;
   . . .
}
```

Example

```
public class Counter
{
   private int value;
   . . .
}
```

Each object of this class has a separate copy of this instance variable.

Instance variables should always be private.

Type of the variable

An object's instance variables store the data required for executing its methods.

An object stores its data in **instance variables**. An *instance* of a class is an object of the class. Thus, an instance variable is a storage location that is present in each object of the class.

You specify instance variables in the class declaration:

```
public class Counter
{
   private int value;
   . . .
}
```

An instance variable declaration consists of the following parts:

- An **access specifier** (`private`)
- The **type** of the instance variable (such as `int`)
- The name of the instance variable (such as `value`)

Each object of a class has its own set of instance variables.

Each object of a class has its own set of instance variables. For example, if `concertCounter` and `boardingCounter` are two objects of the `Counter` class, then each object has its own `value` variable (see Figure 2). As you will see in Section 3.7, the instance variable `value` is set to `0` when a `Counter` object is constructed.

In order to gain a better understanding of how methods affect instance variables, we will have a quick look at the implementation of the methods of the `Counter` class.

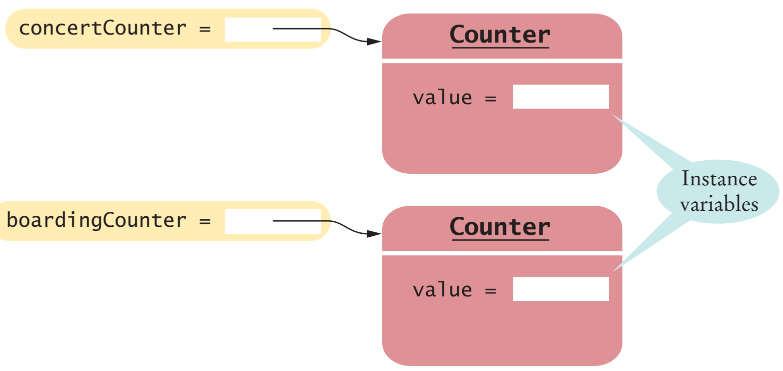


Figure 2 Instance Variables

The count method advances the counter value by 1. We will cover the syntax of the method header in Section 3.3. For now, focus on the body of the method inside the braces:

```
public void count()
{
   value = value + 1;
}
```

Note how the count method accesses the instance variable value. *Which* instance variable? The one belonging to the object on which the method is invoked. For example, consider the call

```
concertCounter.count();
```

This call advances the value variable of the concertCounter object.

The getValue method returns the current value:

```
public int getValue()
{
   return value;
}
```

The return statement is a special statement that terminates the method call and returns a result to the method's caller.

Private instance variables can only be accessed by methods of the same class.

Instance variables are generally declared with the access specifier private. That specifier means that they can be accessed only by the methods of the *same class*, not by any other method. For example, the value variable can be accessed by the count and getValue methods of the Counter class but not a method of another class. Those other methods need to use the Counter class methods if they want to manipulate a counter's value.

In the next section, we discuss the reason for making instance variables private.

SELF CHECK

1. Supply the body of a method public void reset() that resets the counter back to zero.
2. Suppose you use a class Clock with private instance variables hours and minutes. How can you access these variables in your program?

3.2 Encapsulation

In the preceding section, you learned that you should hide instance variables by making them private. Why would a programmer want to hide something? In this section we discuss the benefits of information hiding.

The strategy of information hiding is not unique to computer programming—it is used in many engineering disciplines. Consider the electronic control module that is present in every modern car. It is a device that controls the timing of the spark plugs and the flow of gasoline into the motor. If you ask your mechanic what is inside the electronic control module, you will likely get a shrug.

The module is a *black box*, something that magically does its thing. A car mechanic would never open the control module—it contains electronic parts that can only be serviced at the factory. In general, engineers use the term "black box" to describe any device whose inner workings are hidden. Note that a black box is not totally mysterious. Its interface with the outside world is well-defined. For example, the car mechanic understands how the electronic control module must be connected with sensors and engine parts.

Encapsulation is the process of hiding implementation details and providing methods for data access.

The process of hiding implementation details while publishing an interface is called **encapsulation**. In Java, the `class` construct provides encapsulation. The public methods of a class are the interface through which the private implementation is manipulated.

Why do car manufacturers put black boxes into cars? The black box greatly simplifies the work of the car mechanic. Before engine control modules were invented, gasoline flow was regulated by a mechanical device called a carburetor, and car mechanics had to know how to adjust the springs and latches inside. Nowadays, a mechanic no longer needs to know what is inside the module.

Similarly, a programmer using a class is not burdened by unnecessary detail, as you know from your own experience. In Chapter 2, you used classes for strings, streams, and windows without worrying how these classes are implemented.

Encapsulation allows a programmer to use a class without having to know its implementation.

Information hiding makes it simpler for the implementor of a class to locate errors and change implementations.

Encapsulation also helps with diagnosing errors. A large program may consist of hundreds of classes and thousands of methods, but if there is an error with the internal data of an object, you only need to look at the methods of one class. Finally, encapsulation makes it possible to change the implementation of a class without having to tell the programmers who use the class.

In Chapter 2, you learned to be an object user. You saw how to obtain objects, how to manipulate them, and how to assemble them into a program. In that chapter, your treated objects as black boxes. Your role was roughly analogous to the car mechanic who fixed a car by hooking up a new engine control module.

In this chapter, you will move on to implementing classes. In these sections, your role is analogous to the car parts manufacturer who puts together an engine control module from transistors, capacitors, and other electronic parts. You will learn the necessary Java programming techniques that enable your objects to carry out the desired behavior.

SELF CHECK

3. Consider the `Counter` class. A counter's value starts at `0` and is advanced by the `count` method, so it should never be negative. Suppose you found a negative `value` variable during testing. Where would you look for the error?
4. In Chapters 1 and 2, you used `System.out` as a black box to cause output to appear on the screen. Who designed and implemented `System.out`?
5. Suppose you are working in a company that produces personal finance software. You are asked to design and implement a class for representing bank accounts. Who will be the users of your class?

3.3 Specifying the Public Interface of a Class

In this section, we will discuss the process of specifying the public interface of a class. Imagine that you are a member of a team that works on banking software. A fundamental concept in banking is a *bank account*. Your task is to understand the design of a `BankAccount` class so that you can implement it, which in turn allows other programmers on the team to use it.

In order to implement a class, you first need to know which methods are required.

You need to know exactly what features of a bank account need to be implemented. Some features are essential (such as deposits), whereas others are not important (such as the gift that a customer may receive for opening a bank account). Deciding which features are essential is not always an easy task. We will revisit that issue in Chapters 8 and 12. For now, we will assume that a competent designer has decided that the following are considered the essential operations of a bank account:

- Deposit money
- Withdraw money
- Get the current balance

In Java, operations are expressed as method calls. To figure out the exact specification of the method calls, imagine how a programmer would carry out the bank account operations. We'll assume that the variable `harrysChecking` contains a reference to an object of type `BankAccount`. We want to support method calls such as the following:

```
harrysChecking.deposit(2240.59);
harrysChecking.withdraw(500);
double currentBalance = harrysChecking.getBalance();
```

The first two methods are mutators. They modify the balance of the bank account and don't return a value. The third method is an accessor. It returns a value that you store in a variable or pass to a method.

As you can see from the sample calls, the `BankAccount` class should declare three methods:

- `public void deposit(double amount)`
- `public void withdraw(double amount)`
- `public double getBalance()`

Recall from Chapter 2 that `double` denotes the double-precision floating-point type, and `void` indicates that a method does not return a value.

Here we only give the method *headers*. When you declare a method, you also need to provide the method *body*, consisting of statements that are executed when the method is called.

```
public void deposit(double amount)
{
   implementation—filled in later
}
```

We will supply the method bodies in Section 3.5.

In a method header, you specify the return type, method name, and the types and names of the parameters.

Every method header contains the following parts:

- An **access specifier** (usually `public`)
- The *return type* (the type of the value returned, such as `void` or `double`)
- The name of the method (such as `deposit`)
- A list of the **parameter variables** of the method (if any), enclosed in parentheses (such as `double amount`)

The access specifier controls which other methods can call this method. Most methods should be declared as `public`. That way, all other methods in a program can call them. (Occasionally, it can be useful to have `private` methods. They can only be called from other methods of the same class.)

The return type is the type of the value that the method returns. The `deposit` method does not return a value, whereas the `getBalance` method returns a value of type `double`.

Each parameter of the method has both a type and a name that describes its purpose. For example, the `deposit` method has a single parameter named `amount` of type `double`.

Next, you need to supply **constructors**. A constructor initializes the instance variables of an object. In Java, a constructor is very similar to a method, with two important differences.

- The name of the constructor is always the same as the name of the class (e.g., `BankAccount`).
- Constructors have no return type (not even `void`).

We want to construct bank accounts that initially have a zero balance, as well as accounts that have a given initial balance. For this purpose, we specify two constructors.

- `public BankAccount()`
- `public BankAccount(double initialBalance)`

They are used as follows:

```
BankAccount harrysChecking = new BankAccount();
BankAccount momsSavings = new BankAccount(5000);
```

Constructors set the initial data for objects. The constructor name is always the same as the class name.

Just like a method, a constructor also has a body—a sequence of statements that is executed when a new object is constructed.

```
public BankAccount()
{
   implementation—filled in later
}
```

The statements in the constructor body will set the instance variables of the object that is being constructed—see Section 3.5.

Don't worry about the fact that there are two constructors with the same name—*all* constructors of a class have the same name, that is, the name of the class. The compiler can tell them apart because they take different parameters.

When declaring a class, you place all constructor and method declarations inside, like this:

```
public class BankAccount
{
   private instance variables—filled in later

   // Constructors
   public BankAccount()
   {
      implementation—filled in later
   }

   public BankAccount(double initialBalance)
   {
      implementation—filled in later
   }
```

```
    // Methods
    public void deposit(double amount)
    {
       implementation—filled in later
    }

    public void withdraw(double amount)
    {
       implementation—filled in later
    }

    public double getBalance()
    {
       implementation—filled in later
    }
}
```

The public constructors and methods of a class form the **public interface** of the class. These are the operations that any programmer can use to create and manipulate `BankAccount` objects.

Our `BankAccount` class is simple, but it allows programmers to carry out all of the important operations that commonly occur with bank accounts. For example, consider this program segment, authored by a programmer who uses the `BankAccount` class. These statements transfer an amount of money from one bank account to another:

```
// Transfer from one account to another
double transferAmount = 500;
momsSavings.withdraw(transferAmount);
harrysChecking.deposit(transferAmount);
```

And here is a program segment that adds interest to a savings account:

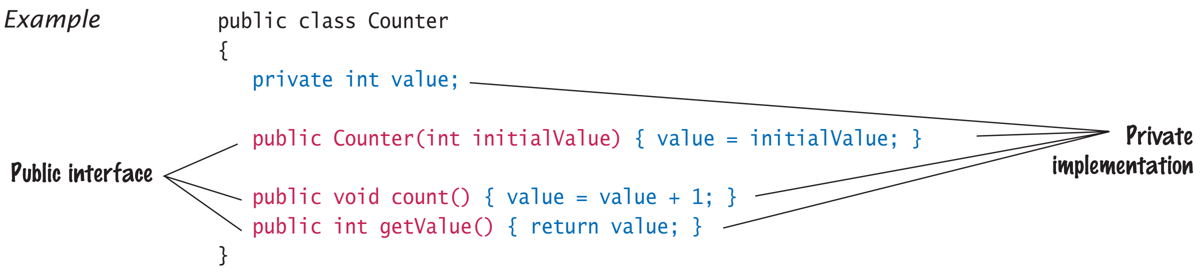
```
double interestRate = 5; // 5% interest
double interestAmount
      = momsSavings.getBalance() * interestRate / 100;
momsSavings.deposit(interestAmount);
```

Syntax 3.2 Class Declaration

Syntax

```
accessSpecifier class ClassName
{
   instance variables
   constructors
   methods
}
```

Example



```
public class Counter
{
   private int value;

   public Counter(int initialValue) { value = initialValue; }

   public void count() { value = value + 1; }
   public int getValue() { return value; }
}
```

As you can see, programmers can use objects of the `BankAccount` class to carry out meaningful tasks, without knowing how the `BankAccount` objects store their data or how the `BankAccount` methods do their work.

Of course, as implementors of the `BankAccount` class, we will need to supply the private implementation. We will do so in Section 3.5. First, however, an important step remains: *documenting* the public interface. That is the topic of the next section.

SELF CHECK

6. How can you use the methods of the public interface to *empty* the `harrysChecking` bank account?
7. What is wrong with this sequence of statements?

```
BankAccount harrysChecking = new BankAccount(10000);
System.out.println(harrysChecking.withdraw(500));
```

8. Suppose you want a more powerful bank account abstraction that keeps track of an *account number* in addition to the balance. How would you change the public interface to accommodate this enhancement?

Common Error 3.1

Declaring a Constructor as `void`

Do not use the `void` reserved word when you declare a constructor:

```
public void BankAccount()  // Error—don't use void!
```

This would declare a method with return type `void` and *not* a constructor. Unfortunately, the Java compiler does not consider this a syntax error.

3.4 Commenting the Public Interface

When you implement classes and methods, you should get into the habit of thoroughly *commenting* their behaviors. In Java there is a very useful standard form for **documentation comments**. If you use this form in your classes, a program called `javadoc` can automatically generate a neat set of HTML pages that describe them. (See Productivity Hint 3.1 on page 84 for a description of this utility.)

Use documentation comments to describe the classes and public methods of your programs.

A documentation comment is placed before the class or method declaration that is being documented. It starts with a `/**`, a special comment delimiter used by the `javadoc` utility. Then you describe the method's *purpose*. Then, for each method parameter, you supply a line that starts with `@param`, followed by the parameter name and a short explanation. Finally, you supply a line that starts with `@return`, describing the return value. You omit the `@param` tag for methods that have no parameters, and you omit the `@return` tag for methods whose return type is `void`.

The `javadoc` utility copies the *first* sentence of each comment to a summary table in the HTML documentation. Therefore, it is best to write that first sentence with some care. It should start with an uppercase letter and end with a period. It does not have to be a grammatically complete sentence, but it should be meaningful when it is pulled out of the comment and displayed in a summary.

Here are two typical examples.

```
/**
   Withdraws money from the bank account.
   @param amount the amount to withdraw
*/
public void withdraw(double amount)
{
   implementation—filled in later
}

/**
   Gets the current balance of the bank account.
   @return the current balance
*/
public double getBalance()
{
   implementation—filled in later
}
```

The comments you have just seen explain individual *methods*. Supply a brief comment for each *class*, explaining its purpose. The comment syntax for class comments is very simple: Just place the documentation comment above the class.

```
/**
   A bank account has a balance that can be changed by
   deposits and withdrawals.
*/
public class BankAccount
{
   . . .
}
```

Your first reaction may well be "Whoa! Am I supposed to write all this stuff?" These comments do seem pretty repetitive. But you should take the time to write them, even if it feels silly.

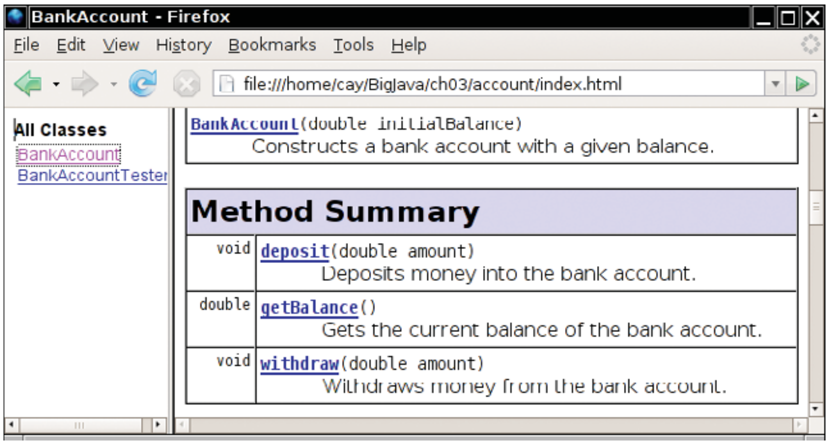
It is always a good idea to write the method comment *first*, before writing the code in the method body. This is an excellent test to see that you firmly understand what you need to program. If you can't explain what a class or method does, you aren't ready to implement it.

Provide documentation comments for every class, every method, every parameter, and every return value.

What about very simple methods? You can easily spend more time pondering whether a comment is too trivial to write than it takes to write it. In practical programming, very simple methods are rare. It is harmless to have a trivial method overcommented, whereas a complicated method without any comment can cause real grief to future maintenance programmers. According to the standard Java documentation style, *every* class, *every* method, *every* parameter, and *every* return value should have a comment.

The javadoc utility formats your comments into a neat set of documents that you can view in a web browser. It makes good use of the seemingly repetitive phrases. The first sentence of the comment is used for a *summary table* of all methods of your class (see Figure 3). The @param and @return comments are neatly formatted in the detail description of each method (see Figure 4). If you omit any of the comments, then javadoc generates documents that look strangely empty.

This documentation format should look familiar. The programmers who implement the Java library use javadoc themselves. They too document every class, every

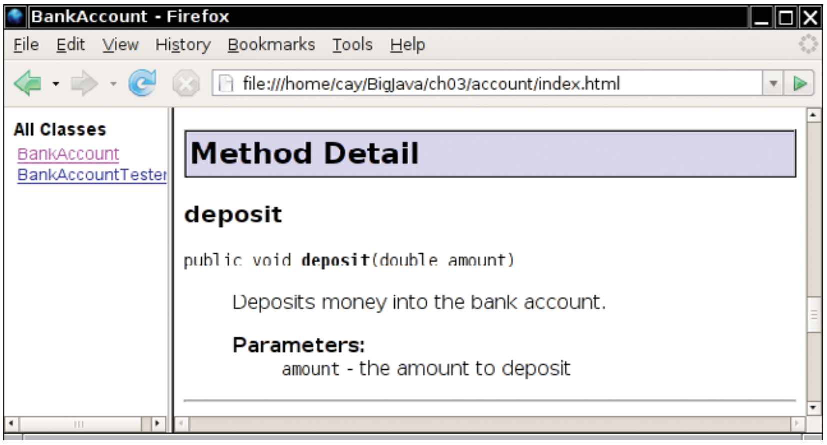

BankAccount - Firefox
File Edit View History Bookmarks Tools Help
file:///home/cay/BigJava/ch03/account/index.html
All Classes
BankAccount
BankAccountTester

BankAccount(double initialBalance)
Constructs a bank account with a given balance.

Method Summary

void	deposit(double amount) Deposits money into the bank account.
double	getBalance() Gets the current balance of the bank account.
void	withdraw(double amount) Withdraws money from the bank account.

Figure 3 A Method Summary Generated by javadoc


BankAccount - Firefox
File Edit View History Bookmarks Tools Help
file:///home/cay/BigJava/ch03/account/index.html
All Classes
BankAccount
BankAccountTester

Method Detail

deposit

public void **deposit**(double amount)

Deposits money into the bank account.

Parameters:
amount - the amount to deposit

Figure 4 Method Detail Generated by javadoc

method, every parameter, and every return value, and then use javadoc to extract the documentation in HTML format.

SELF CHECK

9. Provide documentation comments for the Counter class of Section 3.1.

10. Suppose we enhance the BankAccount class so that each account has an account number. Supply a documentation comment for the constructor

```
public BankAccount(int accountNumber, double initialBalance)
```

11. Why is the following documentation comment questionable?

```
/**
   Each account has an account number.
   @return the account number of this account
*/
public int getAccountNumber()
```

Productivity Hint 3.1

The javadoc Utility

Always insert documentation comments in your code, whether or not you use javadoc to produce HTML documentation. Most people find the HTML documentation convenient, so it is worth learning how to run javadoc. Some programming environments (such as BlueJ) can execute javadoc for you. Alternatively, you can invoke the javadoc utility from a shell window, by issuing the command

```
javadoc MyClass.java
```

or, if you want to document multiple Java files,

```
javadoc *.java
```

The javadoc utility produces files such as MyClass.html in HTML format, which you can inspect in a browser. If you know HTML (see Appendix F), you can embed HTML tags into the comments to specify fonts or add images. Perhaps most importantly, javadoc automatically provides *hyperlinks* to other classes and methods.

You can run javadoc before implementing any methods. Just leave all the method bodies empty. Don't run the compiler—it would complain about missing return values. Simply run javadoc on your file to generate the documentation for the public interface that you are about to implement.

The javadoc tool is wonderful because it does one thing right: It allows you to put the documentation *together with your code*. That way, when you update your programs, you can see right away which documentation needs to be updated. Hopefully, you will update it right then and there. Afterward, run javadoc again and get updated information that is timely and nicely formatted.

3.5 Providing the Class Implementation

Now that you understand the specification of the public interface of the BankAccount class, let's provide the implementation.

The private implementation of a class consists of instance variables, and the bodies of constructors and methods.

First, we need to determine the data that each bank account object contains. In the case of our simple bank account class, each object needs to store a single value, the current balance. (A more complex bank account class might store additional data—perhaps an account number, the interest rate paid, the date for mailing out the next statement, and so on.)

```
public class BankAccount
{
   private double balance;
   . . .
}
```

Now that we have determined the instance variables, let's complete the BankAccount class by supplying the bodies of the constructors and methods. Each body contains a sequence of statements. We'll start with the constructors because they are very straightforward. A constructor has a simple job: to initialize the instance variables of an object.

Recall that we designed the BankAccount class to have two constructors. The first constructor simply sets the balance to zero:

```
public BankAccount()
{
   balance = 0;
}
```

The second constructor sets the balance to the value supplied as the construction parameter:

```
public BankAccount(double initialBalance)
{
   balance = initialBalance;
}
```

To see how these constructors work, let us trace the statement

```
BankAccount harrysChecking = new BankAccount(1000);
```

one step at a time.

Here are the steps that are carried out when the statement executes.

- Create a new object of type BankAccount.
- Call the second constructor (because a parameter value is supplied in the constructor call).
- Set the parameter variable initialBalance to 1000.
- Set the balance instance variable of the newly created object to initialBalance.
- Return an object reference, that is, the memory location of the object, as the value of the new expression.
- Store that object reference in the harrysChecking variable.

Let's move on to implementing the BankAccount methods. Here is the deposit method:

```
public void deposit(double amount)
{
   balance = balance + amount;
}
```

To understand exactly what the method does, consider this statement:

```
harrysChecking.deposit(500);
```

This statement carries out the following steps:

- Set the parameter variable amount to 500.
- Fetch the balance instance variable of the object whose location is stored in harrysChecking.
- Add the value of amount to balance
- Store the sum in the balance instance variable, overwriting the old value.

The withdraw method is very similar to the deposit method:

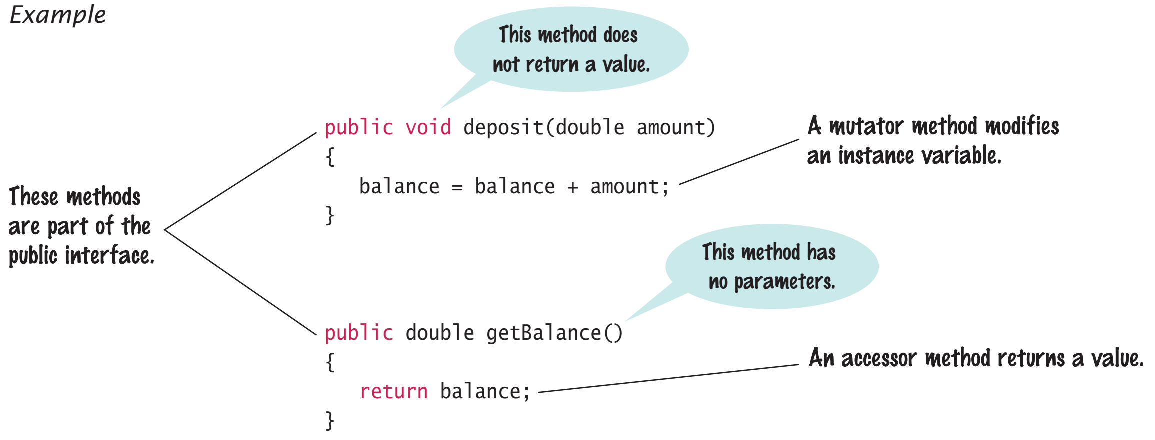
```
public void withdraw(double amount)
{
   balance = balance - amount;
}
```

Syntax 3.3 Method Declaration

Syntax

```
accessSpecifier returnType methodName(parameterType parameterName, . . . )
{
   method body
}
```

Example



```
public void deposit(double amount)
{
   balance = balance + amount;
}

public double getBalance()
{
   return balance;
}
```

This method does not return a value.
A mutator method modifies an instance variable.
These methods are part of the public interface.
This method has no parameters.
An accessor method returns a value.

There is only one method left, `getBalance`. Unlike the `deposit` and `withdraw` methods, which modify the instance variables of the object on which they are invoked, the `getBalance` method returns a value:

```
public double getBalance()
{
   return balance;
}
```

We have now completed the implementation of the `BankAccount` class—see the code listing below. There is only one step remaining: testing that the class works correctly. That is the topic of the next section.

ch03/account/BankAccount.java

```
/**
   A bank account has a balance that can be changed by
   deposits and withdrawals.
*/
public class BankAccount
{
   private double balance;

   /**
      Constructs a bank account with a zero balance.
   */
   public BankAccount()
   {
      balance = 0;
   }

   /**
      Constructs a bank account with a given balance.
      @param initialBalance the initial balance
   */
   public BankAccount(double initialBalance)
   {
      balance = initialBalance;
   }

   /**
      Deposits money into the bank account.
      @param amount the amount to deposit
   */
   public void deposit(double amount)
   {
      balance = balance + amount;
   }

   /**
      Withdraws money from the bank account.
      @param amount the amount to withdraw
   */
   public void withdraw(double amount)
   {
      balance = balance - amount;
   }

   /**
      Gets the current balance of the bank account.
      @return the current balance
   */
   public double getBalance()
   {
      return balance;
   }
}
```

SELF CHECK

12. Suppose we modify the `BankAccount` class so that each bank account has an account number. How does this change affect the instance variables?

13. Why does the following code not succeed in robbing mom's bank account?

```
public class BankRobber
{
   public static void main(String[] args)
   {
      BankAccount momsSavings = new BankAccount(1000);
      momsSavings.balance = 0;
   }
}
```

14. The `Rectangle` class has four instance variables: `x`, `y`, `width`, and `height`. Give a possible implementation of the `getWidth` method.

15. Give a possible implementation of the `translate` method of the `Rectangle` class.

How To 3.1 Implementing a Class

This “How To” section tells you how you implement a class from a given specification.

For example, a homework assignment might ask you to implement a class that models a cash register. Your class should allow a cashier to enter item prices and the amount of money that the customer paid. It should then calculate the change due.

Step 1 Find out which methods you are asked to supply.

In the cash register example, you won’t have to provide every feature of a real cash register—there are too many. The assignment tells you, in plain English, *which aspects* of a cash register your class should simulate. Make a list of them:

- **Ring up the sales price for a purchased item.**
- **Enter the amount of payment.**
- **Calculate the amount of change due to the customer.**

Step 2 Specify the public interface.

Turn the list in Step 1 into a set of methods, with specific types for the parameters and the return values. Many programmers find this step simpler if they write out method calls that are applied to a sample object, like this:

```
CashRegister register = new CashRegister();
register.recordPurchase(29.95);
register.recordPurchase(9.95);
register.enterPayment(50);
double change = register.giveChange();
```

Now we have a specific list of methods.

- `public void recordPurchase(double amount)`
- `public void enterPayment(double amount)`
- `public double giveChange()`

To complete the public interface, you need to specify the constructors. Ask yourself what information you need in order to construct an object of your class. Sometimes you will want two constructors: one that sets all instance variables to a default and one that sets them to user-supplied values.

In the case of the cash register example, we can get by with a single constructor that creates an empty register. A more realistic cash register would start out with some coins and bills so that we can give exact change, but that is beyond the scope of our assignment.

Thus, we add a single constructor:

- `public CashRegister()`

Step 3 Document the public interface.

Here is the documentation, with comments, that describes the class and its methods:

```
/**
   A cash register totals up sales and computes change due.
*/
public class CashRegister
{
   /**
      Constructs a cash register with no money in it.
   */
   public CashRegister()
   {
   }
```

```
      /**
         Records the sale of an item.
         @param amount  the price of the item
      */
      public void recordPurchase(double amount)
      {
      }

      /**
         Enters the payment received from the customer.
         @param amount  the amount of the payment
      */
      public void enterPayment(double amount)
      {
      }

      /**
         Computes the change due and resets the machine for the next customer.
         @return  the change due to the customer
      */
      public double giveChange()
      {
      }
   }
```

Step 4 Determine instance variables.

Ask yourself what information an object needs to store to do its job. Remember, the methods can be called in any order! The object needs to have enough internal memory to be able to process every method using just its instance variables and the method parameters. Go through each method, perhaps starting with a simple one or an interesting one, and ask yourself what you need to carry out the method's task. Make instance variables to store the information that the method needs.

In the cash register example, you would want to keep track of the total purchase amount and the payment. You can compute the change due from these two amounts.

```
public class CashRegister
{
   private double purchase;
   private double payment;
   . . .
}
```

Step 5 Implement constructors and methods.

Implement the constructors and methods in your class, one at a time, starting with the easiest ones. For example, here is the implementation of the `recordPurchase` method:

```
public void recordPurchase(double amount)
{
   purchase = purchase + amount;
}
```

Here is the `giveChange` method. Note that this method is a bit more sophisticated—it computes the change due, and it also resets the cash register for the next sale.

```
public double giveChange()
{
   double change = payment - purchase;
   purchase = 0;
   payment = 0;
   return change;
}
```

If you find that you have trouble with the implementation, you may need to rethink your choice of instance variables. It is common for a beginner to start out with a set of instance variables that cannot accurately reflect the state of an object. Don't hesitate to go back and add or modify instance variables.

Once you have completed the implementation, compile your class and fix any compile-time errors.

You can find the complete implementation in the `ch03/cashregister` directory of the book code.

Step 6 Test your class.

Write a short tester program and execute it. The tester program can carry out the method calls that you found in Step 2.

```
public class CashRegisterTester
{
   public static void main(String[] args)
   {
      CashRegister register = new CashRegister();

      register.recordPurchase(29.50);
      register.recordPurchase(9.25);
      register.enterPayment(50);

      double change = register.giveChange();

      System.out.println(change);
      System.out.println("Expected: 11.25");
   }
}
```

The output of this test program is:

```
11.25
Expected: 11.25
```

Alternatively, if you use a program that lets you test objects interactively, such as BlueJ, construct an object and apply the method calls.

Worked Example 3.1

Making a Simple Menu

Worked Example 3.1 shows how to implement a class that constructs simple menus.

3.6 Unit Testing

A unit test verifies that a class works correctly in isolation, outside a complete program.

In the preceding section, we completed the implementation of the `BankAccount` class. What can you do with it? Of course, you can compile the file `BankAccount.java`. However, you can't *execute* the resulting `BankAccount.class` file. It doesn't contain a `main` method. That is normal—most classes don't contain a `main` method.

In the long run, your class may become a part of a larger program that interacts with users, stores data in files, and so on. However, before integrating a class into a program, it is always a good idea to test it in isolation. Testing in isolation, outside a complete program, is called **unit testing**.

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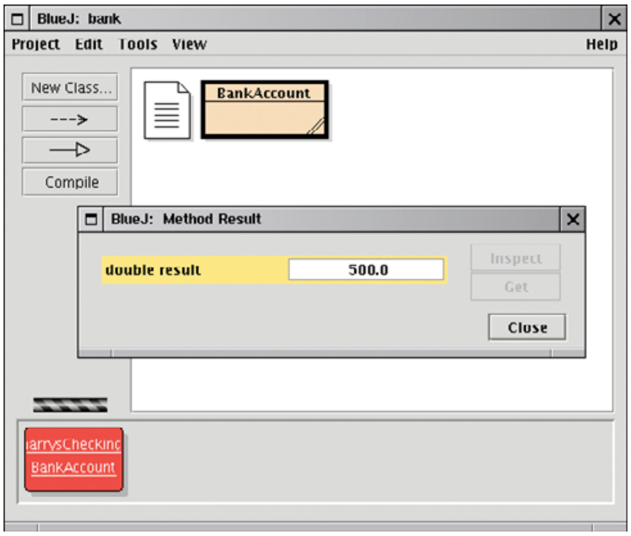

Figure 5
The Return Value of the `getBalance` Method in BlueJ

To test your class, you have two choices. Some interactive development environments have commands for constructing objects and invoking methods (see Special Topic 2.1). Then you can test a class simply by constructing an object, calling methods, and verifying that you get the expected return values. Figure 5 shows the result of calling the `getBalance` method on a `BankAccount` object in BlueJ.

Alternatively, you can write a *tester class*. A tester class is a class with a `main` method that contains statements to run methods of another class. As discussed in Section 2.9, a tester class typically carries out the following steps:

1. Construct one or more objects of the class that is being tested.
2. Invoke one or more methods.
3. Print out one or more results.
4. Print the expected results.

The `MoveTester` class in Section 2.9 is a good example of a tester class. That class runs methods of the `Rectangle` class—a class in the Java library.

Here is a class to run methods of the `BankAccount` class. The `main` method constructs an object of type `BankAccount`, invokes the `deposit` and `withdraw` methods, and then displays the remaining balance on the console.

We also print the value that we expect to see. In our sample program, we deposit $2,000 and withdraw $500. We therefore expect a balance of $1,500.

ch03/account/BankAccountTester.java

```
/**
   A class to test the BankAccount class.
*/
public class BankAccountTester
{
   /**
      Tests the methods of the BankAccount class.
      @param args not used
   */
   public static void main(String[] args)
   {
      BankAccount harrysChecking = new BankAccount();
      harrysChecking.deposit(2000);
      harrysChecking.withdraw(500);
      System.out.println(harrysChecking.getBalance());
      System.out.println("Expected: 1500");
   }
}
```

Program Run

```
1500
Expected: 1500
```

To produce a program, you need to combine the `BankAccount` and the `BankAccountTester` classes. The details for building the program depend on your compiler and development environment. In most environments, you need to carry out these steps:

1. Make a new subfolder for your program.
2. Make two files, one for each class.
3. Compile both files.
4. Run the test program.

Many students are surprised that such a simple program contains two classes. However, this is normal. The two classes have entirely different purposes. The `BankAccount` class describes objects that compute bank balances. The `BankAccountTester` class runs a test that puts a `BankAccount` object through its paces.

SELF CHECK

16. When you run the `BankAccountTester` program, how many objects of class `BankAccount` are constructed? How many objects of type `BankAccountTester`?
17. Why is the `BankAccountTester` class unnecessary in development environments that allow interactive testing, such as BlueJ?

3.7 Local Variables

Local variables are declared in the body of a method.

In this section, we discuss the behavior of *local* variables. A **local variable** is a variable that is declared in the body of a method. For example, the `giveChange` method in How To 3.1 on page 88 declares a local variable `change`:

```
public double giveChange()
{
   double change = payment - purchase;
   purchase = 0;
   payment = 0;
   return change;
}
```

ANIMATION
Lifetime of Variables

Parameter variables are similar to local variables, but they are declared in method headers. For example, the following method declares a parameter variable `amount`:

```
public void enterPayment(double amount)
```

When a method exits, its local variables are removed.

Local and parameter variables belong to methods. When a method runs, its local and parameter variables come to life. When the method exits, they are removed immediately. For example, if you call `register.giveChange()`, then a variable `change` is created. When the method exits, that variable is removed.

In contrast, instance variables belong to objects, not methods. When an object is constructed, its instance variables are created. The instance variables stay alive until no method uses the object any longer. (The Java virtual machine contains an agent called a **garbage collector** that periodically reclaims objects when they are no longer used.)

Instance variables are initialized to a default value, but you must initialize local variables.

An important difference between instance variables and local variables is **initialization**. You must initialize all local variables. If you don't initialize a local variable, the compiler complains when you try to use it. (Note that parameter variables are initialized when the method is called.)

Instance variables are initialized with a default value before a constructor is invoked. Instance variables that are numbers are initialized to `0`. Object references are set to a special value called `null`. If an object reference is `null`, then it refers to no object at all. We will discuss the `null` value in greater detail in Section 5.2.5.

SELF CHECK

18. What do local variables and parameter variables have in common? In which essential aspect do they differ?

19. Why was it necessary to introduce the local variable `change` in the `giveChange` method? That is, why didn't the method simply end with the statement

```
return payment - purchase;
```

Common Error 3.2

Forgetting to Initialize Object References in a Constructor

Just as it is a common error to forget to initialize a local variable, it is easy to forget about instance variables. Every constructor needs to ensure that all instance variables are set to appropriate values.

If you do not initialize an instance variable, the Java compiler will initialize it for you. Numbers are initialized with `0`, but object references—such as string variables—are set to the `null` reference.

Of course, `0` is often a convenient default for numbers. However, `null` is hardly ever a convenient default for objects. Consider this "lazy" constructor for a modified version of the `BankAccount` class:

```
public class BankAccount
{
   private double balance;
   private String owner;
   . . .
   public BankAccount(double initialBalance)
   {
      balance = initialBalance;
   }
}
```

Then `balance` is initialized, but the `owner` variable is set to a `null` reference. This can be a problem—it is illegal to call methods on the `null` reference.

To avoid this problem, it is a good idea to initialize every instance variable:

```
public BankAccount(double initialBalance)
{
   balance = initialBalance;
   owner = "None";
}
```

3.8 Implicit Parameters

In Section 2.4, you learned that a method has an **implicit parameter** (the object on which the method is invoked) in addition to the **explicit parameters**, which are enclosed in parentheses. In this section, we will examine implicit parameters in greater detail.

Have a look at a particular invocation of the deposit method:

```
momsSavings.deposit(500);
```

Here, the implicit parameter is momsSavings and the explicit parameter is 500.

Now look again at the code of the deposit method:

```
public void deposit(double amount)
{
   balance = balance + amount;
}
```

What does balance mean exactly? After all, our program may have multiple BankAccount objects, and *each of them* has its own balance.

Use of an instance variable name in a method denotes the instance variable of the implicit parameter.

Of course, since we are depositing the money into momsSavings, balance must mean momsSavings.balance. In general, when you refer to an instance variable inside a method, it means the instance variable of the implicit parameter.

The this reference denotes the implicit parameter.

If you need to, you can access the implicit parameter—the object on which the method is called—with the reserved word this. For example, in the preceding method invocation, this refers to the same object as momsSavings (see Figure 6).

The statement

```
balance = balance + amount;
```

actually means

```
this.balance = this.balance + amount;
```

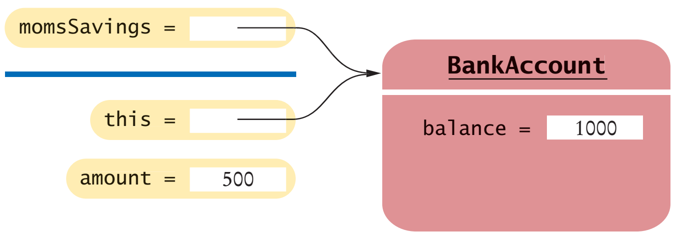

Figure 6 The Implicit Parameter of a Method Call

When you refer to an instance variable in a method, the compiler automatically applies it to the this reference. Some programmers actually prefer to manually insert the this reference before every instance variable because they find it makes the code clearer. Here is an example:

```
public BankAccount(double initialBalance)
{
   this.balance = initialBalance;
}
```

You may want to try it out and see if you like that style.

The this reference can also be used to distinguish between instance variables and local or parameter variables. Consider the constructor

```
public BankAccount(double balance)
{
   this.balance = balance;
}
```

The expression this.balance clearly refers to the balance instance variable. However, the expression balance by itself seems ambiguous. It could denote either the parameter variable or the instance variable. In Java, local and parameter variables are considered first when looking up variable names. Therefore,

```
this.balance = balance;
```

means: "Set the instance variable balance to the parameter variable balance".

There is another situation in which it is important to understand the implicit parameter. Consider the following modification to the BankAccount class. We add a method to apply the monthly account fee:

```
public class BankAccount
{
   . . .
   public void monthlyFee()
   {
      withdraw(10); // Withdraw $10 from this account
   }
}
```

A method call without an implicit parameter is applied to the same object.

That means to withdraw from the *same* bank account object that is carrying out the monthlyFee operation. In other words, the implicit parameter of the withdraw method is the (invisible) implicit parameter of the monthlyFee method.

If you find it confusing to have an invisible parameter, you can use the this reference to make the method easier to read:

```
public class BankAccount
{
   . . .
   public void monthlyFee()
   {
      this.withdraw(10); // Withdraw $10 from this account
   }
}
```

You have now seen how to use objects and implement classes, and you have learned some important technical details about variables and method parameters. The remainder of this chapter continues the optional graphics track. In the next chapter, you will learn more about the most fundamental data types of the Java language.

20. How many implicit and explicit parameters does the `withdraw` method of the `BankAccount` class have, and what are their names and types?

21. In the `deposit` method, what is the meaning of `this.amount`? Or, if the expression has no meaning, why not?

22. How many implicit and explicit parameters does the `main` method of the `BankAccountTester` class have, and what are they called?

Special Topic 3.1

Calling One Constructor from Another

Special Topic 3.1 describes how you can minimize common code in multiple constructors, by using the `this` reserved word for calling one constructor from another.

Random Fact 3.1

Electronic Voting Machines

Random Fact 3.1 discusses issues that arise in the design of electronic voting machines. Many computer scientists believe that electronic voting machines should be complemented by a voter-verifiable paper audit trail because it is impossible, with today's technology, to tell that software is error free and has not been tampered with.

3.9 Shape Classes

In this section, we continue the optional graphics track by discussing how to organize complex drawings in a more object-oriented fashion.

It is a good idea to make a class for any part of a drawing that can occur more than once.

When you produce a drawing that is composed of complex parts, such as the one in Figure 7, it is a good idea to make a separate class for each part. Provide a `draw` method that draws the shape, and provide a constructor to set the position of the shape. For example, here is the outline of the `Car` class.

```
public class Car
{
   public Car(int x, int y)
   {
      // Remember position
      . . .
   }

   public void draw(Graphics2D g2)
   {
      // Drawing instructions
      . . .
   }
}
```

To figure out how to draw a complex shape, make a sketch on graph paper.

You will find the complete class declaration at the end of this section. The `draw` method contains a rather long sequence of instructions for drawing the body, roof,

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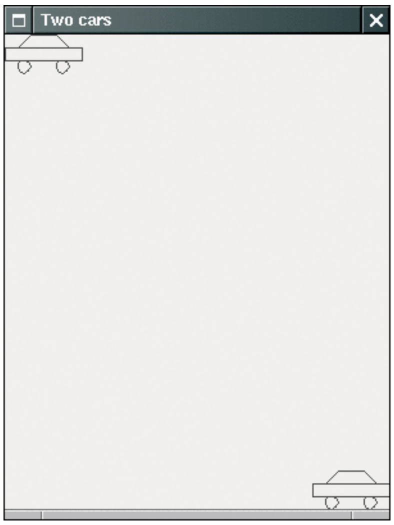
Figure 7
The Car Component Draws Two Car Shapes



and tires. The coordinates of the car parts seem a bit arbitrary. To come up with suitable values, draw the image on graph paper and read off the coordinates (Figure 8).

The program that produces Figure 7 is composed of three classes.

- The `Car` class is responsible for drawing a single car. Two objects of this class are constructed, one for each car.
- The `CarComponent` class displays the drawing.
- The `CarViewer` class shows a frame that contains a `CarComponent`.

Let us look more closely at the `CarComponent` class. The `paintComponent` method draws two cars. We place one car in the top-left corner of the window, and the other car in

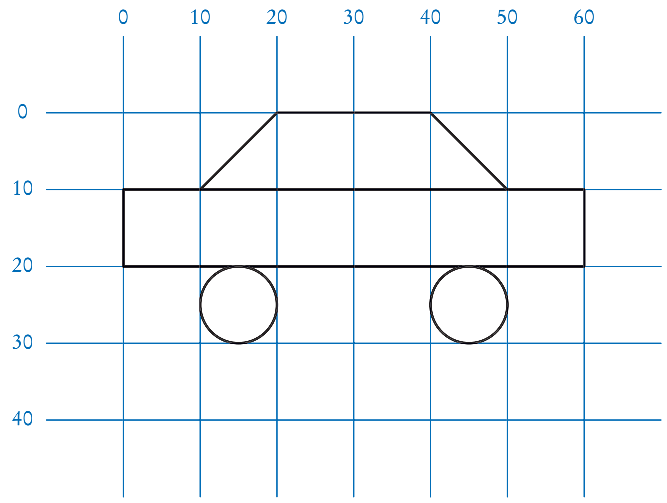


Figure 8 Using Graph Paper to Find Shape Coordinates

the bottom right. To compute the bottom right position, we call the `getWidth` and `getHeight` methods of the `JComponent` class. These methods return the dimensions of the component. We subtract the dimensions of the car to determine the position of `car2`:

```
Car car1 = new Car(0, 0);
int x = getWidth() - 60;
int y = getHeight() - 30;
Car car2 = new Car(x, y);
```

Pay close attention to the call to `getWidth` inside the `paintComponent` method of `CarComponent`. The method call has no implicit parameter, which means that the method is applied to the same object that executes the `paintComponent` method. The component simply obtains *its own* width.

Run the program and resize the window. Note that the second car always ends up at the bottom-right corner of the window. Whenever the window is resized, the `paintComponent` method is called and the car position is recomputed, taking the current component dimensions into account.

ch03/car/CarComponent.java

```
import java.awt.Graphics;
import java.awt.Graphics2D;
import javax.swing.JComponent;

/**
   This component draws two car shapes.
*/
public class CarComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Graphics2D g2 = (Graphics2D) g;

      Car car1 = new Car(0, 0);

      int x = getWidth() - 60;
      int y = getHeight() - 30;

      Car car2 = new Car(x, y);

      car1.draw(g2);
      car2.draw(g2);
   }
}
```

ch03/car/Car.java

```
import java.awt.Graphics2D;
import java.awt.Rectangle;
import java.awt.geom.Ellipse2D;
import java.awt.geom.Line2D;
import java.awt.geom.Point2D;

/**
   A car shape that can be positioned anywhere on the screen.
*/
public class Car
{
   private int xLeft;
   private int yTop;

   /**
      Constructs a car with a given top left corner.
      @param x the x coordinate of the top left corner
      @param y the y coordinate of the top left corner
   */
   public Car(int x, int y)
   {
      xLeft = x;
      yTop = y;
   }

   /**
      Draws the car.
      @param g2 the graphics context
   */
   public void draw(Graphics2D g2)
   {
      Rectangle body
            = new Rectangle(xLeft, yTop + 10, 60, 10);
      Ellipse2D.Double frontTire
            = new Ellipse2D.Double(xLeft + 10, yTop + 20, 10, 10);
      Ellipse2D.Double rearTire
            = new Ellipse2D.Double(xLeft + 40, yTop + 20, 10, 10);

      // The bottom of the front windshield
      Point2D.Double r1
            = new Point2D.Double(xLeft + 10, yTop + 10);
      // The front of the roof
      Point2D.Double r2
            = new Point2D.Double(xLeft + 20, yTop);
      // The rear of the roof
      Point2D.Double r3
            = new Point2D.Double(xLeft + 40, yTop);
      // The bottom of the rear windshield
      Point2D.Double r4
            = new Point2D.Double(xLeft + 50, yTop + 10);

      Line2D.Double frontWindshield
            = new Line2D.Double(r1, r2);
      Line2D.Double roofTop
            = new Line2D.Double(r2, r3);
      Line2D.Double rearWindshield
            = new Line2D.Double(r3, r4);

      g2.draw(body);
      g2.draw(frontTire);
      g2.draw(rearTire);
      g2.draw(frontWindshield);
      g2.draw(roofTop);
      g2.draw(rearWindshield);
   }
}
```

ch03/car/CarViewer.java

```java
import javax.swing.JFrame;

public class CarViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();

      frame.setSize(300, 400);
      frame.setTitle("Two cars");
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

      CarComponent component = new CarComponent();
      frame.add(component);

      frame.setVisible(true);
   }
}
```

SELF CHECK

23. Which class needs to be modified to have the two cars positioned next to each other?
24. Which class needs to be modified to have the car tires painted in black, and what modification do you need to make?
25. How do you make the cars twice as big?

How To 3.2 Drawing Graphical Shapes

You can write programs that display a wide variety of graphical shapes. These instructions give you a step-by-step procedure for decomposing a drawing into parts and implementing a program that produces the drawing. In this How To, we will create a program to draw a national flag.

Step 1 Determine the shapes that you need for the drawing.

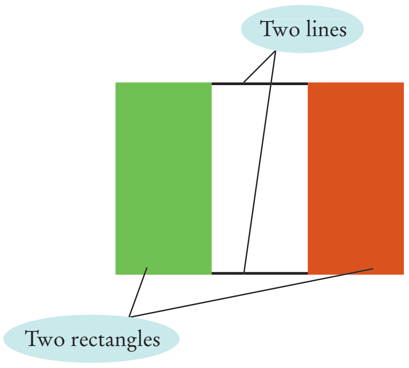
You can use the following shapes:

- Squares and rectangles
- Circles and ellipses
- Lines

The outlines of these shapes can be drawn in any color, and you can fill the insides of these shapes with any color. You can also use text to label parts of your drawing.

Some national flag designs consist of three equally wide sections of different colors, side by side:

You could draw such a flag using three rectangles. But if the middle rectangle is white, as it is, for example, in the flag of Italy (green, white, red), it is easier and looks better to draw a line on the top and bottom of the middle portion:



Step 2 Find the coordinates for the shapes.

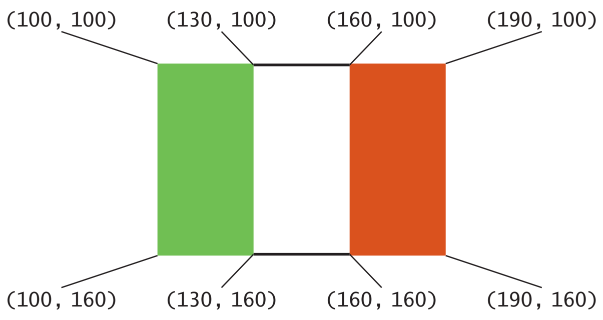
You now need to find the exact positions for the geometric shapes.

- For rectangles, you need the *x*- and *y*-position of the top-left corner, the width, and the height.
- For ellipses, you need the top-left corner, width, and height of the bounding rectangle.
- For lines, you need the *x*- and *y*-positions of the starting point and the end point.
- For text, you need the *x*- and *y*-position of the basepoint.

A commonly-used size for a window is 300 by 300 pixels. You may not want the flag crammed all the way to the top, so perhaps the upper-left corner of the flag should be at point (100, 100).

Many flags, such as the flag of Italy, have a width : height ratio of 3 : 2. (You can often find exact proportions for a particular flag by doing a bit of Internet research on one of several Flags of the World sites.) For example, if you make the flag 90 pixels wide, then it should be 60 pixels tall. (Why not make it 100 pixels wide? Then the height would be $100 \cdot 2 / 3 \approx 67$, which seems more awkward.)

Now you can compute the coordinates of all the important points of the shape:



Step 3 Write Java statements to draw the shapes.

In our example, there are two rectangles and two lines:

```
Rectangle leftRectangle
      = new Rectangle(100, 100, 30, 60);
Rectangle rightRectangle
      = new Rectangle(160, 100, 30, 60);
```

```
Line2D.Double topLine
      = new Line2D.Double(130, 100, 160, 100);
Line2D.Double bottomLine
      = new Line2D.Double(130, 160, 160, 160);
```

If you are more ambitious, then you can express the coordinates in terms of a few variables. In the case of the flag, we have arbitrarily chosen the top-left corner and the width. All other coordinates follow from those choices. If you decide to follow the ambitious approach, then the rectangles and lines are determined as follows:

```
Rectangle leftRectangle = new Rectangle(
      xLeft, yTop,
      width / 3, width * 2 / 3);
Rectangle rightRectangle = new Rectangle(
      xLeft + 2 * width / 3, yTop,
      width / 3, width * 2 / 3);
Line2D.Double topLine = new Line2D.Double(
      xLeft + width / 3, yTop,
      xLeft + width * 2 / 3, yTop);
Line2D.Double bottomLine = new Line2D.Double(
      xLeft + width / 3, yTop + width * 2 / 3,
      xLeft + width * 2 / 3, yTop + width * 2 / 3);
```

Now you need to fill the rectangles and draw the lines. For the flag of Italy, the left rectangle is green and the right rectangle is red. Remember to switch colors before the filling and drawing operations:

```
g2.setColor(Color.GREEN);
g2.fill(leftRectangle);
g2.setColor(Color.RED);
g2.fill(rightRectangle);
g2.setColor(Color.BLACK);
g2.draw(topLine);
g2.draw(bottomLine);
```

Step 4 Combine the drawing statements with the component "plumbing".

```
public class MyComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Graphics2D g2 = (Graphics2D) g;
      // Drawing instructions
      . . .
   }
}
```

In our example, you can simply add all shapes and drawing instructions inside the `paintComponent` method:

```
public class ItalianFlagComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Graphics2D g2 = (Graphics2D) g;
      Rectangle leftRectangle
            = new Rectangle(100, 100, 30, 60);
      . . .
      g2.setColor(Color.GREEN);
      g2.fill(leftRectangle);
      . . .
   }
}
```

That approach is acceptable for simple drawings, but it is not very object-oriented. After all, a flag is an object. It is better to make a separate class for the flag. Then you can draw different flags at different positions. Specify the sizes in a constructor and supply a `draw` method:

```
public class ItalianFlag
{
   private int xLeft;
   private int yTop;
   private int width;

   public ItalianFlag(int x, int y, int aWidth)
   {
      xLeft = x;
      yTop = y;
      width = aWidth;
   }

   public void draw(Graphics2D g2)
   {
      Rectangle leftRectangle = new Rectangle(
            xLeft, yTop,
            width / 3, width * 2 / 3);
      . . .
      g2.setColor(Color.GREEN);
      g2.fill(leftRectangle);
      . . .
   }
}
```

You still need a separate class for the component, but it is very simple:

```
public class ItalianFlagComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Graphics2D g2 = (Graphics2D) g;
      ItalianFlag flag = new ItalianFlag(100, 100, 90);
      flag.draw(g2);
   }
}
```

Step 5 Write the viewer class.

Provide a viewer class, with a `main` method in which you construct a frame, add your component, and make your frame visible. The viewer class is completely routine; you only need to change a single line to show a different component.

```
public class ItalianFlagViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();

      frame.setSize(300, 400);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

      ItalianFlagComponent component = new ItalianFlagComponent();
      frame.add(component);

      frame.setVisible(true);
   }
}
```

Random Fact 3.2

Computer Graphics

Random Fact 3.2 discusses computer graphics, the technology of generating and manipulating visual images on a computer.

Summary of Learning Objectives

Understand instance variables and the methods that access them.

- An object's instance variables store the data required for executing its methods.
- Each object of a class has its own set of instance variables.
- Private instance variables can only be accessed by methods of the same class.

Explain the concept and benefits of encapsulation.

- Encapsulation is the process of hiding implementation details and providing methods for data access.
- Encapsulation allows a programmer to use a class without having to know its implementation.
- Information hiding makes it simpler for the implementor of a class to locate errors and change implementations.

Write method and constructor headers that describe the public interface of a class.

- In order to implement a class, you first need to know which methods are required.
- In a method header, you specify the return type, method name, and the types and names of the parameters.
- Constructors set the initial data for objects. The constructor name is always the same as the class name.

Write class documentation in javadoc format.

- Use documentation comments to describe the classes and public methods of your programs.
- Provide documentation comments for every class, every method, every parameter, and every return value.

Provide the private implementation of a class.

- The private implementation of a class consists of instance variables, and the bodies of constructors and methods.

Write tests that verify that a class works correctly.

- A unit test verifies that a class works correctly in isolation, outside a complete program.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Compare lifetime and initialization of instance, local, and parameter variables.

- Local variables are declared in the body of a method.
- When a method exits, its local variables are removed.
- Instance variables are initialized to a default value, but you must initialize local variables.

Recognize the use of the implicit parameter in method declarations.

- Use of an instance variable name in a method denotes the instance variable of the implicit parameter.
- The `this` reference denotes the implicit parameter.
- A method call without an implicit parameter is applied to the same object.

Implement classes that draw graphical shapes.

- It is a good idea to make a class for any part of a drawing that can occur more than once.
- To figure out how to draw a complex shape, make a sketch on graph paper.

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** Making a Simple Menu
- Lab Exercises
- ***Animation*** Lifetime of Variables
- Practice Quiz
- Code Completion Exercises

Review Exercises

★ **R3.1** What is the interface of a class? How does it differ from the implementation of a class?

★ **R3.2** What is encapsulation? Why is it useful?

★ **R3.3** Instance variables are a part of the hidden implementation of a class, but they aren't actually hidden from programmers who have the source code of the class. Explain to what extent the `private` reserved word provides information hiding.

★ **R3.4** Consider a class `Grade` that represents a letter grade, such as A+ or B. Give two choices of instance variables that can be used for implementing the `Grade` class.

★★ **R3.5** Consider a class `Time` that represents a point in time, such as 9 A.M. or 3:30 P.M. Give two different sets of instance variables that can be used for implementing the `Time` class.

★ **R3.6** Suppose the implementor of the `Time` class of Exercise R3.5 changes from one implementation strategy to another, keeping the public interface unchanged. What do the programmers who use the `Time` class need to do?

★★ **R3.7** You can read the `value` instance variable of the `Counter` class with the `getValue` accessor method. Should there be a `setValue` mutator method to change it? Explain why or why not.

★★ **R3.8** **a.** Show that the `BankAccount(double initialBalance)` constructor is not strictly necessary. That is, if we removed that constructor from the public interface, how could a programmer still obtain `BankAccount` objects with an arbitrary balance?

b. Conversely, could we keep only the `BankAccount(double initialBalance)` constructor and remove the `BankAccount()` constructor?

★★ **R3.9** Why does the `BankAccount` class not have a `reset` method?

★ **R3.10** What happens in our implementation of the `BankAccount` class when more money is withdrawn from the account than the current balance?

★★ **R3.11** What is the `this` reference? Why would you use it?

★★ **R3.12** What does the following method do? Give an example of how you can call the method.

```
public class BankAccount
{
   public void mystery(BankAccount that, double amount)
   {
      this.balance = this.balance - amount;
      that.balance = that.balance + amount;
   }
   . . . // Other bank account methods
}
```

★★ **R3.13** Suppose you want to implement a class `TimeDepositAccount`. A time deposit account has a fixed interest rate that should be set in the constructor, together with the initial balance. Provide a method to get the current balance. Provide a method to add the earned interest to the account. This method should have no parameters because the interest rate is already known. It should have no return value because you already provided a method for obtaining the current balance. It is not possible to deposit additional funds into this account. Provide a `withdraw` method that removes the entire balance. Partial withdrawals are not allowed.

★ **R3.14** Consider the following implementation of a class `Square`:

```
public class Square
{
   private int sideLength;
   private int area; // Not a good idea

   public Square(int length)
   {
      sideLength = length;
   }

   public int getArea()
   {
      area = sideLength * sideLength;
      return area;
   }
}
```

Why is it not a good idea to introduce an instance variable for the area? Rewrite the class so that `area` is a local variable.

★★ **R3.15** Consider the following implementation of a class Square:

```
public class Square
{
   private int sideLength;
   private int area;

   public Square(int initialLength)
   {
      sideLength = initialLength;
      area = sideLength * sideLength;
   }

   public int getArea() { return area; }
   public void grow() { sideLength = 2 * sideLength(); }
}
```

What error does this class have? How would you fix it?

★★T **R3.16** Provide a unit test class for the Counter class in Section 3.1.

★★T **R3.17** Read Exercise P3.7, but do not implement the Car class yet. Write a tester class that tests a scenario in which gas is added to the car, the car is driven, more gas is added, and the car is driven again. Print the actual and expected amount of gas in the tank.

★★G **R3.18** Suppose you want to extend the car viewer program in Section 3.9 to show a suburban scene, with several cars and houses. Which classes do you need?

★★★G **R3.19** Explain why the calls to the getWidth and getHeight methods in the CarComponent class have no explicit parameter.

★★G **R3.20** How would you modify the Car class in order to show cars of varying sizes?

Programming Exercises

★T **P3.1** Write a BankAccountTester class whose main method constructs a bank account, deposits $1,000, withdraws $500, withdraws another $400, and then prints the remaining balance. Also print the expected result.

★ **P3.2** Add a method

```
public void addInterest(double rate)
```

to the BankAccount class that adds interest at the given rate. For example, after the statements

```
BankAccount momsSavings = new BankAccount(1000);
momsSavings.addInterest(10); // 10% interest
```

the balance in momsSavings is $1,100. Also supply a BankAccountTester class that prints the actual and expected balance.

★★ **P3.3** Write a class SavingsAccount that is similar to the BankAccount class, except that it has an added instance variable interest. Supply a constructor that sets both the initial balance and the interest rate. Supply a method addInterest (with no explicit parameter) that adds interest to the account. Write a SavingsAccountTester class that constructs a savings account with an initial balance of $1,000 and an interest rate of 10 percent. Then apply the `addInterest` method and print the resulting balance. Also compute the expected result by hand and print it.

★★★ **P3.4** Add a feature to the `CashRegister` class for computing sales tax. The tax rate should be supplied when constructing a `CashRegister` object. Add `recordTaxablePurchase` and `getTotalTax` methods. (Amounts added with `recordPurchase` are not taxable.) The `giveChange` method should correctly reflect the sales tax that is charged on taxable items.

★★ **P3.5** After closing time, the store manager would like to know how much business was transacted during the day. Modify the `CashRegister` class to enable this functionality. Supply methods `getSalesTotal` and `getSalesCount` to get the total amount of all sales and the number of sales. Supply a method `reset` that resets any counters and totals so that the next day's sales start from zero.

★★ **P3.6** Implement a class `Employee`. An employee has a name (a string) and a salary (a `double`). Provide a constructor with two parameters

```
public Employee(String employeeName, double currentSalary)
```

and methods

```
public String getName()
public double getSalary()
public void raiseSalary(double byPercent)
```

These methods return the name and salary, and raise the employee's salary by a certain percentage. Sample usage:

```
Employee harry = new Employee("Hacker, Harry", 50000);
harry.raiseSalary(10); // Harry gets a 10% raise
```

Supply an `EmployeeTester` class that tests all methods.

★★ **P3.7** Implement a class `Car` with the following properties. A car has a certain fuel efficiency (measured in miles/gallon or liters/km—pick one) and a certain amount of fuel in the gas tank. The efficiency is specified in the constructor, and the initial fuel level is `0`. Supply a method `drive` that simulates driving the car for a certain distance, reducing the amount of gasoline in the fuel tank. Also supply methods `getGasInTank`, returning the current amount of gasoline in the fuel tank, and `addGas`, to add gasoline to the fuel tank. Sample usage:

```
Car myHybrid = new Car(50); // 50 miles per gallon
myHybrid.addGas(20); // Tank 20 gallons
myHybrid.drive(100); // Drive 100 miles
double gasLeft = myHybrid.getGasInTank(); // Get gas remaining in tank
```

You may assume that the `drive` method is never called with a distance that consumes more than the available gas. Supply a `CarTester` class that tests all methods.

★★ **P3.8** Implement a class `Student`. For the purpose of this exercise, a student has a name and a total quiz score. Supply an appropriate constructor and methods `getName()`, `addQuiz(int score)`, `getTotalScore()`, and `getAverageScore()`. To compute the latter, you also need to store the *number of quizzes* that the student took.

Supply a `StudentTester` class that tests all methods.

★ **P3.9** Implement a class `Product`. A product has a name and a price, for example `new Product("Toaster", 29.95)`. Supply methods `getName`, `getPrice`, and `reducePrice`. Supply a program `ProductPrinter` that makes two products, prints the name and price, reduces their prices by $5.00, and then prints the prices again.

★★ **P3.10** Provide a class for authoring a simple letter. In the constructor, supply the names of the sender and the recipient:

```
public Letter(String from, String to)
```

Supply a method

```
public void addLine(String line)
```

to add a line of text to the body of the letter.

Supply a method

```
public String getText()
```

that returns the entire text of the letter. The text has the form:

```
Dear recipient name:
blank line
first line of the body
second line of the body
. . .
last line of the body
blank line
Sincerely,
blank line
sender name
```

Also supply a class `LetterPrinter` that prints this letter.

```
Dear John:

I am sorry we must part.
I wish you all the best.

Sincerely,

Mary
```

Construct an object of the `Letter` class and call `addLine` twice.

Hints: (1) Use the `concat` method to form a longer string from two shorter strings. (2) The special string `"\n"` represents a new line. For example, the statement

```
body = body.concat("Sincerely,").concat("\n");
```

adds a line containing the string `"Sincerely,"` to the body.

★★ **P3.11** Write a class `Bug` that models a bug moving along a horizontal line. The bug moves either to the right or left. Initially, the bug moves to the right, but it can turn to change its direction. In each move, its position changes by one unit in the current direction. Provide a constructor

```
public Bug(int initialPosition)
```

and methods

```
public void turn()
public void move()
public int getPosition()
```

Sample usage:

```
Bug bugsy = new Bug(10);
bugsy.move(); // now the position is 11
bugsy.turn();
bugsy.move(); // now the position is 10
```

Your `BugTester` should construct a bug, make it move and turn a few times, and print the actual and expected position.

★★ **P3.12** Implement a class `Moth` that models a moth flying across a straight line. The moth has a position, the distance from a fixed origin. When the moth moves toward a point of light, its new position is halfway between its old position and the position of the light source. Supply a constructor

```
public Moth(double initialPosition)
```

and methods

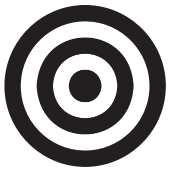
```
public void moveToLight(double lightPosition)
public double getPosition()
```

Your `MothTester` should construct a moth, move it toward a couple of light sources, and check that the moth's position is as expected.

★★ **P3.13** Implement a class `RoachPopulation` that simulates the growth of a roach population. The constructor takes the size of the initial roach population. The `breed` method simulates a period in which the roaches breed, which doubles their population. The `spray` method simulates spraying with insecticide, which reduces the population by 10 percent. The `getRoaches` method returns the current number of roaches. A program called `RoachSimulation` simulates a population that starts out with 10 roaches. Breed, spray, and print the roach count. Repeat three more times.

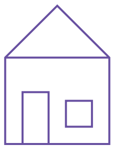
★★ **P3.14** Implement a `VotingMachine` class that can be used for a simple election. Have methods to clear the machine state, to vote for a Democrat, to vote for a Republican, and to get the tallies for both parties. Extra credit if your program gives the nod to your favored party if the votes are tallied after 8 P.M. on the first Tuesday in November, but acts normally on all other dates. (*Hint:* Use the `GregorianCalendar` class—see Programming Project 2.1.)

★★G **P3.15** Draw a "bull's eye"—a set of concentric rings in alternating black and white colors. *Hint:* Fill a black circle, then fill a smaller white circle on top, and so on.



Your program should be composed of classes `BullsEye`, `BullsEyeComponent`, and `BullsEyeViewer`.

★★G **P3.16** Write a program that draws a picture of a house. It could be as simple as the accompanying figure, or if you like, make it more elaborate (3-D, skyscraper, marble columns in the entryway, whatever).



Implement a class `House` and supply a method `draw(Graphics2D g2)` that draws the house.

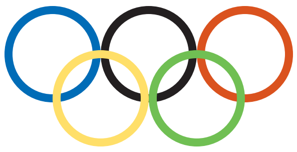
★★G **P3.17** Extend Exercise P3.16 by supplying a `House` constructor for specifying the position and size. Then populate your screen with a few houses of different sizes.

★★G **P3.18** Change the car viewer program in Section 3.9 to make the cars appear in different colors. Each `Car` object should store its own color. Supply modified `Car` and `CarComponent` classes.

★★G **P3.19** Change the `Car` class so that the size of a car can be specified in the constructor. Change the `CarComponent` class to make one of the cars appear twice the size of the original example.

★★G **P3.20** Write a program to plot the string “HELLO”, using only lines and circles. Do not call `drawString`, and do not use `System.out`. Make classes `LetterH`, `LetterE`, `LetterL`, and `LetterO`.

★★G **P3.21** Write a program that displays the Olympic rings. Color the rings in the Olympic colors.



Provide a class `OlympicRingViewer` and a class `OlympicRingComponent`.

★★G **P3.22** Make a bar chart to plot the following data set. Label each bar. Make the bars horizontal for easier labeling.

Bridge Name	Longest Span (ft)
Golden Gate	4,200
Brooklyn	1,595
Delaware Memorial	2,150
Mackinac	3,800

Provide a class `BarChartViewer` and a class `BarChartComponent`.

Programming Projects

Project 3.1 In this project, you will enhance the `BankAccount` class and see how abstraction and encapsulation enable evolutionary changes to software.

Begin with a simple enhancement: charging a fee for every deposit and withdrawal. Supply a mechanism for setting the fee and modify the `deposit` and `withdraw` methods so that the fee is levied. Test your resulting class and check that the fee is computed correctly.

Now make a more complex change. The bank will allow a fixed number of free transactions (deposits or withdrawals) every month, and charge for transactions exceeding the free allotment. The charge is not levied immediately but at the end of the month.

Supply a new method `deductMonthlyCharge` to the `BankAccount` class that deducts the monthly charge and resets the transaction count. (*Hint:* Use `Math.max(actual transaction count, free transaction count)` in your computation.)

Produce a test program that verifies that the fees are calculated correctly over several months.

Project 3.2 In this project, you will explore an object-oriented alternative to the "Hello, World" program in Chapter 1.

Begin with a simple `Greeter` class that has a single method, `sayHello`. That method should *return* a string, not print it. Use BlueJ to create two objects of this class and invoke their `sayHello` methods.

That is boring—of course, both objects return the same answer.

Enhance the `Greeter` class so that each object produces a customized greeting. For example, the object constructed as `new Greeter("Dave")` should say `"Hello, Dave"`. (Use the `concat` method to combine strings to form a longer string, or peek ahead at Section 4.6 to see how you can use the `+` operator for the same purpose.)

Add a method `sayGoodbye` to the `Greeter` class.

Finally, add a method `refuseHelp` to the `Greeter` class. It should return a string such as `"I am sorry, Dave. I am afraid I can't do that."`

Test your class in BlueJ. Make objects that greet the world and Dave, and invoke methods on them.

Answers to Self-Check Questions

1.
```
public void reset()
{
   value = 0;
}
```
2. You can only access them by invoking the methods of the `Clock` class.
3. In one of the methods of the `Counter` class.
4. The programmers who designed and implemented the Java library.
5. Other programmers who work on the personal finance application.
6. `harrysChecking.withdraw(harrysChecking.getBalance())`

7. The `withdraw` method has return type `void`. It doesn't return a value. Use the `getBalance` method to obtain the balance after the withdrawal.
8. Add an `accountNumber` parameter to the constructors, and add a `getAccountNumber` method. There is no need for a `setAccountNumber` method—the account number never changes after construction.
9.
```
/**
   This class models a tally counter.
*/
public class Counter
{
   private int value;

   /**
      Gets the current value of this counter.
      @return the current value
   */
   public int getValue()
   {
      return value;
   }

   /**
      Advances the value of this counter by 1.
   */
   public void count()
   {
      value = value + 1;
   }
}
```
10.
```
/**
   Constructs a new bank account with a given initial balance.
   @param accountNumber the account number for this account
   @param initialBalance the initial balance for this account
*/
```
11. The first sentence of the method description should describe the method—it is displayed in isolation in the summary table.
12. An instance variable

    ```
    private int accountNumber;
    ```

    needs to be added to the class.
13. Because the `balance` instance variable is accessed from the `main` method of `BankRobber`. The compiler will report an error because it is not a method of the `BankAccount` class.
14.
```
public int getWidth()
{
   return width;
}
```
15. There is more than one correct answer. One possible implementation is as follows:

    ```
    public void translate(int dx, int dy)
    {
       int newx = x + dx;
       x = newx;
       int newy = y + dy;
       y = newy;
    }
    ```

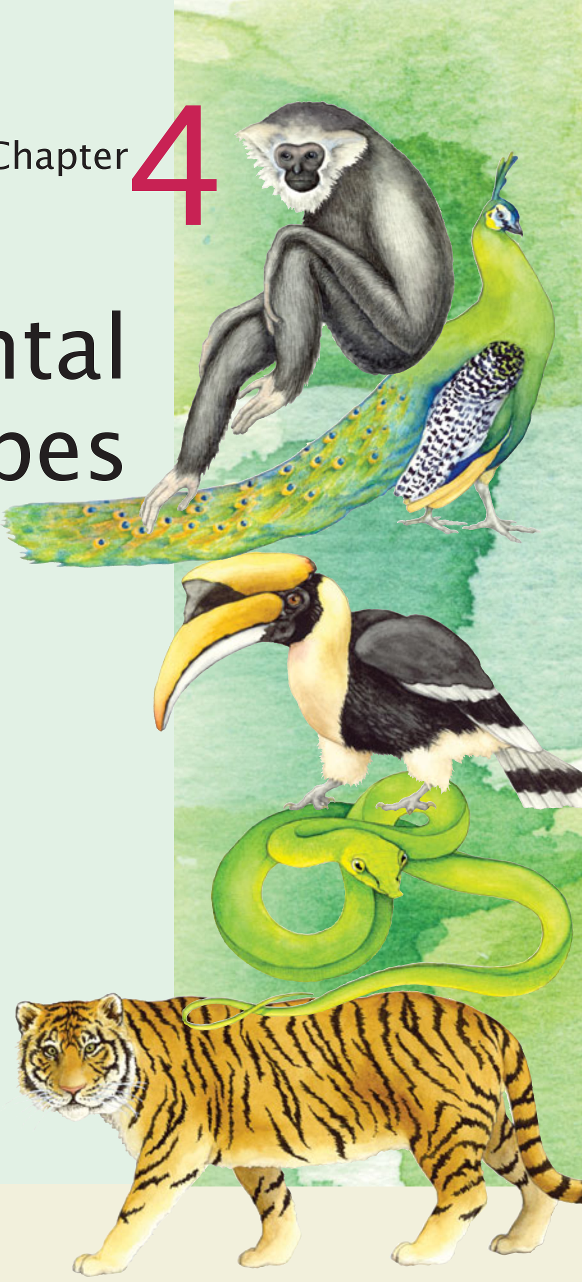
16. One `BankAccount` object, no `BankAccountTester` object. The purpose of the `BankAccountTester` class is merely to hold the `main` method.
17. In those environments, you can issue interactive commands to construct `BankAccount` objects, invoke methods, and display their return values.
18. Variables of both categories belong to methods—they come alive when the method is called, and they die when the method exits. They differ in their initialization. Parameter variables are initialized with the call values; local variables must be explicitly initialized.
19. After computing the change due, `payment` and `purchase` were set to zero. If the method returned `payment - purchase`, it would always return zero.
20. One implicit parameter, called `this`, of type `BankAccount`, and one explicit parameter, called `amount`, of type `double`.
21. It is not a legal expression. `this` is of type `BankAccount` and the `BankAccount` class has no instance variable named `amount`.
22. No implicit parameter—the `main` method is not invoked on any object—and one explicit parameter, called `args`.
23. `CarComponent`
24. In the `draw` method of the `Car` class, call

    ```
    g2.fill(frontTire);
    g2.fill(rearTire);
    ```

25. Double all measurements in the `draw` method of the `Car` class.

Chapter 4

Fundamental Data Types



CHAPTER GOALS

- To understand integer and floating-point numbers
- To recognize the limitations of the numeric types
- To become aware of causes for overflow and roundoff errors
- To understand the proper use of constants
- To write arithmetic expressions in Java
- To use the `String` type to manipulate character strings
- To learn how to read program input and produce formatted output

This chapter teaches how to manipulate numbers and character strings in Java. The goal of this chapter is to gain a firm understanding of these fundamental data types in Java.

You will learn about the properties and limitations of the number types in Java. You will see how to manipulate numbers and strings in your programs. Finally, we cover the important topic of input and output, which enables you to implement interactive programs.

CHAPTER CONTENTS

4.1 Number Types 116
Special Topic 4.1: Big Numbers ⊕
Special Topic 4.2: Binary Numbers ⊕
Random Fact 4.1: The Pentium Floating-Point Bug ⊕

4.2 Constants 118
Syntax 4.1: Constant Declaration 119
Quality Tip 4.1: Do Not Use Magic Numbers 122

4.3 Arithmetic Operations and Mathematical Functions 123
Syntax 4.2: Cast 127
Common Error 4.1: Integer Division 128
Common Error 4.2: Unbalanced Parentheses 128
Quality Tip 4.2: White Space 129
Quality Tip 4.3: Factor Out Common Code 129
Common Error 4.3: Roundoff Errors 130
Special Topic 4.3: Combining Assignment and Arithmetic ⊕

4.4 Calling Static Methods 131
Syntax 4.3: Static Method Call 131
How To 4.1: Carrying Out Computations 132
Worked Example 4.1: Computing the Volume and Surface Area of a Pyramid ⊕

4.5 Strings 134
Productivity Hint 4.1: Reading Exception Reports 137
Special Topic 4.4: Escape Sequences ⊕
Special Topic 4.5: Strings and the char Type ⊕
Random Fact 4.2: International Alphabets ⊕

4.6 Reading Input 138
Worked Example 4.2: Extracting Initials ⊕
Special Topic 4.6: Formatting Numbers ⊕
Special Topic 4.7: Using Dialog Boxes for Input and Output ⊕

4.1 Number Types

Java has eight primitive types, including four integer types and two floating-point types.

In Java, every value is either a reference to an object, or it belongs to one of the eight **primitive types** shown in Table 1.

Six of the primitive types are number types; four of them for integers and two for floating-point numbers.

Each of the integer types has a different range—Special Topic 4.2 on page 118 explains why the range limits are related to powers of two. The largest number that can be represented in an `int` is denoted by `Integer.MAX_VALUE`. Its value is about 2.14 billion. Similarly, `Integer.MIN_VALUE` is the smallest integer, about –2.14 billion.

A numeric computation overflows if the result falls outside the range for the number type.

Generally, you will use the `int` type for integer quantities. However, occasionally, calculations involving integers can *overflow.* This happens if the result of a computation exceeds the range for the number type. For example:

```
int n = 1000000;
System.out.println(n * n);  // Prints –727379968, which is clearly wrong
```

The product `n * n` is 10^{12}, which is larger than the largest integer (about $2 \cdot 10^9$). The result is truncated to fit into an `int`, yielding a value that is completely wrong. Unfortunately, there is no warning when an integer overflow occurs.

If you run into this problem, the simplest remedy is to use the `long` type. Special Topic 4.1 on page 118 shows you how to use the `BigInteger` type in the unlikely event that even the `long` type overflows.

Overflow is not usually a problem for double-precision floating-point numbers. The `double` type has a range of about $\pm 10^{308}$ and about 15 significant digits. However, you want to avoid the `float` type—it has less than 7 significant digits. (Some programmers use `float` to save on memory if they need to store a huge set of numbers that do not require much precision.)

Table 1 Primitive Types

Type	Description	Size
`int`	The integer type, with range –2,147,483,648 (`Integer.MIN_VALUE`) . . . 2,147,483,647 (`Integer.MAX_VALUE`, about 2.14 billion)	4 bytes
`byte`	The type describing a single byte, with range –128 . . . 127	1 byte
`short`	The short integer type, with range –32,768 . . . 32,767	2 bytes
`long`	The long integer type, with range –9,223,372,036,854,775,808 . . . 9,223,372,036,854,775,807	8 bytes
`double`	The double-precision floating-point type, with a range of about $\pm 10^{308}$ and about 15 significant decimal digits	8 bytes
`float`	The single-precision floating-point type, with a range of about $\pm 10^{38}$ and about 7 significant decimal digits	4 bytes
`char`	The character type, representing code units in the Unicode encoding scheme (see Special Topic 4.5)	2 bytes
`boolean`	The type with the two truth values `false` and `true` (see Chapter 5)	1 bit

Rounding errors occur when an exact conversion between numbers is not possible.

Rounding errors are a more serious issue with floating-point values. Rounding errors can occur when you convert between binary and decimal numbers, or between integers and floating-point numbers. When a value cannot be converted exactly, it is rounded to the nearest match. Consider this example:

```
double f = 4.35;
System.out.println(100 * f); // Prints 434.99999999999994
```

This problem is caused because computers represent numbers in the binary number system. In the binary number system, there is no exact representation of the fraction 1/10, just as there is no exact representation of the fraction 1/3 = 0.33333 in the decimal number system. (See Special Topic 4.2 for more information.)

For this reason, the `double` type is not appropriate for financial calculations. In this book, we will continue to use `double` values for bank balances and other financial quantities so that we keep our programs as simple as possible. However, professional programs need to use the `BigDecimal` type for this purpose—see Special Topic 4.1.

In Java, it is legal to assign an integer value to a floating-point variable:

```
int dollars = 100;
double balance = dollars; // OK
```

But the opposite assignment is an error: You cannot assign a floating-point expression to an integer variable.

```
double balance = 13.75;
int dollars = balance; // Error
```

You will see in Section 4.3.5 how to convert a value of type `double` into an integer.

SELF CHECK

1. Which are the most commonly used number types in Java?
2. Suppose you want to write a program that works with population data from various countries. Which Java data type should you use?
3. Which of the following initializations are incorrect, and why?
   a. `int dollars = 100.0;`
   b. `double balance = 100;`

Special Topic 4.1

Big Numbers

Special Topic 4.1 shows you how to use the `BigInteger` and `BigDecimal` types to deal with really large numbers, or to better control roundoff errors.

Special Topic 4.2

Binary Numbers

Special Topic 4.2 discusses how numbers are encoded in the computer, using the binary number system.

Random Fact 4.1

The Pentium Floating-Point Bug

Random Fact 4.1 tells the story of the Intel Pentium floating-point bug, a flaw in a widely-sold processor that caused multiplication errors in rare circumstances. Discovered by a mathematics professor who used a computer in his research on prime numbers, it ultimately caused a recall of all affected chips.

4.2 Constants

In many programs, you need to use numerical **constants**—values that do not change and that have a special significance for a computation.

A typical example for the use of constants is a computation that involves coin values, such as the following:

```
payment = dollars + quarters * 0.25 + dimes * 0.1
      + nickels * 0.05 + pennies * 0.01;
```

Most of the code is self-documenting. However, the four numeric quantities, 0.25, 0.1, 0.05, and 0.01 are included in the arithmetic expression without any explanation. Of course, in this case, you know that the value of a nickel is five cents, which explains the 0.05, and so on. However, the next person who needs to maintain this code may live in another country and may not know that a nickel is worth five cents.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

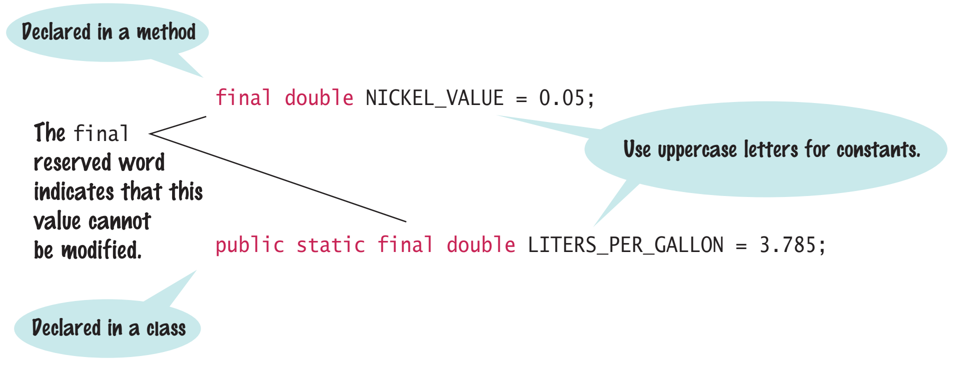
Syntax 4.1 Constant Declaration

Syntax

Declared in a method: `final` *typeName variableName* = *expression*;

Declared in a class: *accessSpecifier* `static final` *typeName variableName* = *expression*;

Example



```
final double NICKEL_VALUE = 0.05;

public static final double LITERS_PER_GALLON = 3.785;
```

Declared in a method
The final reserved word indicates that this value cannot be modified.
Use uppercase letters for constants.
Declared in a class

Thus, it is a good idea to use symbolic names for all values, even those that appear obvious. Here is a clearer version of the computation of the total:

```
double quarterValue = 0.25;
double dimeValue = 0.1;
double nickelValue = 0.05;
double pennyValue = 0.01;
payment = dollars + quarters * quarterValue + dimes * dimeValue
      + nickels * nickelValue + pennies * pennyValue;
```

There is another improvement we can make. There is a difference between the `nickels` and `nickelValue` variables. The `nickels` variable can truly vary over the life of the program, as we calculate different payments. But `nickelValue` is always 0.05.

A `final` variable is a constant. Once its value has been set, it cannot be changed.

In Java, constants are identified with the reserved word `final`. A variable tagged as `final` can never change after it has been set. If you try to change the value of a `final` variable, the compiler will report an error and your program will not compile.

Many programmers use all-uppercase names for constants (`final` variables), such as `NICKEL_VALUE`. That way, it is easy to distinguish between variables (with mostly lowercase letters) and constants. We will follow this convention in this book. However, this rule is a matter of good style, not a requirement of the Java language. The compiler will not complain if you give a `final` variable a name with lowercase letters.

Use named constants to make your programs easier to read and maintain.

Here is an improved version of the code that computes the value of a payment.

```
final double QUARTER_VALUE = 0.25;
final double DIME_VALUE = 0.1;
final double NICKEL_VALUE = 0.05;
final double PENNY_VALUE = 0.01;
payment = dollars + quarters * QUARTER_VALUE + dimes * DIME_VALUE
      + nickels * NICKEL_VALUE + pennies * PENNY_VALUE;
```

Frequently, constant values are needed in several methods. Then you should declare them together with the instance variables of a class and tag them as `static` and `final`. As before, `final` indicates that the value is a constant. The `static` reserved word means that the constant belongs to the class—this is explained in greater detail in Chapter 8.)

```
public class CashRegister
{
   // Constants
   public static final double QUARTER_VALUE = 0.25;
   public static final double DIME_VALUE = 0.1;
   public static final double NICKEL_VALUE = 0.05;
   public static final double PENNY_VALUE = 0.01;

   // Instance variables
   private double purchase;
   private double payment;

   // Methods
   . . .
}
```

We declared the constants as `public`. There is no danger in doing this because constants cannot be modified. Methods of other classes can access a public constant by first specifying the name of the class in which it is declared, then a period, then the name of the constant, such as `CashRegister.NICKEL_VALUE`.

The `Math` class from the standard library declares a couple of useful constants:

```
public class Math
{
   . . .
   public static final double E = 2.7182818284590452354;
   public static final double PI = 3.14159265358979323846;
}
```

You can refer to these constants as `Math.PI` and `Math.E` in any of your methods. For example,

```
double circumference = Math.PI * diameter;
```

The sample program at the end of this section puts constants to work. The program shows a refinement of the `CashRegister` class of How To 3.1. The public interface of that class has been modified in order to solve a common business problem.

Busy cashiers sometimes make mistakes totaling up coin values. Our `CashRegister` class features a method whose inputs are the *coin counts.* For example, the call

```
register.enterPayment(1, 2, 1, 1, 4);
```

enters a payment consisting of one dollar, two quarters, one dime, one nickel, and four pennies. The `enterPayment` method figures out the total value of the payment, $1.69. As you can see from the code listing, the method uses named constants for the coin values.

ch04/cashregister/CashRegister.java

```
/**
   A cash register totals up sales and computes change due.
*/
public class CashRegister
{
   public static final double QUARTER_VALUE = 0.25;
   public static final double DIME_VALUE = 0.1;
```

```java
   public static final double NICKEL_VALUE = 0.05;
   public static final double PENNY_VALUE = 0.01;

   private double purchase;
   private double payment;

   /**
      Constructs a cash register with no money in it.
   */
   public CashRegister()
   {
      purchase = 0;
      payment = 0;
   }

   /**
      Records the purchase price of an item.
      @param amount the price of the purchased item
   */
   public void recordPurchase(double amount)
   {
      purchase = purchase + amount;
   }

   /**
      Enters the payment received from the customer.
      @param dollars the number of dollars in the payment
      @param quarters the number of quarters in the payment
      @param dimes the number of dimes in the payment
      @param nickels the number of nickels in the payment
      @param pennies the number of pennies in the payment
   */
   public void enterPayment(int dollars, int quarters,
         int dimes, int nickels, int pennies)
   {
      payment = dollars + quarters * QUARTER_VALUE + dimes * DIME_VALUE
            + nickels * NICKEL_VALUE + pennies * PENNY_VALUE;
   }

   /**
      Computes the change due and resets the machine for the next customer.
      @return the change due to the customer
   */
   public double giveChange()
   {
      double change = payment - purchase;
      purchase = 0;
      payment = 0;
      return change;
   }
}
```

ch04/cashregister/CashRegisterTester.java

```java
/**
   This class tests the CashRegister class.
*/
public class CashRegisterTester
{
   public static void main(String[] args)
   {
      CashRegister register = new CashRegister();

      register.recordPurchase(0.75);
      register.recordPurchase(1.50);
      register.enterPayment(2, 0, 5, 0, 0);
      System.out.print("Change: ");
      System.out.println(register.giveChange());
      System.out.println("Expected: 0.25");

      register.recordPurchase(2.25);
      register.recordPurchase(19.25);
      register.enterPayment(23, 2, 0, 0, 0);
      System.out.print("Change: ");
      System.out.println(register.giveChange());
      System.out.println("Expected: 2.0");
   }
}
```

Program Run

```
Change: 0.25
Expected: 0.25
Change: 2.0
Expected: 2.0
```

SELF CHECK

4. What is the difference between the following two statements?

```
final double CM_PER_INCH = 2.54;
```

and

```
public static final double CM_PER_INCH = 2.54;
```

5. What is wrong with the following statement sequence?

```
double diameter = . . .;
double circumference = 3.14 * diameter;
```

Quality Tip 4.1

Do Not Use Magic Numbers

A magic number is a numeric constant that appears in your code without explanation. For example, consider the following scary example that actually occurs in the Java library source:

```
h = 31 * h + ch;
```

Why 31? The number of days in January? One less than the number of bits in an integer? Actually, this code computes a "hash code" from a string—a number that is derived from the characters in such a way that different strings are likely to yield different hash codes. The value 31 turns out to scramble the character values nicely.

A better solution is to use a named constant:

```
final int HASH_MULTIPLIER = 31;
h = HASH_MULTIPLIER * h + ch;
```

You should never use magic numbers in your code. Any number that is not completely self-explanatory should be declared as a named constant. Even the most reasonable cosmic constant is going to change one day. You think there are 365 days in a year? Your customers on Mars are going to be pretty unhappy about your silly prejudice. Make a constant

```
final int DAYS_PER_YEAR = 365;
```

By the way, the device

```
final int THREE_HUNDRED_AND_SIXTY_FIVE = 365;
```

is counterproductive and frowned upon.

4.3 Arithmetic Operations and Mathematical Functions

In the following sections, you will learn how to carry out arithmetic calculations in Java.

4.3.1 Arithmetic Operators

Java supports the same four basic arithmetic operations as a calculator—addition, subtraction, multiplication, and division. As you have already seen, addition and subtraction use the familiar `+` and `-` operators, and the `*` operator denotes multiplication. Division is indicated with a `/`, not a fraction bar.
For example,

$$\frac{a+b}{2}$$

becomes

```
(a + b) / 2
```

Parentheses are used just as in algebra: to indicate in which order the subexpressions should be computed. For example, in the expression `(a + b) / 2`, the sum `a + b` is computed first, and then the sum is divided by 2. In contrast, in the expression

```
a + b / 2
```

only `b` is divided by 2, and then the sum of `a` and `b / 2` is formed. Just as in regular algebraic notation, multiplication and division bind more strongly than addition and subtraction. For example, in the expression `a + b / 2`, the `/` is carried out first, even though the `+` operation occurs farther to the left.

4.3.2 Increment and Decrement

Incrementing a value by 1 is so common when writing programs that there is a special shorthand for it, namely

```
items++;
```

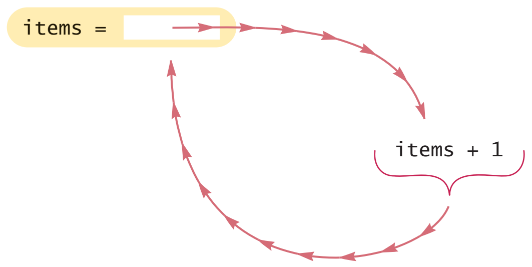


Figure 1 Incrementing a Variable

The ++ and -- operators increment and decrement a variable.

This statement adds 1 to `items`. It is easier to type and read than the equivalent assignment statement

```
items = items + 1;
```

As you might have guessed, there is also a decrement operator `--`. The statement

```
items--;
```

subtracts 1 from `items`.

4.3.3 Integer Division

If both arguments of the / operator are integers, the result is an integer and the remainder is discarded.

Division works as you would expect, as long as at least one of the numbers involved is a floating-point number. That is,

```
7.0 / 4.0
7 / 4.0
7.0 / 4
```

all yield 1.75. However, if both numbers are integers, then the result of the division is always an integer, with the remainder discarded. That is,

```
7 / 4
```

evaluates to 1, because 7 divided by 4 is 1 with a remainder of 3 (which is discarded). Discarding the remainder is often useful, but it can also be a source of subtle programming errors—see Common Error 4.1 on page 128.

The % operator computes the remainder of a division.

If you are interested only in the remainder of an integer division, use the `%` operator:

```
7 % 4
```

is 3, the remainder of the integer division of 7 by 4. The `%` symbol has no analog in algebra. It was chosen because it looks similar to `/`, and the remainder operation is related to division.

Here is a typical use for the integer `/` and `%` operations. Suppose you want to know how much change a cash register should give, using separate values for dollars and cents. You can compute the value as an integer, denominated in cents, and then compute the whole dollar amount and the remaining change:

```
final int PENNIES_PER_NICKEL = 5;
final int PENNIES_PER_DIME = 10;
final int PENNIES_PER_QUARTER = 25;
final int PENNIES_PER_DOLLAR = 100;
```

```
// Compute total value in pennies
int total = dollars * PENNIES_PER_DOLLAR + quarters * PENNIES_PER_QUARTER
      + nickels * PENNIES_PER_NICKEL + dimes * PENNIES_PER_DIME + pennies;

// Use integer division to convert to dollars, cents
int dollars = total / PENNIES_PER_DOLLAR;
int cents = total % PENNIES_PER_DOLLAR;
```

For example, if `total` is 243, then `dollars` is set to 2 and `cents` to 43.

4.3.4 Powers and Roots

The `Math` class contains methods `sqrt` and `pow` to compute square roots and powers.

To compute x^n, you write `Math.pow(x, n)`. However, to compute x^2 it is significantly more efficient simply to compute `x * x`.

To take the square root of a number, you use the `Math.sqrt` method. For example, $\sqrt{x}$ is written as `Math.sqrt(x)`.

In algebra, you use fractions, superscripts for exponents, and radical signs for roots to arrange expressions in a compact two-dimensional form. In Java, you have to write all expressions in a linear arrangement. For example, the subexpression

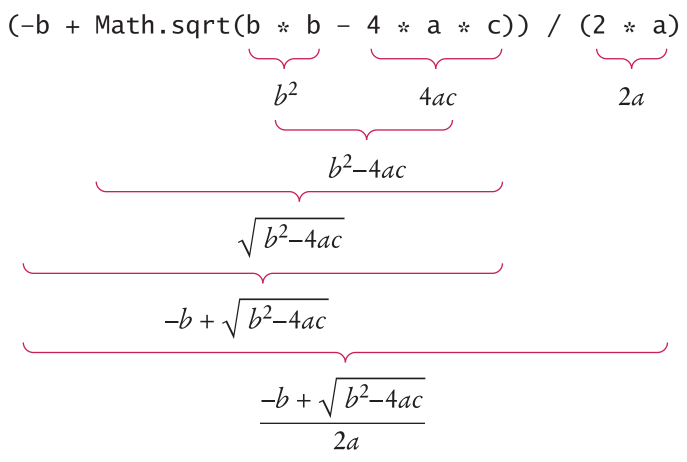
$$\frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

of the quadratic formula becomes

```
(-b + Math.sqrt(b * b - 4 * a * c)) / (2 * a)
```

Figure 2 shows how to analyze such an expression. With complicated expressions like these, it is not always easy to keep the parentheses `()` matched—see Common Error 4.2 on page 128.

Table 2 on page 126 shows additional methods of the `Math` class. Inputs and outputs are floating-point numbers.



```
(-b + Math.sqrt(b * b - 4 * a * c)) / (2 * a)
```

Figure 2 Analyzing an Expression

Table 2 Mathematical Methods

Function	Returns
`Math.sqrt(x)`	Square root of x (≥ 0)
`Math.pow(x, y)`	x^y ($x > 0$, or $x = 0$ and $y > 0$, or $x < 0$ and y is an integer)
`Math.sin(x)`	Sine of x (x in radians)
`Math.cos(x)`	Cosine of x
`Math.tan(x)`	Tangent of x
`Math.asin(x)`	Arc sine ($\sin^{-1} x \in [-\pi/2, \pi/2]$, $x \in [-1, 1]$)
`Math.acos(x)`	Arc cosine ($\cos^{-1} x \in [0, \pi]$, $x \in [-1, 1]$)
`Math.atan(x)`	Arc tangent ($\tan^{-1} x \in [-\pi/2, \pi/2]$)
`Math.atan2(y, x)`	Arc tangent ($\tan^{-1} y/x \in [-\pi, \pi]$), x may be 0
`Math.toRadians(x)`	Convert x degrees to radians (i.e., returns $x \cdot \pi/180$)
`Math.toDegrees(x)`	Convert x radians to degrees (i.e., returns $x \cdot 180/\pi$)
`Math.exp(x)`	e^x
`Math.log(x)`	Natural log ($\ln(x)$, $x > 0$)
`Math.log10(x)`	Decimal log ($\log_{10}(x)$, $x > 0$)
`Math.round(x)`	Closest integer to x (as a `long`)
`Math.ceil(x)`	Smallest integer $\geq x$ (as a `double`)
`Math.floor(x)`	Largest integer $\leq x$ (as a `double`)
`Math.abs(x)`	Absolute value $\|x\|$
`Math.max(x, y)`	The larger of x and y
`Math.min(x, y)`	The smaller of x and y

4.3.5 Casting and Rounding

Occasionally, you have a value of type `double` that you need to convert to the type `int`. Use the *cast* operator `(int)` for this purpose. You write the cast operator before the expression that you want to convert:

```
double balance = total + tax;
int dollars = (int) balance;
```

You use a cast (*typeName*) to convert a value to a different type.

The cast `(int)` converts the floating-point value `balance` to an integer by discarding the fractional part. For example, if `balance` is 13.75, then `dollars` is set to 13.

The cast tells the compiler that you agree to *information loss*, in this case, to the loss of the fractional part. You can also cast to other types, such as `(float)` or `(byte)`.

Syntax 4.2 Cast

Syntax (*typeName*) *expression*

Example

This is the type of the expression after casting.

```
(int) (balance * 100)
```

These parentheses are a part of the cast operator.

Use parentheses here if the cast is applied to an expression with arithmetic operators.

Use the `Math.round` method to round a floating-point number to the nearest integer.

If you want to round a floating-point number to the nearest whole number, use the `Math.round` method. This method returns a `long` integer, because large floating-point numbers cannot be stored in an `int`.

```
long rounded = Math.round(balance);
```

If `balance` is 13.75, then `rounded` is set to 14.

Table 3 Arithmetic Expressions

Mathematical Expression	Java Expression	Comments
$\frac{x+y}{2}$	`(x + y) / 2`	The parentheses are required; `x + y / 2` computes $x + \frac{y}{2}$.
$\frac{xy}{2}$	`x * y / 2`	Parentheses are not required; operators with the same precedence are evaluated left to right.
$\left(1 + \frac{r}{100}\right)^n$	`Math.pow(1 + r / 100, n)`	Complex formulas are "flattened" in Java.
$\sqrt{a^2 + b^2}$	`Math.sqrt(a * a + b * b)`	`a * a` is simpler than `Math.pow(a, 2)`.
$\frac{i+j+k}{3}$	`(i + j + k) / 3.0`	If i, j, and k are integers, using a denominator of 3.0 forces floating-point division.

SELF CHECK

6. What is the value of `n` after the following sequence of statements?

```
n--;
n++;
n--;
```

7. What is the value of `1729 / 100`? Of `1729 % 100`?

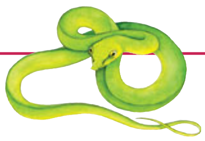
8. Why doesn't the following statement compute the average of s1, s2, and s3?

```
double average = s1 + s2 + s3 / 3; // Error
```

9. What is the value of `Math.sqrt(Math.pow(x, 2) + Math.pow(y, 2))` in mathematical notation?

10. When does the cast `(long) x` yield a different result from the call `Math.round(x)`?

11. How do you round the `double` value `x` to the nearest `int` value, assuming that you know that it is less than $2 \cdot 10^9$?



Common Error 4.1

Integer Division

It is unfortunate that Java uses the same symbol, namely /, for both integer and floating-point division. These are really quite different operations. It is a common error to use integer division by accident. Consider this program segment that computes the average of three integers.

```
int s1 = 5; // Score of test 1
int s2 = 6; // Score of test 2
int s3 = 3; // Score of test 3
double average = (s1 + s2 + s3) / 3;  // Error
System.out.print("Your average score is ");
System.out.println(average);
```

What could be wrong with that? Of course, the average of s1, s2, and s3 is

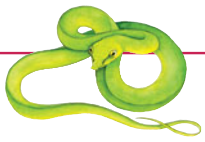
$$\frac{s_1 + s_2 + s_3}{3}$$

Here, however, the / does not mean division in the mathematical sense. It denotes integer division, because the values `s1 + s2 + s3` and 3 are both integers. For example, if the scores add up to 14, the average is computed to be 4, the result of the integer division of 14 by 3. That integer 4 is then moved into the floating-point variable average. The remedy is to make either the numerator or denominator into a floating-point number:

```
double total = s1 + s2 + s3;
double average = total / 3;
```

or

```
double average = (s1 + s2 + s3) / 3.0;
```



Common Error 4.2

Unbalanced Parentheses

Consider the expression

```
1.5 * ((-(b - Math.sqrt(b * b - 4 * a * c)) / (2 * a))
```

What is wrong with it? Count the parentheses. There are five opening parentheses (and four closing parentheses). The parentheses are unbalanced. This kind of typing error is very common with complicated expressions. Now consider this expression.

```
1.5 * (Math.sqrt(b * b - 4 * a * c))) - ((b / (2 * a))
```

This expression has five opening parentheses `(` and five closing parentheses `)`, but it is still not correct. In the middle of the expression,

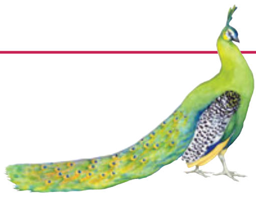
```
1.5 * (Math.sqrt(b * b - 4 * a * c))) - ((b / (2 * a))
```

there are only two opening parentheses `(` but three closing parentheses `)`, which is an error. In the middle of an expression, the count of opening parentheses must be greater than or equal to the count of closing parentheses, and at the end of the expression the two counts must be the same.

Here is a simple trick to make the counting easier without using pencil and paper. It is difficult for the brain to keep two counts simultaneously, so keep only one count when scanning the expression. Start with 1 at the first opening parenthesis; add 1 whenever you see an opening parenthesis; subtract 1 whenever you see a closing parenthesis. Say the numbers aloud as you scan the expression. If the count ever drops below zero, or if it is not zero at the end, the parentheses are unbalanced. For example, when scanning the previous expression, you would mutter

```
1.5 * (Math.sqrt(b * b - 4 * a * c) )  ) - ((b / (2 * a))
      1         2                 1 0  -1
```

and you would find the error.



Quality Tip 4.2

White Space

The compiler does not care whether you write your entire program onto a single line or place every symbol onto a separate line. The human reader, though, cares very much. You should use blank lines to group your code visually into sections. For example, you can signal to the reader that an output prompt and the corresponding input statement belong together by inserting a blank line before and after the group. You will find many examples in the source code listings in this book.

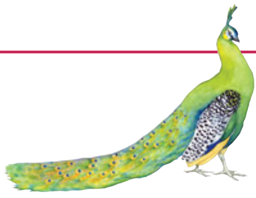
White space inside expressions is also important. It is easier to read

```
x1 = (-b + Math.sqrt(b * b - 4 * a * c)) / (2 * a);
```

than

```
x1=(-b+Math.sqrt(b*b-4*a*c))/(2*a);
```

Simply put spaces around all operators `+ - * / % =`. However, don't put a space after a unary minus: a `-` used to negate a single quantity, as in `-b`. That way, it can be easily distinguished from a binary minus, as in `a - b`. Don't put spaces between a method name and the parentheses, but do put a space after every Java reserved word. That makes it easy to see that the `sqrt` in `Math.sqrt(x)` is a method name, whereas the `if` in `if (x > 0) . . .` is a reserved word.



Quality Tip 4.3

Factor Out Common Code

Suppose you want to find both solutions of the quadratic equation $ax^2 + bx + c = 0$. The quadratic formula tells us that the solutions are

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

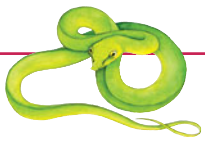
In Java, there is no analog to the ± operation, which indicates how to obtain two solutions simultaneously. Both solutions must be computed separately:

```
x1 = (-b + Math.sqrt(b * b - 4 * a * c)) / (2 * a);
x2 = (-b - Math.sqrt(b * b - 4 * a * c)) / (2 * a);
```

This approach has two problems. First, the computation of `Math.sqrt(b * b - 4 * a * c)` is carried out twice, which wastes time. Second, whenever the same code is replicated, the possibility of a typing error increases. The remedy is to factor out the common code:

```
double root = Math.sqrt(b * b - 4 * a * c);
x1 = (-b + root) / (2 * a);
x2 = (-b - root) / (2 * a);
```

You could go even further and factor out the computation of `2 * a`, but the gain from factoring out very simple computations is too small to warrant the effort.



Common Error 4.3

Roundoff Errors

Roundoff errors are a fact of life when calculating with floating-point numbers. You probably have encountered this phenomenon yourself with manual calculations. If you calculate 1/3 to two decimal places, you get 0.33. Multiplying again by 3, you obtain 0.99, not 1.00.

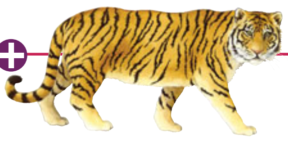
In the processor hardware, numbers are represented in the binary number system, not in decimal. You still get roundoff errors when binary digits are lost. They just may crop up at different places than you might expect. Here is an example:

```
double f = 4.35;
int n = (int) (100 * f);
System.out.println(n); // Prints 434!
```

Of course, one hundred times 4.35 is 435, but the program prints 434.

Computers represent numbers in the binary system (see Special Topic 4.2). In the binary system, there is no exact representation for 4.35, just as there is no exact representation for 1/3 in the decimal system. The representation used by the computer is just a little less than 4.35, so 100 times that value is just a little less than 435. When a floating-point value is converted to an integer, the entire fractional part is discarded, even if it is almost 1. As a result, the integer 434 is stored in `n`. Remedy: Use `Math.round` to convert floating-point numbers to integers. The `round` method returns the *closest* integer.

```
int n = (int) Math.round(100 * f);  // OK, n is 435
```



Special Topic 4.3

Combining Assignment and Arithmetic

Special Topic 4.3 covers special operators that combine assignment and arithmetic. For example, `balance += amount` is equivalent to `balance = balance + amount`.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

4.4 Calling Static Methods

In the preceding section, you encountered the `Math` class, which contains a collection of helpful methods for carrying out mathematical computations. These methods have a special form: they are *static methods* that do not operate on an object.

That is, you don't call

```
double root = 100.sqrt(); // Error
```

In Java, numbers are not objects, so you can never invoke a method on a number. Instead, you pass a number as an explicit parameter to a method, enclosing the number in parentheses after the method name:

```
double root = Math.sqrt(100);
```

A static method does not operate on an object.

This call makes it appear as if the `sqrt` method is applied to an object called `Math`. However, `Math` is a class, not an object. A method such as `Math.sqrt` that does not operate on any object is called a `static` method. (The term "static" is a historical holdover from the C and C++ programming languages. It has nothing to do with the usual meaning of the word.) In contrast, a method that is invoked on an object is class, is called an *instance method*:

```
harrysChecking.deposit(100); // deposit is an instance method
```

Static methods do not operate on objects, but they are still declared inside classes. When calling the method, you specify the class to which the `sqrt` method belongs—hence the call is `Math.sqrt(100)`.

How can you tell that `Math` is a class and not an object? By convention, class names start with an uppercase letter (such as `Math` or `BankAccount`). Objects and methods start with a lowercase letter (such as `harrysChecking` and `println`). Therefore, `harrysChecking.deposit(100)` denotes a call of the `deposit` method on the `harrysChecking` object inside the `System` class. On the other hand, `Math.sqrt(100)` denotes a call to the `sqrt` method inside the `Math` class.

This use of upper- and lowercase letters is merely a convention, not a rule of the Java language. It is, however, a convention that the authors of the Java class libraries follow consistently. You should do the same in your programs so that you don't confuse your fellow programmers.

Syntax 4.3 Static Method Call

Syntax *ClassName.methodName(parameters)*

Example

The class where the `pow` method is declared.

```
Math.pow(10, 3)
```

All parameters of a static method are explicit parameters.

SELF CHECK

12. Why can't you call `x.pow(y)` to compute x^y?

13. Is the call `System.out.println(4)` a static method call?

How To 4.1 Carrying Out Computations

Many programming problems require that you use mathematical formulas to compute values. This How To shows how to turn a problem statement into a sequence of mathematical formulas and, ultimately, a class in the Java programming language.

Step 1 Understand the problem: What are the inputs? What are the desired outputs?

For example, suppose you are asked to simulate a postage stamp vending machine. A customer inserts money into the vending machine. Then the customer pushes a "First class stamps" button. The vending machine gives out as many first-class stamps as the customer paid for. (A first-class stamp cost 44 cents at the time this book was written.) Finally, the customer pushes a "Penny stamps" button. The machine gives the change in penny (1-cent) stamps.

In this problem, there is one input:

- The amount of money the customer inserts

There are two desired outputs:

- The number of first-class stamps the machine returns
- The number of penny stamps the machine returns

Step 2 Work out examples by hand.

This is a very important step. If you can't compute a couple of solutions by hand, it's unlikely that you'll be able to write a program that automates the computation.

Let's assume that a first-class stamp costs 44 cents and the customer inserts $1.00. That's enough for two stamps (88 cents) but not enough for three stamps ($1.32). Therefore, the machine returns two first-class stamps and 12 penny stamps.

Step 3 Design a class that carries out your computations.

How To 3.1 explains how to develop a class by finding methods and instance variables. In our case, the problem statement yields three methods:

- `public void insert(int dollars)`
- `public int giveFirstClassStamps()`
- `public int givePennyStamps()`

A bigger challenge is to determine instance variables that describe the state of the machine. In this example, an excellent choice is to keep a single variable, the customer balance. (See Exercise P4.12 for another choice.)

That balance is incremented by the `insert` method and decremented by the `giveFirstClassStamps` and `givePennyStamps` methods.

Step 4 Write pseudocode for implementing the methods.

Given an amount of money and the price of a first-class stamp, how can you compute how many first-class stamps can be purchased with the money? Clearly, the answer is related to the quotient

$$\frac{\text{amount of money}}{\text{price of first-class stamp}}$$

For example, suppose the customer paid $1.00. Use a pocket calculator to compute the quotient: $1.00/$0.44 ≈ 2.27.

How do you get "2 stamps" out of 2.27? It's the integer part. In Java, this is easy to compute if both arguments are integers. Therefore, let's switch our computation to pennies. Then we have

```
number of first-class stamps = 100 / 44 (integer division, without remainder)
```

What if the user inputs two dollars? Then the numerator becomes 200. What if the price of a stamp goes up? A more general equation is

```
input in pennies = 100 x dollars
number of first-class stamps = input in pennies / price of first-class stamps in pennies (without remainder)
```

How about the remaining balance after dispensing the first class stamps? Here is one way of computing it. When the customer gets the stamps, the remaining balance is the original balance, reduced by the value of the stamps purchased. In our example, the remainder is 12 cents—the difference between 100 and 2 · 44. Here is the general formula:

```
remaining balance = input in pennies – number of first-class stamps x price of first-class stamp in pennies
```

Step 5 Implement the class.

In Step 3, we decided that the state of the vending machine can be represented by the customer balance. In Step 4, it became clear that the balance is best represented in pennies.

It is a good idea to rewrite the pseudocode in terms of this newly found variable. We now use the instance variable `balance` for what was previously called **input in pennies**. When money is inserted, the balance increases:

```
balance = balance + 100 * dollars
```

When the first class stamps are requested, the balance decreases.

```
firstClassStamps = balance / FIRST_CLASS_STAMP_PRICE;
balance = balance - firstClassStamps * FIRST_CLASS_STAMP_PRICE;
```

What was previously called **remaining balance** is now simply the value of the `balance` instance variable.

Here is the implementation of the `StampMachine` class:

```
public class StampMachine
{
   public static final double FIRST_CLASS_STAMP_PRICE = 44;
   private int balance;

   public StampMachine()
   {
      balance = 0;
   }

   public void insert(int dollars)
   {
      balance = balance + 100 * dollars;
   }

   public int giveFirstClassStamps()
   {
      int firstClassStamps = balance / FIRST_CLASS_STAMP_PRICE;
      balance = balance - firstClassStamps * FIRST_CLASS_STAMP_PRICE;
      return firstClassStamps;
   }

   public int givePennyStamps()
   {
      int pennyStamps = balance;
      balance = 0;
      return pennyStamps;
   }
}
```

Step 6 Test your class.

Run a test program (or use an integrated environment such as BlueJ) to verify that the values that your class computes are the same values that you computed by hand.

Here is a test program:

```
public class StampMachineTester
{
   public static void main(String[] args)
   {
      StampMachine machine = new StampMachine();
      machine.insert(1);
      System.out.print("First class stamps: ");
      System.out.println(machine.giveFirstClassStamps());
      System.out.println("Expected: 2");
      System.out.print("Penny stamps: ");
      System.out.println(machine.givePennyStamps());
      System.out.println("Expected: 12");
   }
}
```

Program Run

```
First class stamps: 2
Expected: 2
Penny stamps: 12
Expected: 12
```

Worked Example 4.1

Computing the Volume and Surface Area of a Pyramid

This Worked Example shows how to design a class for computing the volume and surface area of a pyramid.

4.5 Strings

Many programs process text that consists of characters: letters, numbers, punctuation, spaces, and so on. A string is a sequence of characters, such as `"Hello, World!"`. In the following sections, you will learn how to work with strings in Java.

4.5.1 The String Class

A string is a sequence of characters. Strings are objects of the `String` class.

In Java, strings are objects that belong to the class `String`. (You can tell that `String` is a class name because it starts with an uppercase letter. The primitive types `int` and `double` start with lowercase letters.)

You do not need to call a constructor to create a string object. You can obtain a string *literal* simply by enclosing a sequence of characters in double quotation marks. For example, the string literal `"Harry"` is an object of the `String` class.

The number of characters in a string is called the *length* of the string. As you have seen in Chapter 2, you can use the `length` method to obtain the length of a

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string. For example, `"Hello".length()` is 5, and the length of `"Hello, World!"` is 13. (The quotation marks are not part of the string and do not contribute to the length, but you must count spaces and punctuation marks.)

A string of length zero, containing no characters, is called the *empty string* and is written as `""`.

4.5.2 Concatenation

You can use the + operator to put strings together to form a longer string.

```
String name = "Dave";
String message = "Hello, " + name;
```

This process is called **concatenation**.

Strings can be concatenated, that is, put end to end to yield a new longer string. String concatenation is denoted by the + operator.

The + operator concatenates two strings, provided one of the expressions, either to the left or the right of a + operator, is a string. The other one is automatically forced to become a string as well, and both strings are concatenated.

For example, consider this code:

```
String a = "Agent";
int n = 7;
String bond = a + n;
```

Because `a` is a string, `n` is converted from the integer 7 to the string `"7"`. Then the two strings `"Agent"` and `"7"` are concatenated to form the string `"Agent7"`.

Whenever one of the arguments of the + operator is a string, the other argument is converted to a string.

This concatenation is very useful to reduce the number of `System.out.print` instructions. For example, you can combine

```
System.out.print("The total is ");
System.out.println(total);
```

to the single call

```
System.out.println("The total is " + total);
```

The concatenation `"The total is " + total` computes a single string that consists of the string `"The total is "`, followed by the string equivalent of the number `total`.

4.5.3 Converting Strings to Numbers

Sometimes you have a string that contains a number, usually from user input. For example, suppose that the string variable `input` has the value `"19"`. To get the integer value `19`, you use the static `parseInt` method of the `Integer` class.

```
int count = Integer.parseInt(input);
   // count is the integer 19
```

If a string contains the digits of a number, you use the `Integer.parseInt` or `Double.parseDouble` method to obtain the number value.

To convert a string containing floating-point digits to its floating-point value, use the static `parseDouble` method of the `Double` class. For example, suppose `input` is the string `"3.95"`.

```
double price = Double.parseDouble(input);
   // price is the floating-point number 3.95
```

However, if the string contains spaces or other characters that cannot occur inside numbers, an error occurs. For now, we will always assume that user input does not contain invalid characters.

4.5.4 Substrings

Use the substring method to extract a part of a string.

The `substring` method computes substrings of a string. The call

```
s.substring(start, pastEnd)
```

returns a string that is made up of the characters in the string `s`, starting at position `start`, and containing all characters up to, but not including, the position `pastEnd`. Here is an example:

```
String greeting = "Hello, World!";
String sub = greeting.substring(0, 5); // sub is "Hello"
```

String positions are counted starting with 0.

The `substring` operation makes a string that consists of five characters taken from the string `greeting`. A curious aspect of the `substring` operation is the numbering of the starting and ending positions. The first string position is labeled `0`, the second one 1, and so on. For example, Figure 3 shows the position numbers in the `greeting` string.

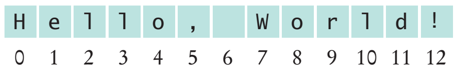

Figure 3
String Positions

The position number of the last character (12 for the string `"Hello, World!"`) is always 1 less than the length of the string.

Let us figure out how to extract the substring `"World"`. Count characters starting at `0`, not 1. You find that `W`, the eighth character, has position number 7. The first character that you don't want, `!`, is the character at position 12 (see Figure 4).

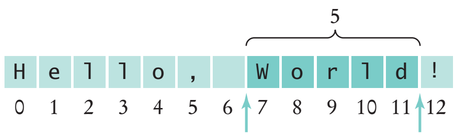

Figure 4
Extracting a Substring

Therefore, the appropriate substring command is

```
String sub2 = greeting.substring(7, 12);
```

It is curious that you must specify the position of the first character that you do want and then the first character that you don't want. There is one advantage to this setup. You can easily compute the length of the substring: It is `pastEnd - start`. For example, the string `"World"` has length 12 – 7 = 5.

If you omit the second parameter of the `substring` method, then all characters from the starting position to the end of the string are copied. For example,

```
String tail = greeting.substring(7); // Copies all characters from position 7 on
```

sets `tail` to the string `"World!"`.

If you supply an illegal string position (a negative number, or a value that is larger than the length of the string), then your program terminates with an error message.

In this section, we have made the assumption that each character in a string occupies a single position. Unfortunately, that assumption is not quite correct. If you process strings that contain characters from international alphabets or special symbols, some characters may occupy two positions—see Special Topic 4.5.

14. Assuming the `String` variable `s` holds the value `"Agent"`, what is the effect of the assignment `s = s + s.length()`?

15. Assuming the `String` variable `river` holds the value `"Mississippi"`, what is the value of `river.substring(1, 2)`? Of `river.substring(2, river.length() - 3)`?

Productivity Hint 4.1

Reading Exception Reports

You will often have programs that terminate and display an error message, such as

```
Exception in thread "main" java.lang.StringIndexOutOfBoundsException:
      String index out of range: -4
   at java.lang.String.substring(String.java:1444)
   at Homework1.main(Homework1.java:16)
```

An amazing number of students simply give up at that point, saying "it didn't work", or "my program died", without ever reading the error message. Admittedly, the format of the exception report is not very friendly. But it is actually easy to decipher it.

When you have a close look at the error message, you will notice two pieces of useful information:

1. The name of the exception, such as `StringIndexOutOfBoundsException`
2. The line number of the code that contained the statement that caused the exception, such as `Homework1.java:16`

The name of the exception is always in the first line of the report, and it ends in `Exception`. If you get a `StringIndexOutOfBoundsException`, then there was a problem with accessing an invalid position in a string. That is useful information.

The line number of the offending code is a little harder to determine. The exception report contains the entire stack trace—that is, the names of all methods that were pending when the exception hit. The first line of the stack trace is the method that actually generated the exception. The last line of the stack trace is a line in `main`. Often, the exception was thrown by a method that is in the standard library. Look for the first line in your code that appears in the exception report. For example, skip the line that refers to

```
java.lang.String.substring(String.java:1444)
```

The next line in our example mentions a line number in your code, `Homework1.java`. Once you have the line number in your code, open up the file, go to that line, and look at it! Also look at the name of the exception. In most cases, these two pieces of information will make it completely obvious what went wrong, and you can easily fix your error.

Special Topic 4.4

Escape Sequences

Special Topic 4.4 shows how you can embed special characters (such as quotation marks or line breaks) inside strings.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Special Topic 4.5

Strings and the `char` Type

Special Topic 4.5 discusses the `char` type. Strings are composed of code units of type `char`. For most programming tasks, you can simply use strings of length 1 instead of `char` values.

Random Fact 4.2

International Alphabets

Random Fact 4.2 explains how the Unicode character set provides an encoding for all characters that are in use around the world, including accented characters, scripts such as Hebrew or Thai, and tens of thousands of ideographs that are used in China, Japan, and Korea.

4.6 Reading Input

The Java programs that you have made so far have constructed objects, called methods, printed results, and exited. They were not interactive and took no user input. In this section, you will learn one method for reading user input.

Because output is sent to `System.out`, you might think that you use `System.in` for input. Unfortunately, it isn't quite that simple. When Java was first designed, not much attention was given to reading keyboard input. It was assumed that all programmers would produce graphical user interfaces with text fields and menus. `System.in` was given a minimal set of features—it can only read one byte at a time. Finally, in Java version 5, a `Scanner` class was added that lets you read keyboard input in a convenient manner.

Use the `Scanner` class to read keyboard input in a console window.

To construct a `Scanner` object, simply pass the `System.in` object to the `Scanner` constructor:

```
Scanner in = new Scanner(System.in);
```

You can create a scanner out of any input stream (such as a file), but you will usually want to use a scanner to read keyboard input from `System.in`.

Once you have a scanner, you use the `nextInt` or `nextDouble` methods to read the next integer or floating-point number.

```
System.out.print("Enter quantity: ");
int quantity = in.nextInt();

System.out.print("Enter price: ");
double price = in.nextDouble();
```

When the `nextInt` or `nextDouble` method is called, the program waits until the user types a number and hits the Enter key. You should always provide instructions for the user (such as `"Enter quantity:"`) before calling a `Scanner` method. Such an instruction is called a **prompt**.

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If the user supplies an input that is not a number, then a run-time exception occurs. You will see in the next chapter how you can check whether the user supplied a numeric input.

The `nextLine` method returns the next line of input (until the user hits the Enter key) as a `String` object. The `next` method returns the next *word*, terminated by any **white space**, that is, a space, the end of a line, or a tab.

```
System.out.print("Enter city: ");
String city = in.nextLine();

System.out.print("Enter state code: ");
String state = in.next();
```

Here, we use the `nextLine` method to read a city name that may consist of multiple words, such as `San Francisco`. We use the `next` method to read the state code (such as `CA`), which consists of a single word.

Here is an example of a program that takes user input. This program uses the `CashRegister` class and simulates a transaction in which a user purchases an item, pays for it, and receives change.

We call this class `CashRegisterSimulator`, not `CashRegisterTester`. We reserve the `Tester` suffix for classes whose sole purpose is to test other classes.

ch04/cashregister/CashRegisterSimulator.java

```java
import java.util.Scanner;

/**
   This program simulates a transaction in which a user pays for an item
   and receives change.
*/
public class CashRegisterSimulator
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      CashRegister register = new CashRegister();

      System.out.print("Enter price: ");
      double price = in.nextDouble();
      register.recordPurchase(price);

      System.out.print("Enter dollars: ");
      int dollars = in.nextInt();
      System.out.print("Enter quarters: ");
      int quarters = in.nextInt();
      System.out.print("Enter dimes: ");
      int dimes = in.nextInt();
      System.out.print("Enter nickels: ");
      int nickels = in.nextInt();
      System.out.print("Enter pennies: ");
      int pennies = in.nextInt();
      register.enterPayment(dollars, quarters, dimes, nickels, pennies);

      System.out.print("Your change: ");
      System.out.println(register.giveChange());
   }
}
```

Program Run

```
Enter price: 7.55
Enter dollars: 10
Enter quarters: 2
Enter dimes: 1
Enter nickels: 0
Enter pennies: 0
Your change: 3.05
```

SELF CHECK

16. Why can't input be read directly from `System.in`?

17. Suppose `in` is a `Scanner` object that reads from `System.in`, and your program calls

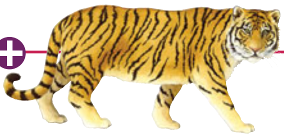
```
String name = in.next();
```

What is the value of `name` if the user enters `John Q. Public`?

Worked Example 4.2

Extracting Initials

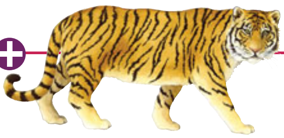
This Worked Example shows how to read names and print a set of corresponding initials.



Special Topic 4.6

Formatting Numbers

Special Topic 4.6 shows you how to control the number of digits after the decimal point when printing a number using the `printf` method. This is useful if you want to show a currency value rounded to two digits, such as 0.30 instead of 0.2975. Other options of the `printf` method are also discussed.



Special Topic 4.7

Using Dialog Boxes for Input and Output

Special Topic 4.7 shows how to use dialog boxes for reading input or displaying output.

Summary of Learning Objectives

Choose appropriate types for representing numeric data.

- Java has eight primitive types, including four integer types and two floating-point types.
- A numeric computation overflows if the result falls outside the range for the number type.
- Rounding errors occur when an exact conversion between numbers is not possible.

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Write code that uses constants to document the purpose of numeric values.

- A `final` variable is a constant. Once its value has been set, it cannot be changed.
- Use named constants to make your programs easier to read and maintain.

Write arithmetic expressions in Java.

- The `++` and `--` operators increment and decrement a variable.
- If both arguments of the `/` operator are integers, the result is an integer and the remainder is discarded.
- The `%` operator computes the remainder of a division.
- The `Math` class contains methods `sqrt` and `pow` to compute square roots and powers.
- You use a cast (*typeName*) to convert a value to a different type.
- Use the `Math.round` method to round a floating-point number to the nearest integer.

Distinguish between static methods and instance methods.

- A static method does not operate on an object.

Process strings in Java programs.

- A string is a sequence of characters. Strings are objects of the `String` class.
- Strings can be concatenated, that is, put end to end to yield a new longer string. String concatenation is denoted by the `+` operator.
- Whenever one of the arguments of the `+` operator is a string, the other argument is converted to a string.
- If a string contains the digits of a number, you use the `Integer.parseInt` or `Double.parseDouble` method to obtain the number value.
- Use the `substring` method to extract a part of a string.
- String positions are counted starting with `0`.

Write programs that read user input.

- Use the `Scanner` class to read keyboard input in a console window.

Classes, Objects, and Methods Introduced in this Chapter

```
java.io.PrintStream
   printf
java.lang.Double
   parseDouble
java.lang.Integer
   MAX_VALUE
   MIN_VALUE
   parseInt
   toString
java.lang.Math
   E
   PI
   abs
   acos
   asin
   atan
   atan2
   ceil
   cos
   exp
   floor
   log
   log10
   max
   min
   pow
   round
   sin
   sqrt
   tan
   toDegrees
   toRadians
java.lang.String
   format
   substring
java.lang.System
   in
java.math.BigDecimal
   add
   multiply
   subtract
java.math.BigInteger
   add
   multiply
   subtract
java.util.Scanner
   next
   nextDouble
   nextInt
   nextLine
javax.swing.JOptionPane
   showInputDialog
   showMessageDialog
```

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** Computing the Volume and Surface Area of a Pyramid
- ***Worked Example*** Extracting Initials
- Lab Exercises
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★★ **R4.1** Write the following mathematical expressions in Java.

$$s = s_0 + v_0 t + \frac{1}{2} g t^2$$

$$G = 4\pi^2 \frac{a^3}{P^2 (m_1 + m_2)}$$

$$\mathrm{FV} = \mathrm{PV} \cdot \left(1 + \frac{\mathrm{INT}}{100}\right)^{\mathrm{YRS}}$$

$$c = \sqrt{a^2 + b^2 - 2ab\cos\gamma}$$

★★ **R4.2** Write the following Java expressions in mathematical notation.

a. `dm = m * (Math.sqrt(1 + v / c) / (Math.sqrt(1 - v / c) - 1));`

b. `volume = Math.PI * r * r * h;`

c. `volume = 4 * Math.PI * Math.pow(r, 3) / 3;`

d. `p = Math.atan2(z, Math.sqrt(x * x + y * y));`

★★★ **R4.3** What is wrong with this version of the quadratic formula?

```
x1 = (-b - Math.sqrt(b * b - 4 * a * c)) / 2 * a;
x2 = (-b + Math.sqrt(b * b - 4 * a * c)) / 2 * a;
```

★★ **R4.4** Give an example of integer overflow. Would the same example work correctly if you used floating-point?

★★ **R4.5** Give an example of a floating-point roundoff error. Would the same example work correctly if you used integers and switched to a sufficiently small unit, such as cents instead of dollars, so that the values don't have a fractional part?

★★ **R4.6** Consider the following code:

```
CashRegister register = new CashRegister();
register.recordPurchase(19.93);
register.enterPayment(20, 0, 0, 0, 0);
System.out.print("Change: ");
System.out.println(register.giveChange());
```

The code segment prints the total as `0.07000000000000028`. Explain why. Give a recommendation to improve the code so that users will not be confused.

★ **R4.7** Let `n` be an integer and `x` a floating-point number. Explain the difference between

```
n = (int) x;
```

and

```
n = (int) Math.round(x);
```

★★★ **R4.8** Let `n` be an integer and `x` a floating-point number. Explain the difference between

```
n = (int) (x + 0.5);
```

and

```
n = (int) Math.round(x);
```

For what values of `x` do they give the same result? For what values of `x` do they give different results?

★ **R4.9** Consider the vending machine implementation in How To 4.1 on page 132. What happens if the `givePennyStamps` method is invoked before the `giveFirstClassStamps` method?

★ **R4.10** Explain the differences between `2`, `2.0`, `'2'`, `"2"`, and `"2.0"`.

★ **R4.11** Explain what each of the following two program segments computes:

```
int x = 2;
int y = x + x;
```

and

```
String s = "2";
String t = s + s;
```

★★ **R4.12** True or false? (`x` is an `int` and `s` is a `String`)

a. `Integer.parseInt("" + x)` is the same as `x`

b. `"" + Integer.parseInt(s)` is the same as `s`

c. `s.substring(0, s.length())` is the same as `s`

★★ **R4.13** How do you get the first character of a string? The last character? How do you remove the first character? The last character?

★★★ **R4.14** How do you get the last digit of an integer? The first digit? That is, if `n` is `23456`, how do you find out that the first digit is `2` and the last digit is `6`? Do not convert the number to a string. *Hint:* `%`, `Math.log`.

★★ **R4.15** This chapter contains several recommendations regarding variables and constants that make programs easier to read and maintain. Summarize these recommendations.

★★★ **R4.16** What is a `final` variable? Can you declare a `final` variable without supplying its value? (Try it out.)

★ **R4.17** What are the values of the following expressions? In each line, assume that

```
double x = 2.5;
double y = -1.5;
int m = 18;
int n = 4;
```

a. `x + n * y - (x + n) * y`

b. `m / n + m % n`

c. `5 * x - n / 5`
d. `Math.sqrt(Math.sqrt(n))`
e. `(int) Math.round(x)`
f. `(int) Math.round(x) + (int) Math.round(y)`
g. `1 - (1 - (1 - (1 - (1 - n))))`

★ **R4.18** What are the values of the following expressions? In each line, assume that

```
int n = 4;
String s = "Hello";
String t = "World";
```

a. `s + t`
b. `s + n`
c. `n + t`
d. `s.substring(1, n)`
e. `s.length() + t.length()`

Programming Exercises

★ **P4.1** Enhance the `CashRegister` class by adding separate methods `enterDollars`, `enterQuarters`, `enterDimes`, `enterNickels`, and `enterPennies`.

Use this tester class:

```
public class CashRegisterTester
{
   public static void main (String[] args)
   {
      CashRegister register = new CashRegister();
      register.recordPurchase(20.37);
      register.enterDollars(20);
      register.enterQuarters(2);
      System.out.println("Change: " + register.giveChange());
      System.out.println("Expected: 0.13");
   }
}
```

★ **P4.2** Enhance the `CashRegister` class so that it keeps track of the total number of items in a sale. Count all recorded purchases and supply a method

```
int getItemCount()
```

that returns the number of items of the current purchase. Remember to reset the count at the end of the purchase.

★★ **P4.3** Implement a class `IceCreamCone` with methods `getSurfaceArea()` and `getVolume()`. In the constructor, supply the height and radius of the cone. Be careful when looking up the formula for the surface area—you should only include the outside area along the side of the cone since the cone has an opening on the top to hold the ice cream.

★★ **P4.4** Write a program that prompts the user for two numbers, then prints

- The sum
- The difference
- The product

- The average
- The distance (absolute value of the difference)
- The maximum (the larger of the two)
- The minimum (the smaller of the two)

To do so, implement a class

```
public class Pair
{
   /**
      Constructs a pair.
      @param aFirst  the first value of the pair
      @param aSecond  the second value of the pair
   */
   public Pair(double aFirst, double aSecond) { . . . }

   /**
      Computes the sum of the values of this pair.
      @return  the sum of the first and second values
   */
   public double getSum() { . . . }
   . . .
}
```

Then implement a class `PairTester` that constructs a `Pair` object, invokes its methods, and prints the results.

★ **P4.5** Declare a class `DataSet` that computes the sum and average of a sequence of integers. Supply methods

- `void addValue(int x)`
- `int getSum()`
- `double getAverage()`

Hint: Keep track of the sum and the count of the values.

Then write a test program `DataSetTester` that calls `addValue` four times and prints the expected and actual results.

★★ **P4.6** Write a class `DataSet` that computes the largest and smallest values in a sequence of numbers. Supply methods

- `void addValue(int x)`
- `int getLargest()`
- `int getSmallest()`

Keep track of the smallest and largest values that you've seen so far. Then use the `Math.min` and `Math.max` methods to update them in the `addValue` method. What should you use as initial values? *Hint:* `Integer.MIN_VALUE`, `Integer.MAX_VALUE`.

Write a test program `DataSetTester` that calls `addValue` four times and prints the expected and actual results.

★ **P4.7** Write a program that prompts the user for a measurement in meters and then converts it into miles, feet, and inches. Use a class

```
public class Converter
{
      /**
         Constructs a converter that can convert between two units.
         @param aConversionFactor the factor by which to multiply
         to convert to the target unit
      */
      public Converter(double aConversionFactor) { . . . }

      /**
         Converts from a source measurement to a target measurement.
         @param fromMeasurement the measurement
         @return the input value converted to the target unit
      */
      public double convertTo(double fromMeasurement) { . . . }

      /**
         Converts from a target measurement to a source measurement.
         @param toMeasurement the target measurement
         @return the value whose conversion is the target measurement
      */
      public double convertFrom(double toMeasurement) { . . . }
   }
```

In your `ConverterTester` class, construct and test the following `Converter` object:

```
final double MILE_TO_KM = 1.609;
Converter milesToMeters = new Converter(1000 * MILE_TO_KM);
```

★ **P4.8** Write a class `Square` whose constructor receives the length of the sides. Then supply methods to compute

- The area and perimeter of the square
- The length of the diagonal (use the Pythagorean theorem)

★★ **P4.9** Implement a class `SodaCan` whose constructor receives the height and diameter of the soda can. Supply methods `getVolume` and `getSurfaceArea`. Supply a `SodaCanTester` class that tests your class.

★★★ **P4.10** Implement a class `Balloon` that models a spherical balloon that is being filled with air. The constructor constructs an empty balloon. Supply these methods:

- `void addAir(double amount)` adds the given amount of air
- `double getVolume()` gets the current volume
- `double getSurfaceArea()` gets the current surface area
- `double getRadius()` gets the current radius

Supply a `BalloonTester` class that constructs a balloon, adds 100 cm^3 of air, tests the three accessor methods, adds another 100 cm^3 of air, and tests the accessor methods again.

★★ **P4.11** *Giving change.* Enhance the `CashRegister` class so that it directs a cashier how to give change. The cash register computes the amount to be returned to the customer, in pennies. Add the following methods to the `CashRegister` class:

- `int giveDollars()`
- `int giveQuarters()`
- `int giveDimes()`
- `int giveNickels()`
- `int givePennies()`

Each method computes the number of dollar bills or coins to return to the customer, and reduces the change due by the returned amount. You may assume that the methods are called in this order. Here is a test class:

```
public class CashRegisterTester
{
   public static void main(String[] args)
   {
      CashRegister register = new CashRegister();

      register.recordPurchase(8.37);
      register.enterPayment(10, 0, 0, 0, 0);
      System.out.println("Dollars: " + register.giveDollars());
      System.out.println("Expected: 1");
      System.out.println("Quarters: " + register.giveQuarters());
      System.out.println("Expected: 2");
      System.out.println("Dimes: " + register.giveDimes());
      System.out.println("Expected: 1");
      System.out.println("Nickels: " + register.giveNickels());
      System.out.println("Expected: 0");
      System.out.println("Pennies: " + register.givePennies());
      System.out.println("Expected: 3");
   }
}
```

★★ **P4.12** In How To 4.1 on page 132, we represented the state of the vending machine by storing the balance in pennies. This is ingenious, but it is perhaps not the most obvious solution. Another possibility is to store the number of dollars that the customer inserted and the change that remains after giving out the first class stamps. Reimplement the vending machine in this way. Of course, the public interface should remain unchanged.

★★★ **P4.13** Write a program that reads in an integer and breaks it into a sequence of individual digits in reverse order. For example, the input 16384 is displayed as

```
4
8
3
6
1
```

You may assume that the input has no more than five digits and is not negative.

Declare a class `DigitExtractor`:

```
public class DigitExtractor
{
   /**
      Constructs a digit extractor that gets the digits
      of an integer in reverse order.
      @param anInteger the integer to break up into digits
   */
   public DigitExtractor(int anInteger) { . . . }

   /**
      Returns the next digit to be extracted.
      @return the next digit
   */
   public int nextDigit() { . . . }
}
```

In your main class `DigitPrinter`, call `System.out.println(myExtractor.nextDigit())` five times.

★★ **P4.14** Implement a class `QuadraticEquation` whose constructor receives the coefficients `a`, `b`, `c` of the quadratic equation $ax^2 + bx + c = 0$. Supply methods `getSolution1` and `getSolution2` that get the solutions, using the quadratic formula. Write a test class `QuadraticEquationTester` that constructs a `QuadraticEquation` object, and prints the two solutions.

★★★ **P4.15** Write a program that reads two times in military format (0900, 1730) and prints the number of hours and minutes between the two times. Here is a sample run. User input is in color.

```
Please enter the first time: 0900
Please enter the second time: 1730
8 hours 30 minutes
```

Extra credit if you can deal with the case where the first time is later than the second:

```
Please enter the first time: 1730
Please enter the second time: 0900
15 hours 30 minutes
```

Implement a class `TimeInterval` whose constructor takes two military times. The class should have two methods `getHours` and `getMinutes`.

★ **P4.16** *Writing large letters.* A large letter `H` can be produced like this:

```
*   *
*   *
*****
*   *
*   *
```

Use the class

```
public class LetterH
{
   public String toString()
   {
      return "*   *\n*   *\n*****\n*   *\n*   *\n";
   }
}
```

Declare similar classes for the letters `E`, `L`, and `O`. Then write the message

```
H
E
L
L
O
```

in large letters.

★★ **P4.17** Write a class `ChristmasTree` whose `toString` method yields a string depicting a Christmas tree:

```
   /\
  /  \
 /    \
/      \
--------
  "  "
  "  "
  "  "
```

Remember to use escape sequences.

★★ **P4.18** Your job is to transform numbers `1`, `2`, `3`, . . ., `12` into the corresponding month names `January`, `February`, `March`, . . ., `December`. Implement a class `Month` whose constructor parameter is the month number and whose `getName` method returns the month name. *Hint:* Make a very long string `"January February March . . . "`, in which you add spaces such that each month name has the same length. Then use `substring` to extract the month you want.

★★ **P4.19** Write a class to compute the date of Easter Sunday. Easter Sunday is the first Sunday after the first full moon of spring. Use this algorithm, invented by the mathematician Carl Friedrich Gauss in 1800:

1. Let `y` be the year (such as 1800 or 2001).
2. Divide `y` by `19` and call the remainder `a`. Ignore the quotient.
3. Divide `y` by `100` to get a quotient `b` and a remainder `c`.
4. Divide `b` by `4` to get a quotient `d` and a remainder `e`.
5. Divide `8 * b + 13` by `25` to get a quotient `g`. Ignore the remainder.
6. Divide `19 * a + b - d - g + 15` by `30` to get a remainder `h`. Ignore the quotient.
7. Divide `c` by `4` to get a quotient `j` and a remainder `k`.
8. Divide `a + 11 * h` by `319` to get a quotient `m`. Ignore the remainder.
9. Divide `2 * e + 2 * j - k - h + m + 32` by `7` to get a remainder `r`. Ignore the quotient.
10. Divide `h - m + r + 90` by `25` to get a quotient `n`. Ignore the remainder.
11. Divide `h - m + r + n + 19` by `32` to get a remainder `p`. Ignore the quotient.

Then Easter falls on day `p` of month `n`. For example, if `y` is `2001`:

```
a = 6               g = 6               r = 6
b = 20              h = 18              n = 4
c = 1               j = 0, k = 1        p = 15
d = 5, e = 0        m = 0
```

Therefore, in 2001, Easter Sunday fell on April 15. Write a class `Easter` with methods `getEasterSundayMonth` and `getEasterSundayDay`.

Programming Projects

Project 4.1 In this project, you will perform calculations with triangles. A triangle is defined by the *x*- and *y*-coordinates of its three corner points.

Your job is to compute the following properties of a given triangle:

- the lengths of all sides
- the angles at all corners
- the perimeter
- the area

Of course, you should implement a `Triangle` class with appropriate methods. Supply a program that prompts a user for the corner point coordinates and produces a nicely formatted table of the triangle properties.

This is a good team project for two students. Both students should agree on the `Triangle` interface. One student implements the `Triangle` class, the other simultaneously implements the user interaction and formatting.

Project 4.2 The `CashRegister` class has an unfortunate limitation: It is closely tied to the coin system in the United States and Canada. Research the system used in most of Europe. Your goal is to produce a cash register that works with euros and cents. Rather than designing another limited `CashRegister` implementation for the European market, you should design a separate `Coin` class and a cash register that can work with coins of all types.

Answers to Self-Check Questions

1. `int` and `double`.
2. The world's most populous country, China, has about 1.2 x 10^9 inhabitants. Therefore, individual population counts could be held in an `int`. However, the world population is over 6×10^9. If you compute totals or averages of multiple countries, you can exceed the largest `int` value. Therefore, `double` is a better choice. You could also use `long`, but there is no benefit because the exact population of a country is not known at any point in time.
3. The first initialization is incorrect. The right hand side is a value of type `double`, and it is not legal to initialize an `int` variable with a `double` value. The second initialization is correct—an `int` value can always be converted to a `double`.
4. The first declaration is used inside a method, the second inside a class.
5. (1) You should use a named constant, not the "magic number" 3.14.
   (2) 3.14 is not an accurate representation of π.
6. One less than it was before.
7. 17 and 29.
8. Only `s3` is divided by 3. To get the correct result, use parentheses. Moreover, if `s1`, `s2`, and `s3` are integers, you must divide by `3.0` to avoid integer division:

   ```
   (s1 + s2 + s3) / 3.0
   ```
9. $\sqrt{x^2 + y^2}$
10. When the fractional part of `x` is ≥ 0.5.
11. By using a cast: `(int) Math.round(x)`.
12. `x` is a number, not an object, and you cannot invoke methods on numbers.
13. No—the `println` method is called on the object `System.out`.
14. `s` is set to the string "`Agent5`".
15. The strings `"i"` and `"ssissi"`.
16. The class only has a method to read a single byte. It would be very tedious to form characters, strings, and numbers from those bytes.
17. The value is `"John"`. The `next` method reads the next *word*.

Chapter 5

Decisions

CHAPTER GOALS

- To be able to implement decisions using `if` statements
- To effectively group statements into blocks
- To learn how to compare integers, floating-point numbers, strings, and objects
- To correctly order decisions in multiple branches and nested branches
- To program conditions using Boolean operators and variables

T To be able to design tests that cover all parts of a program

The programs we have seen so far were able to do fast computations and render graphs, but they were very inflexible. Except for variations in the input, they worked the same way with every program run. One of the essential features of nontrivial computer programs is their ability to make decisions and to carry out different actions, depending on the nature of the inputs. The goal of this chapter is to learn how to program simple and complex decisions.

CHAPTER CONTENTS

5.1 The if Statement 152

SYNTAX 5.1: The if Statement 154

QUALITY TIP 5.1: Brace Layout 154

PRODUCTIVITY HINT 5.1: Indentation and Tabs 155

COMMON ERROR 5.1: A Semicolon After the if Condition 156

SPECIAL TOPIC 5.1: The Conditional Operator ⊕

5.2 Comparing Values 156

SYNTAX 5.2: Comparisons 158

COMMON ERROR 5.2: Using == to Compare Strings 160

QUALITY TIP 5.2: Avoid Conditions with Side Effects 162

HOW TO 5.1: Implementing an if Statement 163

WORKED EXAMPLE 5.1: Extracting the Middle ⊕

5.3 Multiple Alternatives 165

SPECIAL TOPIC 5.2: The switch Statement ⊕

COMMON ERROR 5.3: The Dangling else Problem 170

PRODUCTIVITY HINT 5.2: Hand-Tracing 171

PRODUCTIVITY HINT 5.3: Make a Schedule and Make Time for Unexpected Problems 172

SPECIAL TOPIC 5.3: Enumeration Types ⊕

SYNTAX 5.3: Declaring an Enumeration Type ⊕

5.4 Using Boolean Expressions 173

COMMON ERROR 5.4: Multiple Relational Operators 176

COMMON ERROR 5.5: Confusing && and || Conditions 177

SPECIAL TOPIC 5.4: Lazy Evaluation of Boolean Operators ⊕

SPECIAL TOPIC 5.5: De Morgan's Law ⊕

RANDOM FACT 5.1: Artificial Intelligence ⊕

5.5T Code Coverage 178

QUALITY TIP 5.3: Calculate Sample Data Manually 179

QUALITY TIP 5.4: Prepare Test Cases Ahead of Time 179

SPECIAL TOPIC 5.6: Logging 180

5.1 The if Statement

Computer programs often need to make *decisions*, taking different actions depending on a condition.

Consider the bank account class of Chapter 3. The withdraw method allows you to withdraw as much money from the account as you like. The balance just moves ever further into the negatives. That is not a realistic model for a bank account. Let's implement the withdraw method so that you cannot withdraw more money than you have in the account. That is, the withdraw method must make a *decision:* whether to allow the withdrawal or not.

The if statement lets a program carry out different actions depending on a condition.

The if statement is used to implement a decision. The if statement has two parts: a condition and a body. If the *condition* is true, the *body* of the statement is executed. The body of the if statement consists of a statement:

```
if (amount <= balance)  // Condition
   balance = balance - amount;  // Body
```

The assignment statement is carried out only when the amount to be withdrawn is less than or equal to the balance (see Figure 1).

Let us make the withdraw method of the BankAccount class even more realistic. Most banks not only disallow withdrawals that exceed your account balance; they also charge you a penalty for every attempt to do so.

This operation can't be programmed simply by providing two complementary if statements, such as:

```
if (amount <= balance)
   balance = balance - amount;
if (amount > balance) // Use if/else instead
   balance = balance - OVERDRAFT_PENALTY;
```

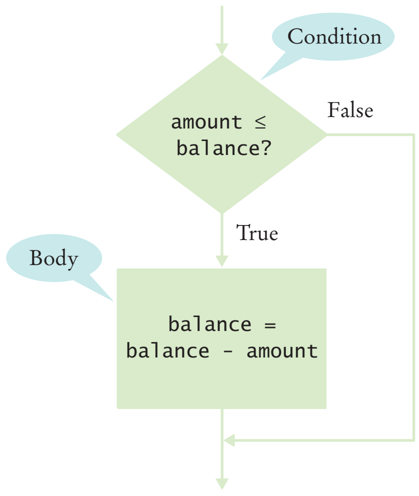


Figure 1
Flowchart for an `if` Statement

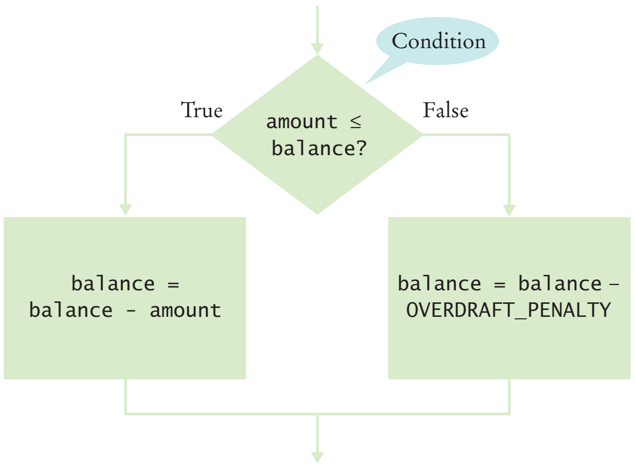

Condition
True
False
amount ≤ balance?
balance = balance - amount
balance = balance - OVERDRAFT_PENALTY

Figure 2
Flowchart for an `if/else` Statement

There are two problems with this approach. First, if you need to modify the condition `amount <= balance` for some reason, you must remember to update the condition `amount > balance` as well. If you do not, the logic of the program will no longer be correct. More importantly, if you modify the value of `balance` in the body of the first `if` statement (as in this example), then the second condition uses the new value.

To implement a choice between alternatives, use the `if/else` statement:

```
if (amount <= balance)
   balance = balance - amount;
else
   balance = balance - OVERDRAFT_PENALTY;
```

Now there is only one condition. If it is satisfied, the first statement is executed. Otherwise, the second is executed. The flowchart in Figure 2 gives a graphical representation of the branching behavior.

A block statement groups several statements together.

Quite often, however, the body of the `if` statement consists of multiple statements that must be executed in sequence whenever the condition is true. These statements must be grouped together to form a **block** statement by enclosing them in braces `{ }`. Here is an example.

```
if (amount <= balance)
{
   double newBalance = balance - amount;
   balance = newBalance;
}
```

In general, the body of an `if` statement must be a block statement, a *simple* statement, such as

```
balance = balance - amount;
```

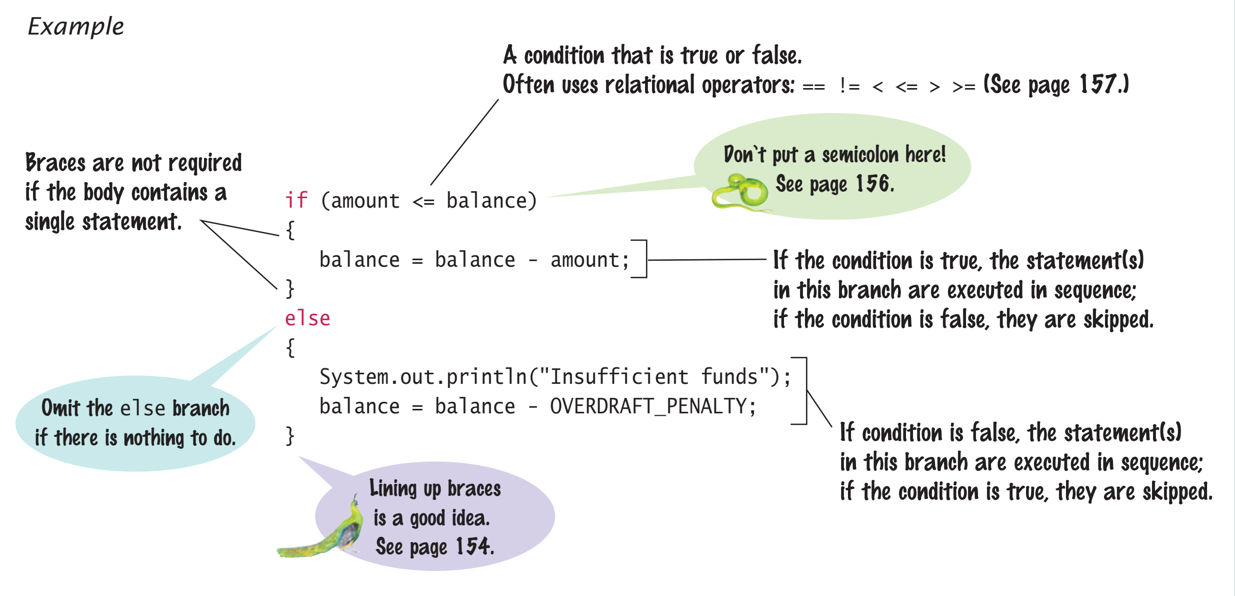
or a *compound* statement (another `if` statement or a loop—see Chapter 6). The `else` alternative also must be a statement—that is, a simple statement, a compound statement, or a block statement.

Syntax 5.1 The if Statement

Syntax

```
if (condition)
   statement

if (condition)
   statement1
else
   statement2
```

Example



```
if (amount <= balance)
{
   balance = balance - amount;
}
else
{
   System.out.println("Insufficient funds");
   balance = balance - OVERDRAFT_PENALTY;
}
```

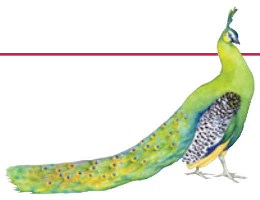
A condition that is true or false.
Often uses relational operators: == != < <= > >= (See page 157.)
Braces are not required if the body contains a single statement.
Don't put a semicolon here! See page 156.
If the condition is true, the statement(s) in this branch are executed in sequence; if the condition is false, they are skipped.
Omit the else branch if there is nothing to do.
If condition is false, the statement(s) in this branch are executed in sequence; if the condition is true, they are skipped.
Lining up braces is a good idea. See page 154.

SELF CHECK

1. Why did we use the condition `amount <= balance` and not `amount < balance` in the example for the `if/else` statement?
2. What is logically wrong with the statement

   ```
   if (amount <= balance)
      newBalance = balance - amount; balance = newBalance;
   ```

   and how do you fix it?



Quality Tip 5.1

Brace Layout

The compiler doesn't care where you place braces, but we strongly recommend that you follow a simple rule: *Line up* { and }.

```
if (amount <= balance)
{
   double newBalance = balance - amount;
   balance = newBalance;
}
```

This scheme makes it easy to spot matching braces.

Some programmers put the opening brace on the same line as the `if`:

```
if (amount <= balance) {
   double newBalance = balance - amount;
   balance = newBalance;
}
```

This saves a line of code, but it makes it harder to match the braces.

It is important that you pick a layout scheme and stick with it. Which scheme you choose may depend on your personal preference or a coding style guide that you must follow.

Productivity Hint 5.1

Indentation and Tabs

When writing Java programs, use indentation to indicate nesting levels:

```
public class BankAccount
{
|  . . .
|  public void withdraw(double amount)
|  {
|  |  if (amount <= balance)
|  |  {
|  |  |  double newBalance = balance - amount;
|  |  |  balance = newBalance;
|  |  }
|  }
|  . . .
}
0  1  2  3
Indentation level
```

How many spaces should you use per indentation level? Some programmers use eight spaces per level, but that isn't a good choice:

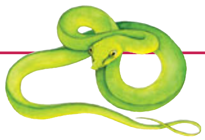
```
public class BankAccount
{
        . . .
        public void withdraw(double amount)
        {
                if (amount <= balance)
                {
                        double newBalance =
                                balance - amount;
                        balance = newBalance;
                }
        }
        . . .
}
```

It crowds the code too much to the right side of the screen. As a consequence, long expressions frequently must be broken into separate lines. More common values are two, three, or four spaces per indentation level.

How do you move the cursor from the leftmost column to the appropriate indentation level? A perfectly reasonable strategy is to hit the space bar a sufficient number of times. However, many programmers use the Tab key instead. A tab moves the cursor to the next tab stop. By default, there are tab stops every eight columns, but most editors let you change that value; you should find out how to set your editor's tab stops to, say, every three columns.

Some editors help you out with an *autoindent* feature. They automatically insert as many tabs or spaces as the preceding line because the new line is quite likely to belong to the same logical indentation level. If it isn't, you must add or remove a tab, but that is still faster than tabbing all the way from the left margin.

While the Tab *key* is nice, some editors use *tab characters* for alignment, which is not so nice. Tab characters can lead to problems when you send your file to another person or a printer. There is no universal agreement on the width of a tab character, and some software will ignore tab characters altogether. It is therefore best to save your files with spaces instead of tabs. Most editors have settings to automatically convert all tabs to spaces. Look at your development environment's documentation to find out how to activate this useful setting.



Common Error 5.1

A Semicolon After the if Condition

The following code fragment has an unfortunate error:

```
if (input < 0) ; // ERROR
   System.out.println("Bad input");
```

There should be no semicolon after the `if` condition. The compiler interprets this statement as follows: If `input` is less than `0`, execute the statement that is denoted by a single semicolon, that is, the do-nothing statement. The statement that follows the semicolon is no longer a part of the `if` statement. It is always executed—the error message appears for all inputs.

Special Topic 5.1

The Conditional Operator

Special Topic 5.1 discusses the `? :` conditional operator for conditions inside expressions.

5.2 Comparing Values

5.2.1 Relational Operators

Relational operators compare values. The == operator tests for equality.

A **relational operator** tests the relationship between two values. An example is the `<=` operator that we used in the test

```
if (amount <= balance)
```

Java has six relational operators, as shown in the table on page 157.

As you can see, only two relational operators (> and <) look as you would expect from the mathematical notation. Computer keyboards do not have keys for ≥, ≤, or ≠, but the `>=`, `<=`, and `!=` operators are easy to remember because they look similar.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Java	Math Notation	Description
`>`	$>$	Greater than
`>=`	$\geq$	Greater than or equal
`<`	$<$	Less than
`<=`	$\leq$	Less than or equal
`==`	$=$	Equal
`!=`	$\neq$	Not equal

The `==` operator is initially confusing to most newcomers to Java. In Java, the `=` symbol already has a meaning, namely assignment. The `==` operator denotes equality testing:

```
a = 5; // Assign 5 to a
if (a == 5) . . . // Test whether a equals 5
```

You will have to remember to use `==` for equality testing, and to use `=` for assignment.

The relational operators have a lower precedence than the arithmetic operators. That means, you can write arithmetic expressions on either side of the relational operator without using parentheses. For example, in the expression

```
amount + fee <= balance
```

both sides (`amount + fee` and `balance`) of the < operator are evaluated, and the results are compared. Appendix B shows a table of the Java operators and their precedence.

5.2.2 Comparing Floating-Point Numbers

You have to be careful when comparing floating-point numbers, in order to cope with roundoff errors. For example, the following code multiplies the square root of 2 by itself and then subtracts 2.

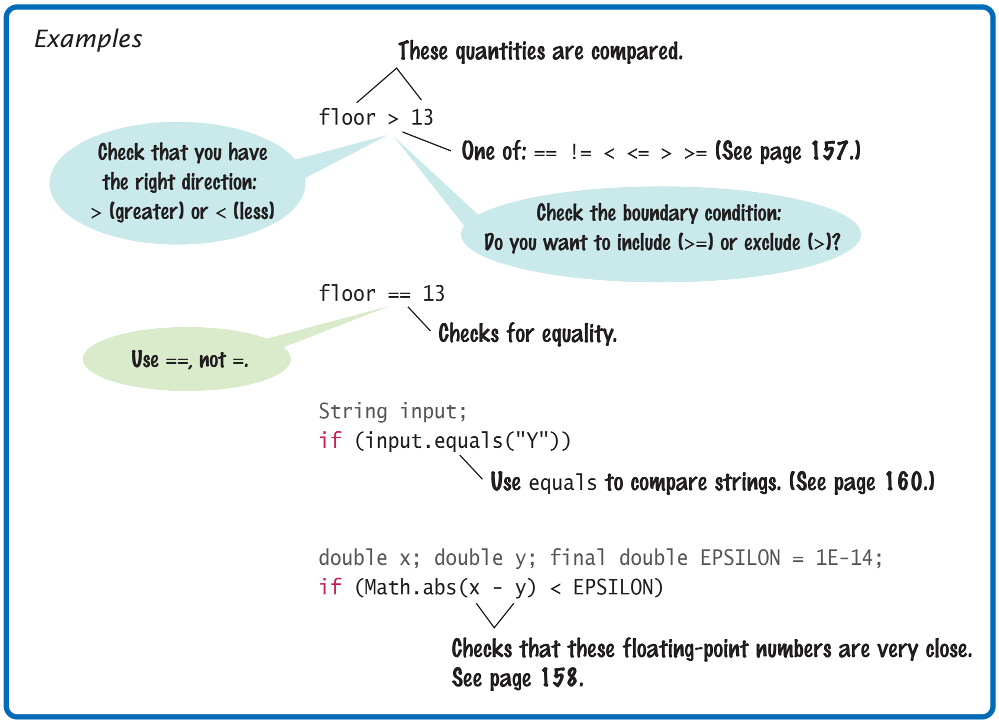
```
double r = Math.sqrt(2);
double d = r * r - 2;
if (d == 0)
   System.out.println("sqrt(2) squared minus 2 is 0");
else
   System.out.println(
      "sqrt(2) squared minus 2 is not 0 but " + d);
```

Even though the laws of mathematics tell us that $\left(\sqrt{2}\right)^2 - 2$ equals `0`, this program fragment prints

```
sqrt(2) squared minus 2 is not 0 but 4.440892098500626E-16
```

Unfortunately, such roundoff errors are unavoidable. It plainly does not make sense in most circumstances to compare floating-point numbers exactly. Instead, test whether they are *close enough*.

Syntax 5.2 Comparisons


Examples
These quantities are compared.
Check that you have the right direction: > (greater) or < (less)
One of: == != < <= > >= (See page 157.)
Check the boundary condition: Do you want to include (>=) or exclude (>)?
Checks for equality.
Use ==, not =.
Use equals to compare strings. (See page 160.)
Checks that these floating-point numbers are very close. See page 158.

```
floor > 13

floor == 13

String input;
if (input.equals("Y"))

double x; double y; final double EPSILON = 1E-14;
if (Math.abs(x - y) < EPSILON)
```

When comparing floating-point numbers, don't test for equality. Instead, check whether they are close enough.

To test whether a number x is close to zero, you can test whether the absolute value $|x|$ (that is, the number with its sign removed) is less than a very small threshold number. That threshold value is often called ε (the Greek letter epsilon). It is common to set ε to 10^{-14} when testing `double` numbers.

Similarly, you can test whether two numbers are approximately equal by checking whether their difference is close to 0.

$$|x - y| \le \varepsilon$$

In Java, we program the test as follows:

```
final double EPSILON = 1E-14;
if (Math.abs(x - y) <= EPSILON)
   // x is approximately equal to y
```

5.2.3 Comparing Strings

To test whether two strings are equal to each other, you must use the method called `equals`:

```
if (string1.equals(string2)) . . .
```

Do not use the == operator to compare strings. Use the equals method instead.

Do not use the `==` operator to compare strings. The expression

```
if (string1 == string2) // Not useful
```

has an unrelated meaning. It tests whether the two string variables refer to the identical string object. You can have strings with identical contents stored in different objects, so this test never makes sense in actual programming; see Common Error 5.2 on page 160.

In Java, letter case matters. For example, "Harry" and "HARRY" are not the same string. To ignore the letter case, use the equalsIgnoreCase method:

```
if (string1.equalsIgnoreCase(string2)) . . .
```

The compareTo method compares strings in dictionary order.

If two strings are not identical to each other, you still may want to know the relationship between them. The compareTo method compares strings in dictionary order. If

```
string1.compareTo(string2) < 0
```

then the string string1 comes before the string string2 in the dictionary. For example, this is the case if string1 is "Harry", and string2 is "Hello". If

```
string1.compareTo(string2) > 0
```

then string1 comes after string2 in dictionary order. Finally, if

```
string1.compareTo(string2) == 0
```

then string1 and string2 are equal.

Table 1 Relational Operator Examples

Expression	Value	Comment
`3 <= 4`	`true`	3 is less than 4; <= tests for "less than or equal".
🚫 `3 =< 4`	**Error**	The "less than or equal" operator is <=, not =<, with the "less than" symbol first.
`3 > 4`	`false`	> is the opposite of <=.
`4 < 4`	`false`	The left-hand side must be strictly smaller than the right-hand side.
`4 <= 4`	`true`	Both sides are equal; <= tests for "less than or equal".
`3 == 5 - 2`	`true`	== tests for equality.
`3 != 5 - 1`	`true`	!= tests for inequality. It is true that 3 is not 5 – 1.
🚫 `3 = 6 / 2`	**Error**	Use == to test for equality.
`1.0 / 3.0 == 0.333333333`	`false`	Although the values are very close to one another, they are not exactly equal. See Common Error 4.3.
🚫 `"10" > 5`	**Error**	You cannot compare a string to a number.
`"Tomato".substring(0, 3).equals("Tom")`	`true`	Always use the equals method to check whether two strings have the same contents.
`"Tomato".substring(0, 3) == ("Tom")`	`false`	Never use == to compare strings; it only checks whether the strings are stored in the same location. See Common Error 5.2 on page 160.
`"Tom".equalsIgnoreCase("TOM")`	`true`	Use the equalsIgnoreCase method if you don't want to distinguish between uppercase and lowercase letters.

Actually, the "dictionary" ordering used by Java is slightly different from that of a normal dictionary. Java is case sensitive and sorts characters by putting numbers first, then uppercase characters, then lowercase characters. For example, `1` comes before `B`, which comes before `a`. The space character comes before all other characters.

Let us investigate the comparison process closely. When Java compares two strings, corresponding letters are compared until one of the strings ends or the first difference is encountered. If one of the strings ends, the longer string is considered the later one. If a character mismatch is found, the characters are compared to determine which string comes later in the dictionary sequence. This process is called lexicographic comparison. For example, let's compare `"car"` with `"cargo"`. The first three letters match, and we reach the end of the first string. Therefore `"car"` comes before `"cargo"` in the lexicographic ordering. Now compare `"cathode"` with `"cargo"`. The first two letters match. In the third character position, `t` comes after `r`, so the string `"cathode"` comes after `"cargo"` in lexicographic ordering. (See Figure 3.)

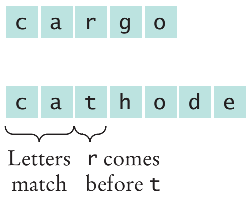


Figure 3
Lexicographic Comparison

Common Error 5.2

Using == to Compare Strings

It is an extremely common error in Java to write `==` when `equals` is intended. This is particularly true for strings. If you write

```
if (nickname == "Rob")
```

then the test succeeds only if the variable `nickname` refers to the exact same string object as the string constant `"Rob"`. For efficiency, Java makes only one string object for every string constant. Therefore, the following test will pass:

```
String nickname = "Rob";
. . .
if (nickname == "Rob") // Test is true
```

However, if the string with the letters `R o b` has been assembled in some other way, then the test will fail:

```
String name = "Robert";
String nickname = name.substring(0, 3);
. . .
if (nickname == "Rob") // Test is false
```

This is a particularly distressing situation: The wrong code will sometimes do the right thing, sometimes the wrong thing. Because string objects are always constructed by the compiler, you never have an interest in whether two string objects are shared. You must remember never to use `==` to compare strings. Always use `equals` or `compareTo` to compare strings.

5.2.4 Comparing Objects

If you compare two object references with the == operator, you test whether the references refer to the same object. Here is an example:

```
Rectangle box1 = new Rectangle(5, 10, 20, 30);
Rectangle box2 = box1;
Rectangle box3 = new Rectangle(5, 10, 20, 30);
```

The comparison

```
box1 == box2
```

is `true`. Both object variables refer to the same object. But the comparison

```
box1 == box3
```

is `false`. The two object variables refer to different objects (see Figure 4). It does not matter that the objects have identical contents.

The == operator tests whether two object references are identical. To compare the contents of objects, you need to use the `equals` method.

You can use the `equals` method to test whether two rectangles have the same contents, that is, whether they have the same upper-left corner and the same width and height. For example, the test

```
box1.equals(box3)
```

is true.

However, you must be careful when using the `equals` method. It works correctly only if the implementors of the class have supplied it. The `Rectangle` class has an `equals` method that is suitable for comparing rectangles.

For your own classes, you need to supply an appropriate `equals` method. You will learn how to do that in Chapter 10. Until that point, you should not use the `equals` method to compare objects of your own classes.

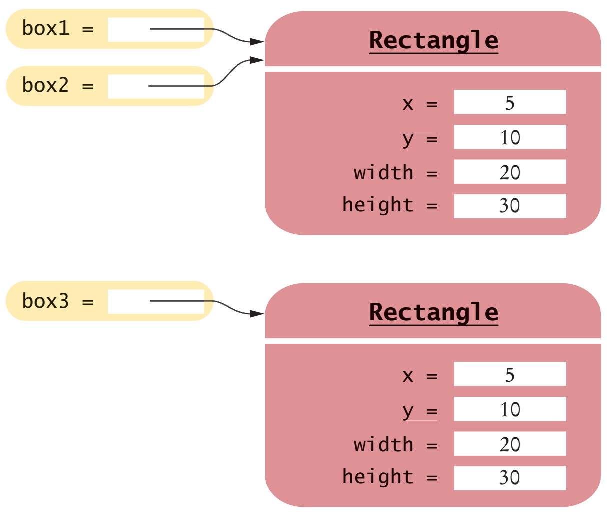


Figure 4 Comparing Object References

5.2.5 Testing for `null`

The `null` reference refers to no object.

An object reference can have the special value `null` if it refers to no object at all. It is common to use the `null` value to indicate that a value has never been set. For example,

```
String middleInitial = null; // Not set
if ( . . . )
   middleInitial = middleName.substring(0, 1);
```

You use the `==` operator (and not `equals`) to test whether an object reference is a `null` reference:

```
if (middleInitial == null)
   System.out.println(firstName + " " + lastName);
else
   System.out.println(firstName + " " + middleInitial + ". " + lastName);
```

Note that the `null` reference is not the same as the empty string `""`. The empty string is a valid string of length 0, whereas a `null` indicates that a string variable refers to no string at all.

SELF CHECK

3. What is the value of `s.length()` if `s` is
   a. the empty string `""`?
   b. the string `" "` containing a space?
   c. `null`?

4. Which of the following comparisons are syntactically incorrect? Which of them are syntactically correct, but logically questionable?

```
String a = "1";
String b = "one";
double x = 1;
double y = 3 * (1.0 / 3);
```

   a. `a == "1"`
   b. `a == null`
   c. `a.equals("")`
   d. `a == b`
   e. `a == x`
   f. `x == y`
   g. `x - y == null`
   h. `x.equals(y)`

Quality Tip 5.2

Avoid Conditions with Side Effects

In Java, it is legal to nest assignments inside test conditions:

```
if ((d = b * b - 4 * a * c) >= 0) r = Math.sqrt(d);
```

It is legal to use the decrement operator inside other expressions:

```
if (n-- > 0) . . .
```

These are bad programming practices, because they mix a test with another activity. The other activity (setting the variable `d`, decrementing `n`) is called a **side effect** of the test.

As you will see in Special Topic 6.3, conditions with side effects can occasionally be helpful to simplify loops; for `if` statements they should always be avoided.

How To 5.1 Implementing an `if` Statement

This How To walks you through the process of implementing an `if` statement. We will illustrate the steps with the following example problem:

The university bookstore has a Kilobyte Day sale every October 24, giving an 8 percent discount on all computer accessory purchases if the price is less than $128, and a 16 percent discount if the price is at least $128. Write a program that asks the cashier for the original price and then prints the discounted price.

Step 1 In our sample problem, the obvious choice for the condition is:

```
original price < 128?
```

That is just fine, and we will use that condition in our solution.

But you could equally well come up with a correct solution if you choose the opposite condition: Is the original price at least $128? You might choose this condition if you put yourself into the position of a shopper who wants to know when the bigger discount applies.

Step 2 Give pseudocode for the work that needs to be done when the condition is fulfilled.

In this step, you list the action or actions that are taken in the "positive" branch. The details depend on your problem. You may want to print a message, compute values, or even exit the program.

In our example, we need to apply an 8 percent discount:

```
discounted price = 0.92 x original price
```

Step 3 Give pseudocode for the work (if any) that needs to be done when the condition is *not* fulfilled.

What do you want to do in the case that the condition of Step 1 is not fulfilled? Sometimes, you want to do nothing at all. In that case, use an `if` statement without an `else` branch.

In our example, the condition tested whether the price was less than $128. If that condition is *not* fulfilled, the price is at least $128, so the higher discount of 16 percent applies to the sale:

```
discounted price = 0.84 x original price
```

Step 4 Double-check relational operators.

First, be sure that the test goes in the right *direction*. It is a common error to confuse > and <. Next, consider whether you should use the < operator or its close cousin, the <= operator.

What should happen if the original price is exactly $128? Reading the problem carefully, we find that the lower discount applies if the original price is *less than* $128, and the higher discount applies when it is *at least* $128. A price of $128 should therefore *not* fulfill our condition, and we must use <, not <=.

Step 5 Remove duplication.

Check which actions are common to both branches, and move them outside. (See Quality Tip 4.3.)

In our example, we have two statements of the form

```
discounted price = ___ x original price
```

They only differ in the discount rate. It is best to just set the rate in the branches, and to do the computation afterwards:

```
If original price < 128
    discount rate = 0.92
Else
    discount rate = 0.84
discounted price = discount rate x original price
```

Step 6 Test both branches.

Formulate two test cases, one that fulfills the condition of the `if` statement, and one that does not. Ask yourself what should happen in each case. Then follow the pseudocode and act each of them out.

In our example, let us consider two scenarios for the original price: $100 and $200. We expect that the first price is discounted by $8, the second by $32.

When the original price is 100, then the condition 100 < 128 is true, and we get

```
discount rate = 0.92
discounted price = 0.92 x 100 = 92
```

When the original price is 200, then the condition 200 < 128 is false, and

```
discount rate = 0.84
discounted price = 0.84 x 200 = 168
```

In both cases, we get the expected answer.

Step 7 Assemble the `if` statement in Java.

Type the skeleton

```
if ()
{
}
else
{
}
```

and fill it in, as shown in Syntax 5.1 on page 154. Omit the `else` branch if it is not needed.

In our example, the completed statement is

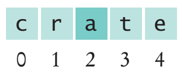
```
double HIGH_DISCOUNT_THRESHOLD = 128;
double HIGH_DISCOUNT = 0.92;
double LOW_DISCOUNT = 0.84;

if (originalPrice < HIGH_DISCOUNT_THRESHOLD)
{
   discountRate = HIGH_DISCOUNT;
}
else
{
   discountRate = LOW_DISCOUNT;
}
discountedPrice = discountRate * originalPrice;
```

Here we used named constants to make the program more maintainable (see Quality Tip 4.1).

Worked Example 5.1

Extracting the Middle

This Worked Example shows how to extract the middle character from a string, or the two middle characters if the length of the string is even.



Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

5.3 Multiple Alternatives

5.3.1 Sequences of Comparisons

Many computations require more than a single `if/else` decision. Sometimes, you need to make a series of related comparisons.

Multiple conditions can be combined to evaluate complex decisions. The correct arrangement depends on the logic of the problem to be solved.

The following program asks for a value describing the magnitude of an earthquake on the Richter scale and prints a description of the likely impact of the quake. The Richter scale is a measurement for the strength of an earthquake. Every step in the scale, for example from 6.0 to 7.0, signifies a tenfold increase in the strength of the quake. The 1989 Loma Prieta earthquake that damaged the Bay Bridge in San Francisco and destroyed many buildings in several Bay area cities registered 7.1 on the Richter scale.

ch05/quake/Earthquake.java

```java
/**
   A class that describes the effects of an earthquake.
*/
public class Earthquake
{
   private double richter;

   /**
      Constructs an Earthquake object.
      @param magnitude the magnitude on the Richter scale
   */
   public Earthquake(double magnitude)
   {
      richter = magnitude;
   }

   /**
      Gets a description of the effect of the earthquake.
      @return the description of the effect
   */
   public String getDescription()
   {
      String r;
      if (richter >= 8.0)
         r = "Most structures fall";
      else if (richter >= 7.0)
         r = "Many buildings destroyed";
      else if (richter >= 6.0)
         r = "Many buildings considerably damaged, some collapse";
      else if (richter >= 4.5)
         r = "Damage to poorly constructed buildings";
      else if (richter >= 3.5)
         r = "Felt by many people, no destruction";
      else if (richter >= 0)
         r = "Generally not felt by people";
      else
         r = "Negative numbers are not valid";
      return r;
   }
}
```

ch05/quake/EarthquakeRunner.java

```
import java.util.Scanner;

/**
   This program prints a description of an earthquake of a given magnitude.
*/
public class EarthquakeRunner
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      System.out.print("Enter a magnitude on the Richter scale: ");
      double magnitude = in.nextDouble();
      Earthquake quake = new Earthquake(magnitude);
      System.out.println(quake.getDescription());
   }
}
```

Program Run

```
Enter a magnitude on the Richter scale: 7.1
Many buildings destroyed
```

Here we must sort the conditions and test against the largest cutoff first. Suppose we reverse the order of tests:

```
if (richter >= 0) // Tests in wrong order
   r = "Generally not felt by people";
else if (richter >= 3.5)
   r = "Felt by many people, no destruction";
else if (richter >= 4.5)
   r = "Damage to poorly constructed buildings";
else if (richter >= 6.0)
   r = "Many buildings considerably damaged, some collapse";
else if (richter >= 7.0)
   r = "Many buildings destroyed";
else if (richter >= 8.0)
   r = "Most structures fall";
```

This does not work. All nonnegative values of `richter` fall into the first case, and the other tests will never be attempted.

In this example, it is also important that we use an `if/else if/else` test, not just multiple independent `if` statements. Consider this sequence of independent tests:

```
if (richter >= 8.0) // Didn't use else
   r = "Most structures fall";
if (richter >= 7.0)
   r = "Many buildings destroyed";
if (richter >= 6.0)
   r = "Many buildings considerably damaged, some collapse";
if (richter >= 4.5)
   r = "Damage to poorly constructed buildings";
if (richter >= 3.5)
   r = "Felt by many people, no destruction";
if (richter >= 0)
   r = "Generally not felt by people";
```

Now the alternatives are no longer exclusive. If `richter` is 6.0, then the last four tests all match, and `r` is set four times.

Special Topic 5.2

The switch Statement

Special Topic 5.2 discusses the `switch` statement, an alternative to the `if/else if/else` statement sequence in which all conditions test the same value against constants.

5.3.2 Nested Branches

Some computations have multiple *levels* of decision making. You first make one decision, and each of the outcomes leads to another decision. Here is a typical example.

In the United States, taxpayers pay federal income tax at different rates depending on their incomes and marital status. There are two main tax schedules: one for single taxpayers and one for married taxpayers “filing jointly”, meaning that the married taxpayers add their incomes together and pay taxes on the total. Table 2 gives the tax rate computations for each of the filing categories, using a simplified version of the values for the 2008 federal tax return.

Table 2 Federal Tax Rate Schedule (2008, simplified)

If your filing status is Single:		If your filing status is Married:	
Tax Bracket	Percentage	Tax Bracket	Percentage
\$0 . . . \$32,000	10%	\$0 . . . \$64,000	10%
Amount over \$32,000	25%	Amount over \$64,000	25%

Now let us compute the taxes due, given a filing status and an income figure. First, we must branch on the filing status. Then, for each filing status, we must have another branch on income level. (See Figure 5 for a flowchart.)

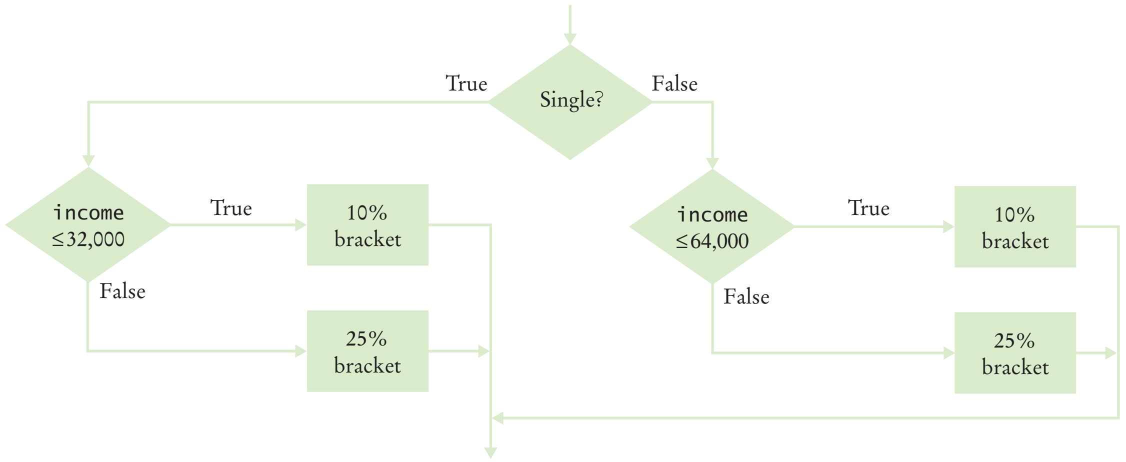


Figure 5 Income Tax Computation Using Simplified 2008 Schedule

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

The two-level decision process is reflected in two levels of `if` statements. We say that the income test is *nested* inside the test for filing status.

ch05/tax/TaxReturn.java

```java
/**
   A tax return of a taxpayer in 2008.
*/
public class TaxReturn
{
   public static final int SINGLE = 1;
   public static final int MARRIED = 2;

   private static final double RATE1 = 0.10;
   private static final double RATE2 = 0.25;
   private static final double RATE1_SINGLE_LIMIT = 32000;
   private static final double RATE1_MARRIED_LIMIT = 64000;

   private double income;
   private int status;

   /**
      Constructs a TaxReturn object for a given income and
      marital status.
      @param anIncome the taxpayer income
      @param aStatus either SINGLE or MARRIED
   */
   public TaxReturn(double anIncome, int aStatus)
   {
      income = anIncome;
      status = aStatus;
   }

   public double getTax()
   {
      double tax1 = 0;
      double tax2 = 0;

      if (status == SINGLE)
      {
         if (income <= RATE1_SINGLE_LIMIT)
         {
            tax1 = RATE1 * income;
         }
         else
         {
            tax1 = RATE1 * RATE1_SINGLE_LIMIT;
            tax2 = RATE2 * (income - RATE1_SINGLE_LIMIT);
         }
      }
      else
      {
         if (income <= RATE1_MARRIED_LIMIT)
         {
            tax1 = RATE1 * income;
         }
         else
         {
            tax1 = RATE1 * RATE1_MARRIED_LIMIT;
            tax2 = RATE2 * (income - RATE1_MARRIED_LIMIT);
         }
      }

      return tax1 + tax2;
   }
}
```

ch05/tax/TaxCalculator.java

```java
import java.util.Scanner;

/**
   This program calculates a simple tax return.
*/
public class TaxCalculator
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      System.out.print("Please enter your income: ");
      double income = in.nextDouble();

      System.out.print("Are you married? (Y/N) ");
      String input = in.next();
      int status;
      if (input.equalsIgnoreCase("Y"))
         status = TaxReturn.MARRIED;
      else
         status = TaxReturn.SINGLE;
      TaxReturn aTaxReturn = new TaxReturn(income, status);

      System.out.println("Tax: "
            + aTaxReturn.getTax());
   }
}
```

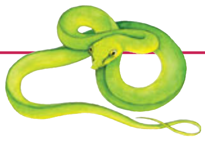
Program Run

```
Please enter your income: 80000
Are you married? (Y/N) Y
Tax: 10400.0
```

SELF CHECK

5. The `if/else/else` statement for the earthquake strength first tested for higher values, then descended to lower values. Can you reverse that order?

6. Some people object to higher tax rates for higher incomes, claiming that you might end up with *less* money after taxes when you get a raise for working hard. What is the flaw in this argument?



Common Error 5.3

The Dangling `else` Problem

When an `if` statement is nested inside another `if` statement, the following error may occur.

```
if (richter >= 0)
   if (richter <= 4)
      System.out.println("The earthquake is harmless");
else // Pitfall!
   System.out.println("Negative value not allowed");
```

The indentation level seems to suggest that the `else` is grouped with the test `richter >= 0`. Unfortunately, that is not the case. The compiler ignores all indentation and follows the rule that an `else` always belongs to the closest `if`, like this:

```
if (richter >= 0)
   if (richter <= 4)
      System.out.println("The earthquake is harmless");
   else // Pitfall!
      System.out.println("Negative value not allowed");
```

That isn't what we want. We want to group the `else` with the first `if`. For that, we must use braces.

```
if (richter >= 0)
{
   if (richter <= 4)
      System.out.println("The earthquake is harmless");
}
else
   System.out.println("Negative value not allowed");
```

To avoid having to think about the pairing of the `else`, we recommend that you *always* use a set of braces when the body of an `if` contains another `if`. In the following example, the braces are not strictly necessary, but they help clarify the code:

```
if (richter >= 0)
{
   if (richter <= 4)
      System.out.println("The earthquake is harmless");
   else
      System.out.println("Damage may occur");
}
```

The ambiguous `else` is called a *dangling* `else`, and it is enough of a syntactical blemish that some programming language designers developed an improved syntax that avoids it altogether. For example, Algol 68 uses the construction

```
if condition then statement else statement fi;
```

The `else` part is optional, but since the end of the `if` statement is clearly marked, the grouping is unambiguous if there are two `if`s and only one `else`. Here are the two possible cases:

```
if c1 then if c2 then s1 else s2 fi fi;
if c1 then if c2 then s1 fi else s2 fi;
```

By the way, `fi` is just `if` backwards. Other languages use `endif`, which has the same purpose but is less fun.

Productivity Hint 5.2

Hand-Tracing

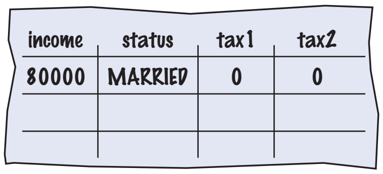
A very useful technique for understanding whether a program works correctly is called *hand-tracing*. You simulate the program's activity on a sheet of paper. You can use this method with pseudocode or Java code.

Get an index card, a cocktail napkin, or whatever sheet of paper is within reach. Make a column for each variable. Have the program code ready. Use a marker, such as a paper clip, to mark the current statement. In your mind, execute statements one at a time. Every time the value of a variable changes, cross out the old value and write the new value below the old one.

For example, let's trace the `getTax` method with the data from the program run on page 169.

When the `TaxReturn` object is constructed, the `income` instance variable is set to 80,000 and `status` is set to `MARRIED`. Then the `getTax` method is called. In lines 31 and 32 of `TaxReturn.java`, `tax1` and `tax2` are initialized to `0`.

```
29 public double getTax()
30 {
31    double tax1 = 0;
32    double tax2 = 0;
33
```



income	status	tax1	tax2
80000	MARRIED	0	0

Because `status` is not `SINGLE`, we move to the `else` branch of the outer `if` statement (line 46).

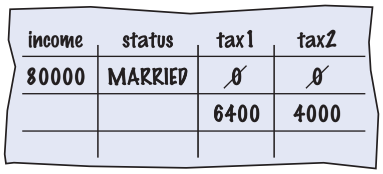
```
34    if (status == SINGLE)
35    {
36       if (income <= RATE1_SINGLE_LIMIT)
37       {
38          tax1 = RATE1 * income;
39       }
40       else
41       {
42          tax1 = RATE1 * RATE1_SINGLE_LIMIT;
43          tax2 = RATE2 * (income - RATE1_SINGLE_LIMIT);
44       }
45    }
46    else
47    {
```

Since `income` is not `<= 64000`, we move to the `else` branch of the inner `if` statement (line 52).

```
48       if (income <= RATE1_MARRIED_LIMIT)
49       {
50          tax1 = RATE1 * income;
51       }
52       else
53       {
54          tax1 = RATE1 * RATE1_MARRIED_LIMIT;
55          tax2 = RATE2 * (income - RATE1_MARRIED_LIMIT);
56       }
```

The values of `tax1` and `tax2` are updated.

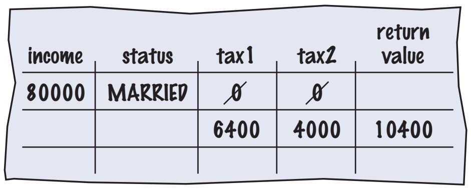
```
53       {
54          tax1 = RATE1 * RATE1_MARRIED_LIMIT;
55          tax2 = RATE2 * (income - RATE1_MARRIED_LIMIT);
56       }
57    }
```



income	status	tax1	tax2
80000	MARRIED	~~0~~	~~0~~
		6400	4000

Their sum is returned and the method ends.

```
58
59    return tax1 + tax2;
60 }
```



income	status	tax1	tax2	return value
80000	MARRIED	~~0~~	~~0~~	
		6400	4000	10400

Because the program trace shows the expected return value ($10,400), it successfully demonstrates that this test case works correctly.

Productivity Hint 5.3

Make a Schedule and Make Time for Unexpected Problems

Commercial software is notorious for being delivered later than promised. For example, Microsoft originally promised that its Windows Vista operating system would be available late in 2003, then in 2005, then in March 2006; it was finally released in January 2007. Some of the early promises might not have been realistic. It is in Microsoft's interest to let prospective customers expect the imminent availability of the product, so that they do not switch to a different product in the meantime. Undeniably, though, Microsoft had not anticipated the full complexity of the tasks it had set itself to solve.

Microsoft can delay the delivery of its product, but it is likely that you cannot. As a student or a programmer, you are expected to manage your time wisely and to finish your assignments on time. You can probably do simple programming exercises the night before the due date, but an assignment that looks twice as hard may well take four times as long, because more things can go wrong. You should therefore make a schedule whenever you start a programming project.

First, estimate realistically how much time it will take you to

- Design the program logic.
- Develop test cases.
- Type the program in and fix compile-time errors.
- Test and debug the program.

For example, for the income tax program I might estimate 30 minutes for the design, because it is mostly done; 30 minutes for developing test cases; one hour for data entry and fixing compile-time errors; and 2 hours for testing and debugging. That is a total of 4 hours. If I work 2 hours a day on this project, it will take me two days.

Then think of things that can go wrong. Your computer might break down. The lab might be crowded. You might be stumped by a problem with the computer system. (That is a particularly important concern for beginners. It is *very* common to lose a day over a trivial problem just because it takes time to track down a person who knows the "magic" command to overcome it.) As a rule of thumb, *double* the time of your estimate. That is, you should start four days, not two days, before the due date. If nothing goes wrong, great; you have the program done two days early. When the inevitable problem occurs, you have a cushion of time that protects you from embarrassment and failure.

Special Topic 5.3

Enumeration Types

Special Topic 5.3 introduces enumeration types—types that an hold one of a finite number of values. An example of an enumeration type is a type `FilingStatus` with values `SINGLE` and `MARRIED`. This is safer than using integer values, as we did in the `TaxReturn` class.

5.4 Using Boolean Expressions

5.4.1 The boolean Type

In Java, an expression such as `amount < 1000` has a value, just as the expression `amount + 1000` has a value. The value of a relational expression is either `true` or `false`. For example, if `amount` is 500, then the value of `amount < 1000` is `true`. Try it out: The program fragment

```
double amount = 0;
System.out.println(amount < 1000);
```

The `boolean` type has two values: `true` and `false`.

prints `true`. The values `true` and `false` are not numbers, nor are they objects of a class. They belong to a separate type, called `boolean`. The **Boolean type** is named after the mathematician George Boole (1815–1864), a pioneer in the study of logic.

5.4.2 Predicate Methods

A **predicate method** is a method that returns a `boolean` value. Here is an example of a predicate method:

A predicate method returns a `boolean` value.

```
public class BankAccount
{
   public boolean isOverdrawn()
   {
      return balance < 0; // Returns true or false
   }
}
```

You can use the return value of the method as the condition of an `if` statement:

```
if (harrysChecking.isOverdrawn()) . . .
```

There are several useful static predicate methods in the `Character` class:

```
isDigit
isLetter
isUpperCase
isLowerCase
```

that let you test whether a character is a digit, a letter, an uppercase letter, or a lowercase letter:

```
if (Character.isUpperCase(ch)) . . .
```

It is a common convention to give the prefix "`is`" or "`has`" to the name of a predicate method.

The `Scanner` class has useful predicate methods for testing whether the next input will succeed. The `hasNextInt` method returns `true` if the next character sequence denotes an integer. It is a good idea to call that method before calling `nextInt`:

```
if (in.hasNextInt()) input = in.nextInt();
```

Similarly, the `hasNextDouble` method tests whether a call to `nextDouble` will succeed.

5.4.3 The Boolean Operators

Suppose you want to find whether `amount` is between `0` and `1000`. Then two conditions have to be true: `amount` must be greater than `0`, *and* it must be less than `1000`. In Java you use the `&&` operator to represent the *and* when combining test conditions. That is, you can write the test as follows:

You can form complex tests with the Boolean operators `&&` (*and*), `||` (*or*), and `!` (*not*).

```
if (0 < amount && amount < 1000) . . .
```

The `&&` (*and*) operator combines several tests into a new test that passes only when all conditions are true. An operator that combines Boolean values is called a **Boolean operator**.

The `&&` operator has a lower precedence than the relational operators. For that reason, you can write relational expressions on either side of the `&&` operator without using parentheses. For example, in the expression

```
0 < amount && amount < 1000
```

the expressions `0 < amount` and `amount < 1000` are evaluated first. Then the `&&` operator combines the results. Appendix B shows a table of the Java operators and their precedence.

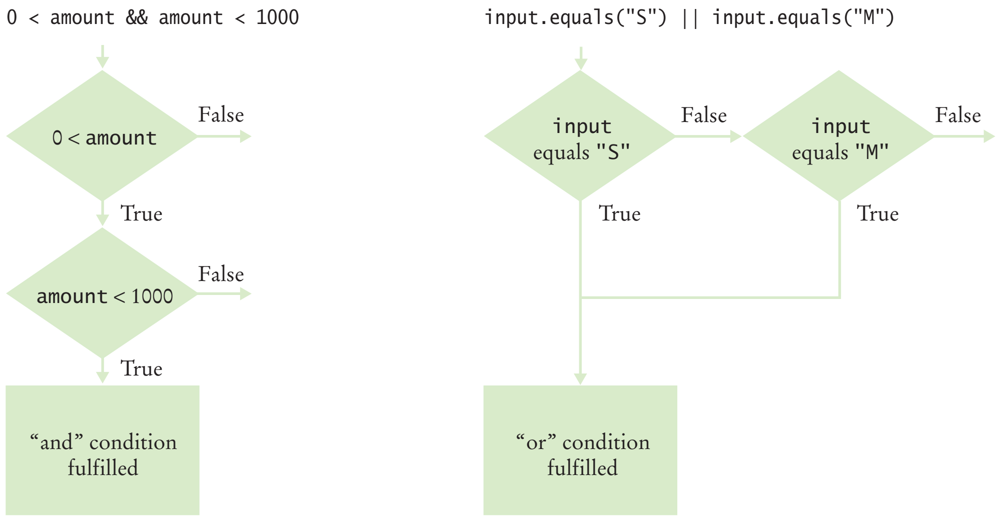


Figure 6 Flowcharts for `&&` and `||` Combinations

The `||` (*or*) logical operator also combines two or more conditions. The resulting test succeeds if at least one of the conditions is true. For example, here is a test to check whether the string `input` is an `"S"` or `"M"`:

```
if (input.equals("S") || input.equals("M")) . . .
```

Figure 6 shows flowcharts for these examples.

Sometimes you need to *invert* a condition with the `!` (*not*) logical operator. For example, we may want to carry out a certain action only if two strings are *not* equal:

```
if (!input.equals("S")) . . .
```

The `!` operator takes a single condition and evaluates to `true` if that condition is false and to `false` if the condition is true.

Here is a summary of the three logical operations:

A	B	A && B
`true`	`true`	`true`
`true`	`false`	`false`
`false`	*Any*	`false`

A	B	A || B
`true`	*Any*	`true`
`false`	`true`	`true`
`false`	`false`	`false`

A	!A
`true`	`false`
`false`	`true`

Table 3 Boolean Operators

Expression	Value	Comment
`0 < 200 && 200 < 100`	`false`	Only the first condition is true.
`0 < 200 || 200 < 100`	`true`	The first condition is true.
`0 < 200 || 100 < 200`	`true`	The `||` is not a test for "either-or". If both conditions are true, the result is true.
🚫 `0 < 100 < 200`	Syntax error	**Error:** The expression `0 < 100` is true, which cannot be compared against `200`.
🚫 `0 < x || x < 100`	`true`	**Error:** This condition is always true. The programmer probably intended `0 < x && x < 100`. (See Common Error 5.5).
`0 < x && x < 100 || x == -1`	`(0 < x && x < 100) || x == -1`	The `&&` operator binds more strongly than the `||` operator. (See Appendix B.)
`!(0 < 200)`	`false`	`0 < 200` is `true`, therefore its negation is `false`.
`frozen == true`	`frozen`	There is no need to compare a Boolean variable with `true`.
`frozen == false`	`!frozen`	It is clearer to use `!` than to compare with `false`.

5.4.4 Using Boolean Variables

You can use a Boolean variable if you know that there are only two possible values. Have another look at the tax program in Section 5.3.2. The marital status is either single or married. Instead of using an integer, you can use a variable of type `boolean`:

You can store the outcome of a condition in a Boolean variable.

```
private boolean married;
```

The advantage is that you can't accidentally store a third value in the variable.

Then you can use the Boolean variable in a test:

```
if (married)
   . . .
else
   . . .
```

Sometimes Boolean variables are called *flags* because they can have only two states: "up" and "down".

It pays to think carefully about the naming of Boolean variables. In our example, it would not be a good idea to give the name `maritalStatus` to the Boolean variable. What does it mean that the marital status is `true`? With a name like `married` there is no ambiguity; if `married` is `true`, the taxpayer is married.

By the way, it is considered gauche to write a test such as

```
if (married == true) . . . // Don't
```

Just use the simpler test

```
if (married) . . .
```

In Chapter 6 we will use Boolean variables to control complex loops.

SELF CHECK

7. When does the statement

```
System.out.println(x > 0 || x < 0);
```

print `false`?

8. Rewrite the following expression, avoiding the comparison with `false`:

```
if (Character.isDigit(ch) == false) . . .
```

Common Error 5.4

Multiple Relational Operators

Consider the expression

```
if (0 < amount < 1000) . . . // Error
```

This looks just like the mathematical notation for "`amount` is between 0 and 1000". But in Java, it is a syntax error.

Let us dissect the condition. The first half, `0 < amount`, is a test with outcome `true` or `false`. The outcome of that test (`true` or `false`) is then compared against 1000. This seems to make no sense. Is `true` larger than 1000 or not? Can one compare truth values and numbers? In Java, you cannot. The Java compiler rejects this statement.

Instead, use `&&` to combine two separate tests:

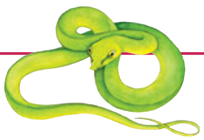
```
if (0 < amount && amount < 1000) . . .
```

Another common error, along the same lines, is to write

```
if (ch == 'S' || 'M') . . . // Error
```

to test whether `ch` is `'S'` or `'M'`. Again, the Java compiler flags this construct as an error. You cannot apply the `||` operator to characters. You need to write two Boolean expressions and join them with the `||` operator:

```
if (ch == 'S' || ch == 'M') . . .
```



Common Error 5.5

Confusing && and || Conditions

It is a surprisingly common error to confuse *and* and *or* conditions. A value lies between 0 and 100 if it is at least 0 *and* at most 100. It lies outside that range if it is less than 0 *or* greater than 100. There is no golden rule; you just have to think carefully.

Often the *and* or *or* is clearly stated, and then it isn't too hard to implement it. Sometimes, though, the wording isn't as explicit. It is quite common that the individual conditions are nicely set apart in a bulleted list, but with little indication of how they should be combined. The instructions for the 1992 tax return say that you can claim single filing status if any one of the following is true:

- You were never married.
- You were legally separated or divorced on December 31, 1992.
- You were widowed before January 1, 1992, and did not remarry in 1992.

Because the test passes if *any one* of the conditions is true, you must combine the conditions with *or.* Elsewhere, the same instructions state that you may use the more advantageous status of married filing jointly if all five of the following conditions are true:

- Your spouse died in 1990 or 1991 and you did not remarry in 1992.
- You have a child whom you can claim as dependent.
- That child lived in your home for all of 1992.
- You paid over half the cost of keeping up your home for this child.
- You filed (or could have filed) a joint return with your spouse the year he or she died.

Because *all* of the conditions must be true for the test to pass, you must combine them with an *and*.

Special Topic 5.4

Lazy Evaluation of Boolean Operators

Special Topic 5.4 explains lazy evaluation of Boolean operators: the fact that the right-hand side of && and || expressions is not evaluated if the left-hand side already determines the outcome.

Special Topic 5.5

De Morgan's Law

Special Topic 5.5 covers DeMorgan's law, a law of logic that is used to simplify conditions in which *not* operators are applied to *and*/*or* expressions.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Random Fact 5.1

Artificial Intelligence

Random Fact 5.1 discusses artificial intelligence computer processes that appear to simulate intelligent human reasoning.

5.5 Code Coverage

Black-box testing describes a testing method that does not take the structure of the implementation into account.

Testing the functionality of a program without consideration of its internal structure is called **black-box testing**. This is an important part of testing, because, after all, the users of a program do not know its internal structure. If a program works perfectly on all inputs, then it surely does its job.

However, it is impossible to ensure absolutely that a program will work correctly on all inputs just by supplying a finite number of test cases. As the famous computer scientist Edsger Dijkstra pointed out, testing can show only the presence of bugs—not their absence. To gain more confidence in the correctness of a program, it is useful to consider its internal structure. Testing strategies that look inside a program are called **white-box testing**. Performing unit tests of each method is a part of white-box testing.

White-box testing uses information about the structure of a program.

You want to make sure that each part of your program is exercised at least once by one of your test cases. This is called **code coverage**. If some code is never executed by any of your test cases, you have no way of knowing whether that code would perform correctly if it ever were executed by user input. That means that you need to look at every `if/else` branch to see that each of them is reached by some test case. Many conditional branches are in the code only to take care of strange and abnormal inputs, but they still do something. It is a common phenomenon that they end up doing something incorrectly, but those faults are never discovered during testing, because nobody supplied the strange and abnormal inputs. Of course, these flaws become immediately apparent when the program is released and the first user types in an unusual input and is incensed when the program misbehaves. The remedy is to ensure that each part of the code is covered by some test case.

Code coverage is a measure of how many parts of a program have been tested.

For example, in testing the `getTax` method of the `TaxReturn` class, you want to make sure that every `if` statement is entered for at least one test case. You should test both single and married taxpayers, with incomes in each of the three tax brackets.

When you select test cases, you should make it a habit to include *boundary test cases:* legal values that lie at the boundary of the set of acceptable inputs.

Boundary test cases are test cases that are at the boundary of acceptable inputs.

For example, what happens when you compute the taxes for an income of `0` or if a bank account has an interest rate of `0` percent? Boundary cases are still legitimate inputs, and you expect that the program will handle them correctly—often in some trivial way or through special cases. Testing boundary cases is important, because programmers often make mistakes dealing with boundary conditions. Division by zero, extracting characters from empty strings, and accessing null references are common symptoms of boundary errors.

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SELF CHECK

9. How many test cases do you need to cover all branches of the `getDescription` method of the `Earthquake` class?

10. Give a boundary test case for the `EarthquakeRunner` program. What output do you expect?

Quality Tip 5.3

Calculate Sample Data Manually

It is usually difficult or impossible to prove that a given program functions correctly in all cases. For gaining confidence in the correctness of a program, or for understanding why it does not function as it should, manually calculated sample data are invaluable. If the program arrives at the same results as the manual calculation, our confidence in it is strengthened. If the manual results differ from the program results, we have a starting point for the debugging process.

Surprisingly, many programmers are reluctant to perform any manual calculations as soon as a program carries out the slightest bit of algebra. Their math phobia kicks in, and they irrationally hope that they can avoid the algebra and beat the program into submission by random tinkering, such as rearranging the `+` and `-` signs. Random tinkering is always a great time sink, but it rarely leads to useful results.

You should calculate test cases by hand to double-check that your application computes the correct answer.

Let's have another look at the `TaxReturn` class. Suppose a single taxpayer earns $50,000. The rules in Table 2 on page 167 state that the first $32,000 are taxed at 10 percent. Compute 32,000 × 0.10 = 3,200. The amount above $32,000, is taxed at 25 percent. It is time to take out your calculator—real world numbers are usually nasty. That is (50,000 – 32,000) × 0.25 = 4,500. The total tax is the sum, 3,200 + 4,500 = 7,700. Now, that wasn't so hard.

Run the program and compare the results. Because the results match, we have an increased confidence in the correctness of the program.

It is even better to make manual calculations before writing the program. Doing so helps you understand the task at hand, and you will be able to implement your solution more quickly.

Quality Tip 5.4

Prepare Test Cases Ahead of Time

Let us consider how we can test the tax computation program. Of course, we cannot try out all possible inputs of filing status and income level. Even if we could, there would be no point in trying them all. If the program correctly computes one or two tax amounts in a given bracket, then we have a good reason to believe that all amounts within that bracket will be correct. We want to aim for complete *coverage* of all cases.

There are two possibilities for the filing status and three tax brackets for each status. That makes six test cases. Then we want to test *boundary conditions,* such as zero income or incomes that are at the boundary between two brackets. That makes six test cases. Compute manually the answers you expect (See Quality Tip 5.3). Write down the test cases before you start coding.

Test Case	Married	Expected Output	Comment
30,000	N	3,000	10% bracket
72,000	N	13,200	3,200 + 25% of 40,000
50,000	Y	5,000	10% bracket

Test Case	Married	Expected Output	Comment
104,000	Y	16,400	6,400 + 25% of 40,000
32,000	N	3,200	boundary case
0		0	boundary case

Should you really test six inputs for this simple program? You certainly should. Furthermore, if you find an error in the program that wasn't covered by one of the test cases, make another test case and add it to your collection. After you fix the known mistakes, *run all test cases again.* Experience has shown that the cases that you just tried to fix are probably working now, but that errors that you fixed two or three iterations ago have a good chance of coming back! If you find that an error keeps coming back, that is usually a reliable sign that you did not fully understand some subtle interaction between features of your program.

It is always a good idea to design test cases *before* starting to code. There are two reasons for this. Working through the test cases gives you a better understanding of the algorithm that you are about to program. Furthermore, it has been noted that programmers instinctively shy away from testing fragile parts of their code. That seems hard to believe, but you will often make that observation about your own work. Watch someone else test your program. There will be times when that person enters input that makes you very nervous because you are not sure that your program can handle it, and you never dared to test it yourself. This is a well-known phenomenon, and making the test plan before writing the code offers some protection.

Special Topic 5.6

Logging

Sometimes you run a program and you are not sure where it spends its time. To get a printout of the program flow, you can insert trace messages into the program, such as this one:

```
public double getTax()
{
   . . .
   if (status == SINGLE)
   {
      System.out.println("status is SINGLE");
      . . .
   }
   . . .
}
```

However, there is a problem with using `System.out.println` for trace messages. When you are done testing the program, you need to remove all print statements that produce trace messages. If you find another error, however, you need to stick the print statements back in.

To overcome this problem, you should use the `Logger` class, which allows you to turn off the trace messages without removing them from the program.

Instead of printing directly to `System.out`, use the global logger object that is returned by the call `Logger.getGlobal()`. (Prior to Java 7, you obtained the global logger as `Logger.getLogger("global")`.) Then call the `info` method:

```
Logger.getGlobal().info("status is SINGLE");
```

Logging messages can be deactivated when testing is complete.

By default, the message is printed. But if you call

```
Logger.getGlobal().setLevel(Level.OFF);
```

at the beginning of the main method of your program, all log message printing is suppressed. Set the level to Level.INFO to turn logging of info messages on again. Thus, you can turn off the log messages when your program works fine, and you can turn them back on if you find another error. In other words, using Logger.getGlobal().info is just like System.out.println, except that you can easily activate and deactivate the logging.

A common trick for tracing execution flow is to produce log messages when a method is called, and when it returns. At the beginning of a method, print out the parameters:

```
public TaxReturn(double anIncome, int aStatus)
{
   Logger.getGlobal().info("Parameters: anIncome = " + anIncome
         + " aStatus = " + aStatus);
   . . .
}
```

At the end of a method, print out the return value:

```
public double getTax()
{
   . . .
   Logger.getGlobal().info("Return value = " + tax);
   return tax;
}
```

The Logger class has many other options for industrial-strength logging. Check out the API documentation if you want to have more control over logging.

Summary of Learning Objectives

Use the if statement to implement a decision.

- The if statement lets a program carry out different actions depending on a condition.
- A block statement groups several statements together.

Implement comparisons of numbers and objects.

- Relational operators compare values. The == operator tests for equality.
- When comparing floating-point numbers, don't test for equality. Instead, check whether they are close enough.
- Do not use the == operator to compare strings. Use the equals method instead.
- The compareTo method compares strings in dictionary order.
- The == operator tests whether two object references are identical. To compare the contents of objects, you need to use the equals method.
- The null reference refers to no object.

Implement complex decisions that require multiple if statements.

- Multiple conditions can be combined to evaluate complex decisions. The correct arrangement depends on the logic of the problem to be solved.

Use the Boolean data type to store and combine conditions that can be true or false.

- The `boolean` type has two values: `true` and `false`.
- A predicate method returns a `boolean` value.
- You can form complex tests with the Boolean operators `&&` (*and*), `||` (*or*), and `!` (*not*).
- You can store the outcome of a condition in a Boolean variable.

Design test cases that cover all parts of a program.

- Black-box testing describes a testing method that does not take the structure of the implementation into account.
- White-box testing uses information about the structure of a program.
- Code coverage is a measure of how many parts of a program have been tested.
- Boundary test cases are test cases that are at the boundary of acceptable inputs.
- You should calculate test cases by hand to double-check that your application computes the correct answer.

Use the Java logging library for messages that can be easily turned on or off.

- Logging messages can be deactivated when testing is complete.

Classes, Objects, and Methods Introduced in this Chapter

```
java.lang.Character
   isDigit
   isLetter
   isLowerCase
   isUpperCase
java.lang.Object
   equals
java.lang.String
   equals
   equalsIgnoreCase
   compareTo
java.util.Scanner
   hasNextDouble
   hasNextInt
java.util.logging.Level
   INFO
   OFF
java.util.logging.Logger
   getGlobal
   info
   setLevel
```

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** Extracting the Middle
- Lab Exercises
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★ **R5.1** What is the value of each variable after the `if` statement?

a. `int n = 1; int k = 2; int r = n; if (k < n) r = k;`

b. `int n = 1; int k = 2; int r; if (n < k) r = k; else r = k + n;`

c. `int n = 1; int k = 2; int r = k; if (r < k) n = r; else k = n;`

d. `int n = 1; int k = 2; int r = 3; if (r < n + k) r = 2 * n; else k = 2 * r;`

★★ **R5.2** Find the errors in the following `if` statements.

a. `if (1 + x > Math.pow(x, Math.sqrt(2)) y = y + x;`

b. `if (x = 1) y++; else if (x = 2) y = y + 2;`

c.
```
int x = Integer.parseInt(input);
if (x != null) y = y + x;
```

★★ **R5.3** Find the error in the following `if` statement that is intended to select a language from a given country and state/province.

```
language = "English";
if (country.equals("Canada"))
   if (stateOrProvince.equals("Quebec")) language = "French";
else if (country.equals("China"))
   language = "Chinese";
```

★★ **R5.4** Find the errors in the following `if` statements.

a. `if (x && y == 0) { x = 1; y = 1; }`

b.
```
if (1 <= x <= 10)
   System.out.println(x);
```

c.
```
if (!s.equals("nickels") || !s.equals("pennies")
      || !s.equals("dimes") || !s.equals("quarters"))
   System.out.print("Input error!");
```

d.
```
if (input.equalsIgnoreCase("N") || "NO")
   return;
```

★ **R5.5** Explain the following terms, and give an example for each construct:

a. Expression

b. Condition

c. Statement

d. Simple statement

e. Compound statement

f. Block

★ **R5.6** Explain the difference between an `if` statement with multiple `else` branches and nested `if` statements. Give an example for each.

★ **R5.7** Give an example for an `if/else if/else` statement where the order of the tests does not matter. Give an example where the order of the tests matters.

★ **R5.8** Of the following pairs of strings, which comes first in lexicographic order?

a. `"Tom", "Jerry"`

b. `"Tom", "Tomato"`

c. `"church", "Churchill"`

d. `"car manufacturer", "carburetor"`

e. `"Harry", "hairy"`

f. `"C++", " Car"`

g. `"Tom", "Tom"`

h. `"Car", "Carl"`

i. `"car", "bar"`

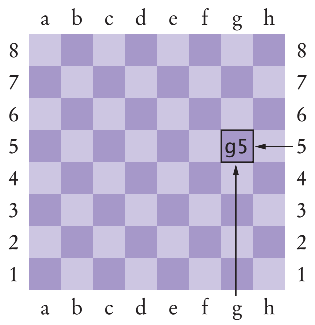
j. `"101", "11"`

k. `"1.01", "10.1"`

★ **R5.9** Complete the following truth table by finding the truth values of the Boolean expressions for all combinations of the Boolean inputs `p`, `q`, and `r`.

p	q	r	`(p && q) || !r`	`!(p && (q || !r))`
false	false	false		
false	false	false		
false	false	false		
. . .	. . .	. . .		
5 more combinations				
. . .				

★★ **R5.10** Each square on a chess board can be described by a letter and number, such as `g5` in this example:



The following pseudocode describes an algorithm that determines whether a square with a given letter and number is dark (black) or light (white).

```
If the letter is an a, c, e, or g
    If the number is odd
        color = "black"
    Else
        color = "white"
Else
    If the number is even
        color = "black"
    Else
        color = "white"
```

Using the procedure in Productivity Hint 5.2 on page 171, trace this pseudocode with input `g5`.

★ **R5.11** Give a set of four test cases for the algorithm of Exercise R5.10 that covers all branches.

★★ **R5.12** In a scheduling program, we want to check whether two appointments overlap. For simplicity, appointments start at a full hour, and we use military time (with hours

0–24). The following pseudocode describes an algorithm that determines whether the appointment with start time start1 and end time end1 overlaps with the appointment with start time start2 and end time end2.

```
If start1 > start2
    s = start1
Else
    s = start2
If end1 < end2
    e = endl
Else
    e = end2
If s < e
    The appointments overlap.
Else
    The appointments don't overlap.
```

Trace this algorithm with an appointment from 10–12 and one from 11–13, then with an appointment from 10–11 and one from 12–13.

★ **R5.13** Write pseudocode for a program that prompts the user for a month and day and prints out whether it is one of the following four holidays:

- New Year's Day (January 1)
- Independence Day (July 4)
- Veterans Day (November 11)
- Christmas Day (December 25)

★★★ **R5.14** True or false? *A* && *B* is the same as *B* && *A* for any Boolean conditions *A* and *B*.

★ **R5.15** Explain the difference between

```
s = 0;
if (x > 0) s++;
if (y > 0) s++;
```

and

```
s = 0;
if (x > 0) s++;
else if (y > 0) s++;
```

★★ **R5.16** Use de Morgan's law to simplify the following Boolean expressions.

a. `!(x > 0 && y > 0)`

b. `!(x != 0 || y != 0)`

c.
```
!(country.equals("US") && !state.equals("HI")
      && !state.equals("AK"))
```

d. `!(x % 4 != 0 || !(x % 100 == 0 && x % 400 == 0))`

★★ **R5.17** Make up another Java code example that shows the dangling `else` problem, using the following statement: A student with a GPA of at least 1.5, but less than 2, is on probation; with less than 1.5, the student is failing.

★ **R5.18** Explain the difference between the `==` operator and the `equals` method when comparing strings.

★★ **R5.19** Explain the difference between the tests

```
r == s
```

and

```
r.equals(s)
```

where both `r` and `s` are of type `Rectangle`.

★★★ **R5.20** What is wrong with this test to see whether `r` is `null`? What happens when this code runs?

```
Rectangle r;
. . .
if (r.equals(null))
   r = new Rectangle(5, 10, 20, 30);
```

★ **R5.21** Explain how the lexicographic ordering of strings differs from the ordering of words in a dictionary or telephone book. *Hint:* Consider strings, such as `IBM`, `wiley.com`, `Century 21`, `While-U-Wait`, and `7-11`.

★★★ **R5.22** Write Java code to test whether two objects of type `Line2D.Double` represent the same line when displayed on the graphics screen. *Do not* use `a.equals(b)`.

```
Line2D.Double a;
Line2D.Double b;

if (your condition goes here)
   g2.drawString("They look the same!", x, y);
```

Hint: If `p` and `q` are points, then `Line2D.Double(p, q)` and `Line2D.Double(q, p)` look the same.

★ **R5.23** Explain why it is more difficult to compare floating-point numbers than integers. Write Java code to test whether an integer `n` equals 10 and whether a floating-point number `x` is approximately equal to 10.

★★ **R5.24** Consider the following test to see whether a point falls inside a rectangle.

```
Point2D.Double p = . . .
Rectangle r = . . .
boolean xInside = false;
if (r.getX() <= p.getX() && p.getX() <= r.getX() + r.getWidth())
   xInside = true;
boolean yInside = false;
if (r.getY() <= p.getY() && p.getY() <= r.getY() + r.getHeight())
   yInside = true;
if (xInside && yInside)
   g2.drawString("p is inside the rectangle.",
         p.getX(), p.getY());
```

Rewrite this code to eliminate the explicit `true` and `false` values, by setting `xInside` and `yInside` to the values of Boolean expressions.

★T **R5.25** Give a set of test cases for the earthquake program in Section 5.3.1. Ensure coverage of all branches.

★T **R5.26** Give an example of a boundary test case for the earthquake program in Section 5.3.1. What result do you expect?

Programming Exercises

★★ **P5.1** Write a program that prints all real solutions to the quadratic equation $ax^2 + bx + c = 0$. Read in a, b, c and use the quadratic formula. If the *discriminant* $b^2 - 4ac$ is negative, display a message stating that there are no real solutions.

Implement a class `QuadraticEquation` whose constructor receives the coefficients `a`, `b`, `c` of the quadratic equation. Supply methods `getSolution1` and `getSolution2` that get the solutions, using the quadratic formula, or `0` if no solution exists. The `getSolution1` method should return the smaller of the two solutions.

Supply a method

```
boolean hasSolutions()
```

that returns `false` if the discriminant is negative.

★★ **P5.2** Write a program that takes user input describing a playing card in the following shorthand notation:

Notation	Meaning
`A`	Ace
`2 ... 10`	Card values
`J`	Jack
`Q`	Queen
`K`	King
`D`	Diamonds
`H`	Hearts
`S`	Spades
`C`	Clubs

Your program should print the full description of the card. For example,

```
Enter the card notation:
4S
Four of spades
```

Implement a class `Card` whose constructor takes the card notation string and whose `getDescription` method returns a description of the card. If the notation string is not in the correct format, the `getDescription` method should return the string `"Unknown"`.

★★ **P5.3** Write a program that reads in three floating-point numbers and prints the three inputs in sorted order. For example,

```
Please enter three numbers:
4
9
2.5
The inputs in sorted order are:
2.5
4
9
```

★ **P5.4** Write a program that translates a letter grade into a number grade. Letter grades are `A B C D F`, possibly followed by `+` or `-`. Their numeric values are 4, 3, 2, 1, and 0. There is no `F+` or `F-`. A `+` increases the numeric value by 0.3, a `-` decreases it by 0.3. However, an `A+` has the value 4.0. All other inputs have value –1.

```
Enter a letter grade:
B-
Numeric value: 2.7.
```

Use a class `Grade` with a method `getNumericGrade`.

★ **P5.5** Write a program that translates a number into the closest letter grade. For example, the number 2.8 (which might have been the average of several grades) would be converted to `B-`. Break ties in favor of the better grade; for example, 2.85 should be a `B`. Any value ≥ 4.15 should be an `A+`.

Use a class `Grade` with a method `getLetterGrade`.

★ **P5.6** Write a program that reads in three strings and prints them in lexicographically sorted order:

```
Please enter three strings:
Tom
Dick
Harry
The inputs in sorted order are:
Dick
Harry
Tom
```

★★ **P5.7** Change the implementation of the `getTax` method in the `TaxReturn` class, by setting a variable `rate1_limit`, depending on the marital status. Then have a single formula that computes the tax, depending on the income and the limit. Verify that your results are identical to that of the `TaxReturn` class in this chapter.

★★★ **P5.8** The original U.S. income tax of 1913 was quite simple. The tax was

- 1 percent on the first \$50,000.
- 2 percent on the amount over \$50,000 up to \$75,000.
- 3 percent on the amount over \$75,000 up to \$100,000.
- 4 percent on the amount over \$100,000 up to \$250,000.
- 5 percent on the amount over \$250,000 up to \$500,000.
- 6 percent on the amount over \$500,000.

There was no separate schedule for single or married taxpayers. Write a program that computes the income tax according to this schedule.

★★ **P5.9** Write a program that prompts for the day and month of the user's birthday and then prints a horoscope. Make up fortunes for programmers, like this:

```
Please enter your birthday (month and day): 6 16
Gemini are experts at figuring out the behavior of complicated programs.
You feel where bugs are coming from and then stay one step ahead. Tonight,
your style wins approval from a tough critic.
```

Each fortune should contain the name of the astrological sign. (You will find the names and date ranges of the signs at a distressingly large number of sites on the Internet.)

★ **P5.10** When two points in time are compared, each given as hours (in military time, ranging from 0 and 23) and minutes, the following pseudocode determines which comes first.

```
If hour1 < hour2
    time1 comes first.
Else if hour1 and hour2 are the same
    If minute1 < minute2
        time1 comes first.
    Else if minute1 and minute2 are the same
        time1 and time2 are the same.
    Else
        time2 comes first.
Else
    time2 comes first.
```

Write a program that prompts the user for two points in time and prints the time that comes first, then the other time.

★ **P5.11** The following algorithm yields the season (Spring, Summer, Fall, or Winter) for a given month and day.

```
If month is 1, 2, or 3, season = "Winter"
Else if month is 4, 5, or 6, season = "Spring"
Else if month is 7, 8, or 9, season = "Summer"
Else if month is 10, 11, or 12, season = "Fall"
If month is divisible by 3 and day >= 21
    If season is "Winter", season = "Spring"
    Else if season is "Spring", season = "Summer"
    Else if season is "Summer", season = "Fall"
    Else season = "Winter"
```

Write a program that prompts the user for a month and day and then prints the season, as determined by this algorithm.

★ **P5.12** A year with 366 days is called a *leap year*. A year is a leap year if it is divisible by 4 (for example, 1980). However, since the introduction of the Gregorian calendar on October 15, 1582, a year is not a leap year if it is divisible by 100 (for example, 1900); however, it is a leap year if it is divisible by 400 (for example, 2000). Write a program that asks the user for a year and computes whether that year is a leap year. Implement a class `Year` with a predicate method `boolean isLeapYear()`.

★ **P5.13** Write a program that asks the user to enter a month (1 = January, 2 = February, and so on) and then prints the number of days of the month. For February, print "28 days".

```
Enter a month (1-12):
5
31 days
```

Implement a class `Month` with a method `int getDays()`. Do not use a separate `if` or `else` statement for each month. Use Boolean operators.

★★★ **P5.14** Write a program that reads in two floating-point numbers and tests (a) whether they are the same when rounded to two decimal places and (b) whether they differ by less than 0.01.

Here are two sample runs.

```
Enter two floating-point numbers:
2.0
1.99998
They are the same when rounded to two decimal places.
They differ by less than 0.01.

Enter two floating-point numbers:
0.999
0.991
They are different when rounded to two decimal places.
They differ by less than 0.01.
```

★ **P5.15** Enhance the `BankAccount` class of Chapter 3 by

- Rejecting negative amounts in the `deposit` and `withdraw` methods
- Rejecting withdrawals that would result in a negative balance

★ **P5.16** Write a program that reads in the hourly wage of an employee. Then ask how many hours the employee worked in the past week. Be sure to accept fractional hours. Compute the pay. Any overtime work (over 40 hours per week) is paid at 150 percent of the regular wage. Solve this problem by implementing a class `Paycheck`.

★★ **P5.17** Write a unit conversion program that asks users to identify the unit from which they want to convert and the unit to which they want to convert. Legal units are *in*, *ft*, *mi*, *mm*, *cm*, *m*, and *km*. Declare two objects of a class `UnitConverter` that convert between meters and a given unit.

```
Convert from:
in
Convert to:
mm
Value:
10
10 in = 254 mm
```

★★★ **P5.18** A line in the plane can be specified in various ways:

- by giving a point (x, y) and a slope m
- by giving two points (x_1, y_1), (x_2, y_2)
- as an equation in slope-intercept form $y = mx + b$
- as an equation $x = a$ if the line is vertical

Implement a class `Line` with four constructors, corresponding to the four cases above. Implement methods

```
boolean intersects(Line other)
boolean equals(Line other)
boolean isParallel(Line other)
```

★★G **P5.19** Write a program that draws a circle with radius 100 and center (200, 200). Ask the user to specify the x- and y-coordinates of a point. Draw the point as a small circle. If the point lies inside the circle, color the small circle green. Otherwise, color it red. In your exercise, declare a class `Circle` and a method `boolean isInside(Point2D.Double p)`.

★★★G **P5.20** Write a graphics program that asks the user to specify the radii of two circles. The first circle has center (100, 200), and the second circle has center (200, 100). Draw the circles. If they intersect, then color both circles green. Otherwise, color them red. *Hint:* Compute the distance between the centers and compare it to the radii. Your program should draw nothing if the user enters a negative radius. In your exercise, declare a class `Circle` and a method `boolean intersects(Circle other)`.

Programming Projects

Project 5.1 Implement a *combination lock* class. A combination lock has a dial with 26 positions labeled A . . . Z. The dial needs to be set three times. If it is set to the correct combination, the lock can be opened. When the lock is closed again, the combination can be entered again. If a user sets the dial more than three times, the last three settings determine whether the lock can be opened. An important part of this exercise is to implement a suitable interface for the `CombinationLock` class.

Project 5.2 Get the instructions for last year's form 1040 from `http://www.irs.ustreas.gov`. Find the tax brackets that were used last year for all categories of taxpayers (single, married filing jointly, married filing separately, and head of household). Write a program that computes taxes following that schedule. Ignore deductions, exemptions, and credits. Simply apply the tax rate to the income.

Answers to Self-Check Questions

1. If the withdrawal amount equals the balance, the result should be a zero balance and no penalty.
2. Only the first assignment statement is part of the `if` statement. Use braces to group both assignment statements into a block statement.
3. (a) 0; (b) 1; (c) An exception occurs.
4. Syntactically incorrect: e, g, h. Logically questionable: a, d, f
5. Yes, if you also reverse the comparisons:

```
if (richter < 3.5)
   r = "Generally not felt by people";
else if (richter < 4.5)
   r = "Felt by many people, no destruction";
else if (richter < 6.0)
   r = "Damage to poorly constructed buildings";
. . .
```

6. The higher tax rate is only applied on the income in the higher bracket. Suppose you are single and make $31,900. Should you try to get a $200 raise? Absolutely: you get to keep 90 percent of the first $100 and 75 percent of the next $100.
7. When `x` is zero.
8. `if (!Character.isDigit(ch)) . . .`
9. Seven
10. An input of 0 should yield an output of `"Generally not felt by people"`. (If the output is `"Negative numbers are not allowed"`, there is an error in the program.)

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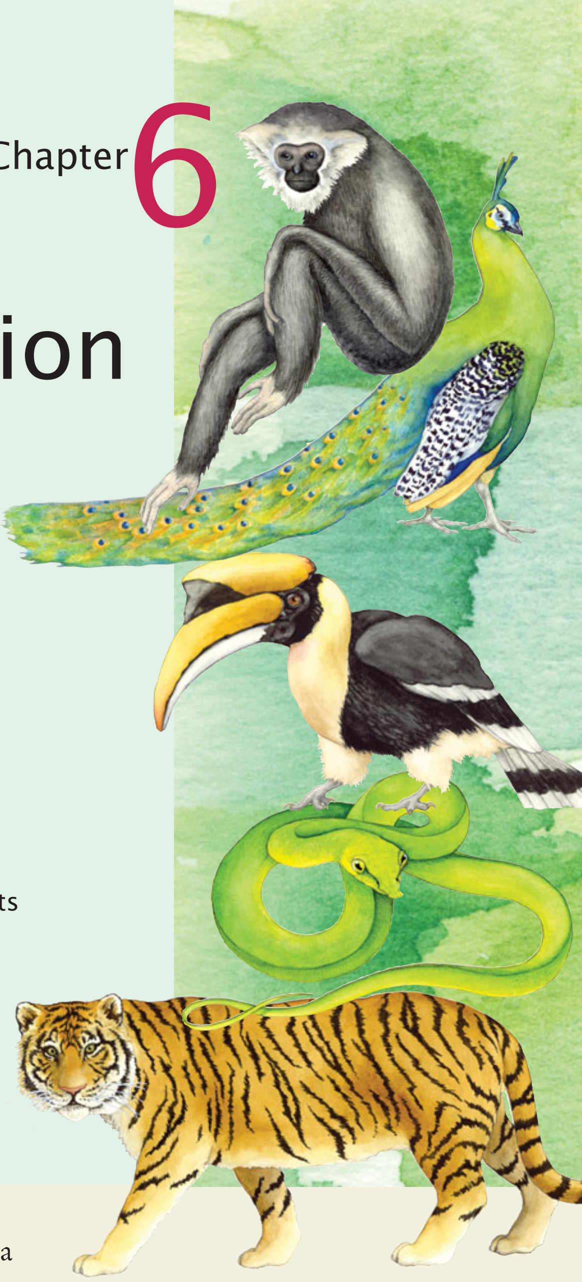
Chapter 6

Iteration



CHAPTER GOALS

- To be able to program loops with the `while` and `for` statements
- To avoid infinite loops and off-by-one errors
- To be able to use common loop algorithms
- To understand nested loops
- To implement simulations

T To learn about the debugger

This chapter presents the various iteration constructs of the Java language. These constructs execute one or more statements repeatedly until a goal is reached. You will see how the techniques that you learn in this chapter can be applied to the processing of input data and the programming of simulations.

CHAPTER CONTENTS

6.1 while Loops 194
Syntax 6.1: The while Statement 196
Productivity Hint 6.1: Hand-Tracing Loops 198
Common Error 6.1: Infinite Loops 200
Common Error 6.2: Off-by-One Errors 200
Special Topic 6.1: do Loops ⊕

6.2 for Loops 201
Syntax 6.2: The for Statement 204
Quality Tip 6.1: Use for Loops for Their Intended Purpose 206
Common Error 6.3: Forgetting a Semicolon 207
Common Error 6.4: A Semicolon Too Many 207
Quality Tip 6.2: Don't Use != to Test the End of a Range 208
Special Topic 6.2: Variables Declared in a for Loop Header ⊕
Quality Tip 6.3: Symmetric and Asymmetric Bounds 208
Quality Tip 6.4: Count Iterations 209

6.3 Common Loop Algorithms 210
How To 6.1: Writing a Loop 215
Worked Example 6.1: Credit Card Processing ⊕
Special Topic 6.3: The "Loop and a Half" Problem ⊕
Special Topic 6.4: The break and continue Statements ⊕

6.4 Nested Loops 218
Worked Example 6.2: Manipulating the Pixels in an Image ⊕

6.5 Application: Random Numbers and Simulations 221
Special Topic 6.5: Loop Invariants ⊕

6.6T Using a Debugger 223
How To 6.2: Debugging 226
Worked Example 6.3: A Sample Debugging Session ⊕
Random Fact 6.1: The First Bug 228

6.1 while Loops

In this chapter you will learn how to write programs that repeatedly execute one or more statements. We will illustrate these concepts by looking at typical investment situations. Consider a bank account with an initial balance of $10,000 that earns 5 percent interest. The interest is computed at the end of every year on the current balance and then deposited into the bank account. For example, after the first year, the account has earned $500 (5 percent of $10,000) of interest. The interest gets added to the bank account. Next year, the interest is $525 (5 percent of $10,500), and the balance is $11,025.

How many years does it take for the balance to reach $20,000? Of course, it won't take longer than 20 years, because at least $500 is added to the bank account each year. But it will take less than 20 years, because interest is computed on increasingly larger balances. To know the exact answer, we will write a program that repeatedly adds interest until the balance is reached.

A while statement executes a block of code repeatedly. A condition controls how long the loop is executed.

In Java, the while statement implements such a repetition. The construct

```
while (condition)
   statement
```

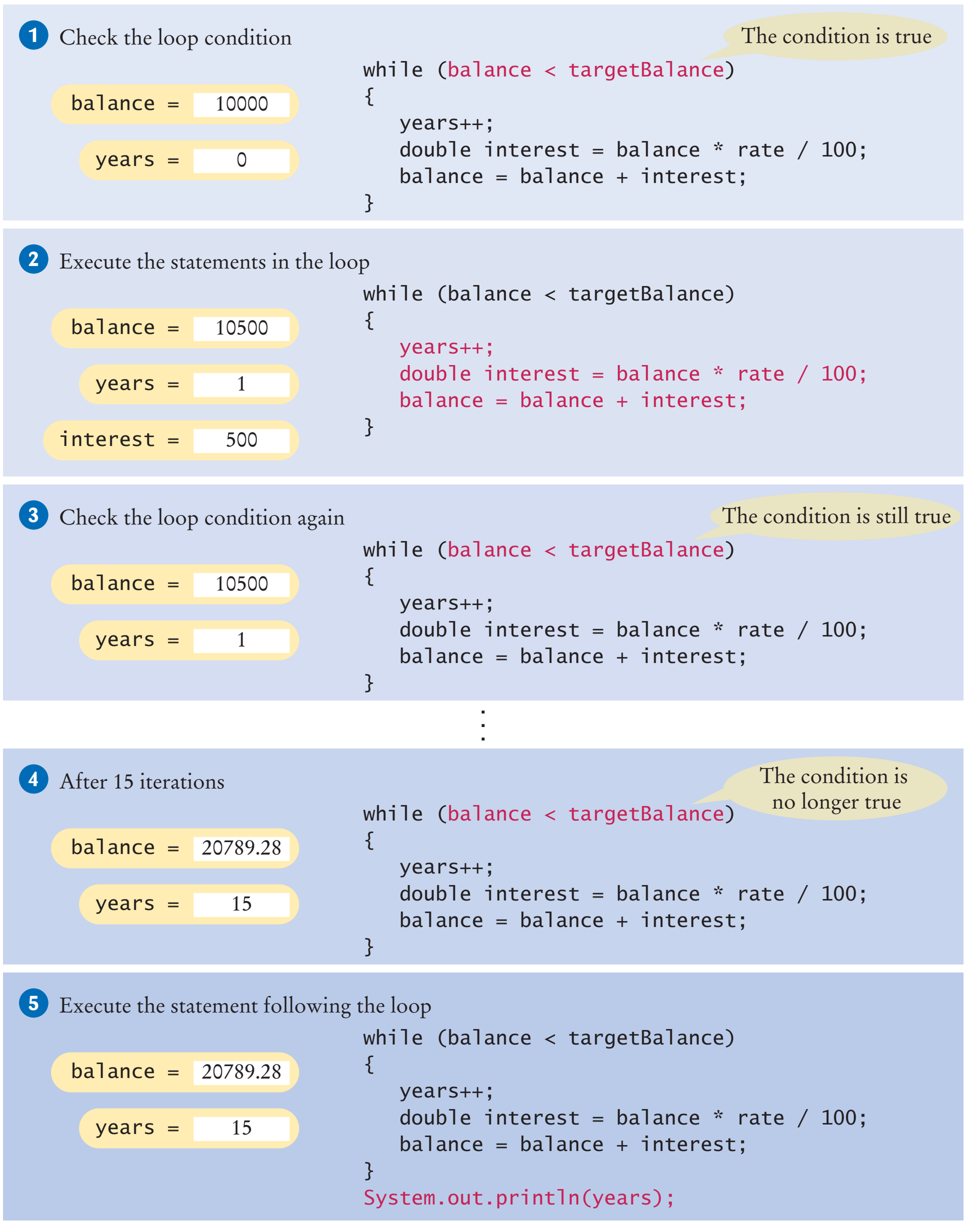
keeps executing the statement while the condition is true.

Most commonly, the statement is a block statement, that is, a set of statements delimited by { }.

In our case, we want to know when the bank account has reached a particular balance. While the balance is less, we keep adding interest and incrementing the years counter:

```
while (balance < targetBalance)
{
   years++;
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

Figure 1 shows the flow of execution of this loop.


1 Check the loop condition
The condition is true
balance = 10000
years = 0
2 Execute the statements in the loop
balance = 10500
years = 1
interest = 500
3 Check the loop condition again
The condition is still true
balance = 10500
years = 1
4 After 15 iterations
The condition is no longer true
balance = 20789.28
years = 15
5 Execute the statement following the loop
balance = 20789.28
years = 15

```
while (balance < targetBalance)
{
   years++;
   double interest = balance * rate / 100;
   balance = balance + interest;
}
System.out.println(years);
```

Figure 1 Execution of a `while` Loop

For the full text of the sample program that solves our investment problem, see `ch06/invest1/Investment.java` in your source code, or view it in WileyPLUS.

ANIMATION
Tracing a Loop

A `while` statement is often called a *loop*. If you draw a flowchart, you will see that the control loops backwards to the test after every iteration (see Figure 2).

When you declare a variable *inside* the loop body, the variable is created for each iteration of the loop and removed after the end of each iteration. For example, consider the `interest` variable in this loop:

```
while (balance < targetBalance)
{
   years++;
   double interest = balance * rate / 100;
      // A new interest variable is created
      //  in each iteration
   balance = balance + interest;
} // interest no longer declared here
```

If a variable needs to be updated in multiple loop iterations, do not declare it inside the loop. For example, it would not make sense to declare the `balance` variable inside this loop.

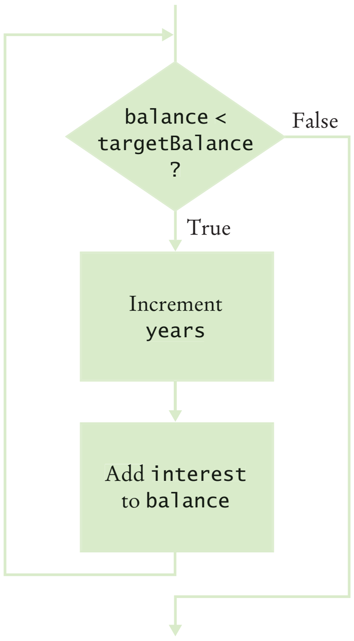


Figure 2 Flowchart of a `while` Loop

Syntax 6.1 The `while` Statement

Syntax

```
while (condition)
   statement
```

Example

```
double balance = 0;
.
.
.
while (balance < TARGET)
{
   double interest = balance * RATE / 100;
   balance = balance + interest;
}
```

This variable is declared outside the loop and updated in the loop.

If the condition never becomes false, an infinite loop occurs. See page 200.

Beware of "off-by-one" errors in the loop condition. See page 200.

Don't put a semicolon here! See page 207.

These statements are executed while the condition is true.

This variable is created in each loop iteration.

Lining up braces is a good idea. See page 154.

Braces are not required if the body contains a single statement.

The following loop,

```
while (true)
   statement
```

executes the statement over and over, without terminating. Whoa! Why would you want that? The program would never stop. There are two reasons. Some programs indeed never stop; the software controlling an automated teller machine, a telephone switch, or a microwave oven doesn't ever stop (at least not until the device is turned off). Our programs aren't usually of that kind, but even if you can't terminate the loop, you can exit from the method that contains it. This can be helpful when the termination test naturally falls in the middle of the loop (see Special Topic 6.3 on page 218).

Table 1 `while` Loop Examples

Loop	Output	Explanation

`i = 0; sum = 0;`
`while (sum < 10)`
`{`
`   i++; sum = sum + i;`
`   `**Print** `i` **and** `sum;`
`}`
	`1 1`
	`2 3`
	`3 6`
	`4 10`
		When `sum` is 10, the loop condition is false, and the loop ends.

`i = 0; sum = 0;`
`while (sum < 10)`
`{`
`   i++; sum = sum - i;`
`   `**Print** `i` **and** `sum;`
`}`
	`1 -1`
	`2 -3`
	`3 -6`
	`4 -10`
	`. . .`
		Because `sum` never reaches 10, this is an "infinite loop" (see Common Error 6.1 on page 200).

`i = 0; sum = 0;`
`while (sum < 0)`
`{`
`   i++; sum = sum - i;`
`   `**Print** `i` **and** `sum;`
`}`
	(No output)	The statement `sum < 0` is false when the condition is first checked, and the loop is never executed.

`i = 0; sum = 0;`
`while (sum >= 10)`
`{`
`   i++; sum = sum + i;`
`   `**Print** `i` **and** `sum;`
`}`
	(No output)	The programmer probably thought, "Stop when the sum is at least 10." However, the loop condition controls when the loop is executed, not when it ends.

`i = 0; sum = 0;`
`while (sum < 10) ;`
`{`
`   i++; sum = sum + i;`
`   `**Print** `i` **and** `sum;`
`}`
	(No output, program does not terminate)	Note the semicolon before the `{`. This loop has an empty body. It runs forever, checking whether `sum < 10` and doing nothing in the body (see Common Error 6.4 on page 207).

SELF CHECK

1. How many times is the following statement in the loop executed?

   `while (false)` *statement*`;`

2. What would happen if `RATE` was set to `0` in the `main` method of the `InvestmentRunner` program?

Productivity Hint 6.1

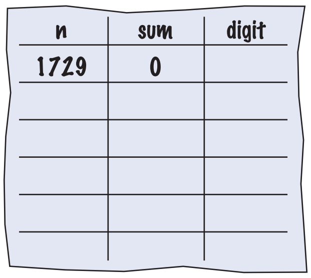
Hand-Tracing Loops

In Programming Tip 5.2, you learned about the method of hand-tracing. This method is particularly effective for understanding how a loop works.

Consider this example loop. What value is displayed?

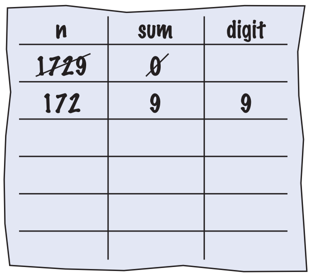
```
int n = 1729;  ①
int sum = 0;
while (n > 0)  ②
{
   int digit = n % 10;  ③ ④ ⑤ ⑥
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);  ⑦
```

1. There are three variables: `n`, `sum`, and `digit`. The first two variables are initialized with 1729 and `0` before the loop is entered.



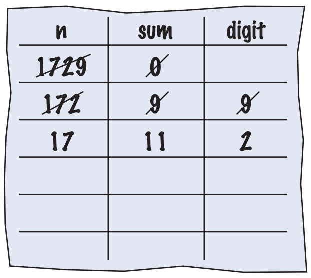
n	sum	digit
1729	0	

2. Because `n` is positive, enter the loop.
3. The variable `digit` is set to 9 (the remainder of dividing 1729 by 10). The variable `sum` is set to `0` + 9 = 9. Finally, `n` becomes 172. (Recall that the remainder in the division 1729 / 10 is discarded because both arguments are integers.). Cross out the old values and write the new ones under the old ones.



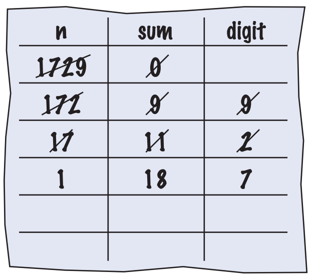
n	sum	digit
~~1729~~	~~0~~	
172	9	9

4. Because `n > 0`, we repeat the loop. Now `digit` becomes 2, `sum` is set to 9 + 2 = 11, and `n` is set to 17.



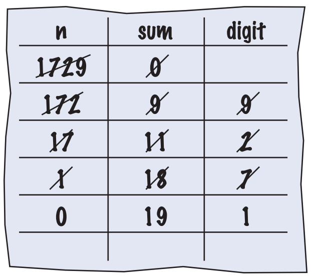
n	sum	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
17	11	2

5. Because `n` is still not zero, we repeat the loop, setting `digit` to 7, `sum` to 11 + 7 = 18, and `n` to 1.



n	sum	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
1	18	7

6. We enter the loop one last time. Now `digit` is set to 1, `sum` to 19, and `n` becomes zero.



n	sum	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
~~1~~	~~18~~	~~7~~
0	19	1

7. The condition `n > 0` is now false, and we continue with the output statement after the loop. The value that is output is 19.

Of course, you can get the same answer simply by running the code. The hope is that by hand-tracing, you gain an *insight*. Consider again what happens in each iteration:

- We extract the last digit of `n`.
- We add that digit to `sum`.
- We strip the digit off `n`.

In other words, the loop forms the sum of the digits in `n`. You now know what the loop does for any value of `n`, not just the one in the example.

Why would anyone want to form the sum of the digits? Operations of this kind are useful for checking the validity of credit card numbers and other forms of ID number—see Exercise P6.2.

Common Error 6.1

Infinite Loops

One of the most annoying loop errors is an infinite loop: a loop that runs forever and can be stopped only by killing the program or restarting the computer. If there are output statements in the loop, then reams and reams of output flash by on the screen. Otherwise, the program just sits there and hangs, seeming to do nothing. On some systems you can kill a hanging program by hitting Ctrl+Break or Ctrl+C. On others, you can close the window in which the program runs.

A common reason for infinite loops is forgetting to advance the variable that controls the loop:

```
int years = 0;
while (years < 20)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

Here the programmer forgot to add a statement for incrementing `years` in the loop. As a result, the value of `years` always stays `0`, and the loop never comes to an end.

Another common reason for an infinite loop is accidentally incrementing a counter that should be decremented (or vice versa). Consider this example:

```
int years = 20;
while (years > 0)
{
   years++; // Oops, should have been years--
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

The `years` variable really should have been decremented, not incremented. This is a common error, because incrementing counters is so much more common than decrementing that your fingers may type the `++` on autopilot. As a consequence, `years` is always larger than `0`, and the loop never terminates. (Actually, `years` eventually will exceed the largest representable positive integer and wrap around to a negative number. Then the loop exits—of course, that takes a long time, and the result is completely wrong.)

Common Error 6.2

Off-by-One Errors

Consider our computation of the number of years that are required to double an investment:

```
int years = 0;
while (balance < 2 * initialBalance)
{
   years++;
   double interest = balance * rate / 100;
   balance = balance + interest;
}
System.out.println("The investment reached the target after "
      + years + " years.");
```

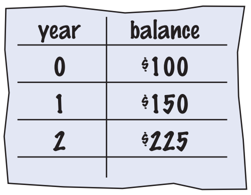
Should `years` start at 0 or at 1? Should you test for `balance < 2 * initialBalance` or for `balance <= 2 * initialBalance`? It is easy to be *off by one* in these expressions.

Some people try to solve off-by-one errors by randomly inserting `+1` or `-1` until the program seems to work. That is, of course, a terrible strategy. It can take a long time to compile and test all the various possibilities. Expending a small amount of mental effort is a real time saver.

An off-by-one error is a common error when programming loops. Think through simple test cases to avoid this type of error.

Fortunately, off-by-one errors are easy to avoid, simply by thinking through a couple of test cases and using the information from the test cases to come up with a rationale for the correct loop condition.

Should `years` start at `0` or at `1`? Look at a scenario with simple values: an initial balance of $100 and an interest rate of 50 percent. After year 1, the balance is $150, and after year 2 it is $225, or over $200. So the investment doubled after 2 years. The loop executed two times, incrementing `years` each time. Hence `years` must start at `0`, not at `1`.



year	balance
0	$100
1	$150
2	$225

In other words, the `balance` variable denotes the balance *after* the end of the year. At the outset, the `balance` variable contains the balance after year `0` and not after year 1.

Next, should you use a `<` or `<=` comparison in the test? That is harder to figure out, because it is rare for the balance to be exactly twice the initial balance. Of course, there is one case when this happens, namely when the interest is 100 percent. The loop executes once. Now `years` is 1, and `balance` is exactly equal to `2 * initialBalance`. Has the investment doubled after one year? It has. Therefore, the loop should *not* execute again. If the test condition is `balance < 2 * initialBalance`, the loop stops, as it should. If the test condition had been `balance <= 2 * initialBalance`, the loop would have executed once more.

In other words, you keep adding interest while the balance *has not yet doubled*.

Special Topic 6.1

do Loops

Special Topic 6.1 discusses the `do` loop, an optional loop construct that tests the loop condition at the end of the loop body.

6.2 for Loops

One of the most common loop types has the form

```
i = start;
while (i <= end)
{
   . . .
   i++;
}
```

Because this loop is so common, there is a special form for it that emphasizes the pattern:

```
for (i = start; i <= end; i++)
{
   . . .
}
```

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

You can also declare the loop counter variable inside the for loop header. That convenient shorthand restricts the use of the variable to the body of the loop (as will be discussed further in Special Topic 6.2).

```
for (int i = start; i <= end; i++)
{
   . . .
}
```

A for loop can be used to find out the size of our $10,000 investment if 5 percent interest is compounded for 20 years. Of course, the balance will be larger than $20,000, because at least $500 is added every year. You may be surprised to find out just how much larger the balance is.

You use a for loop when a variable runs from a starting to an ending value with a constant increment or decrement.

In our loop, we let i go from 1 to numberOfYears, the number of years for which we want to compound interest.

```
for (int i = 1; i <= numberOfYears; i++)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

Figure 3 shows the corresponding flowchart. Figure 4 shows the flow of execution. The complete program is on page 205.

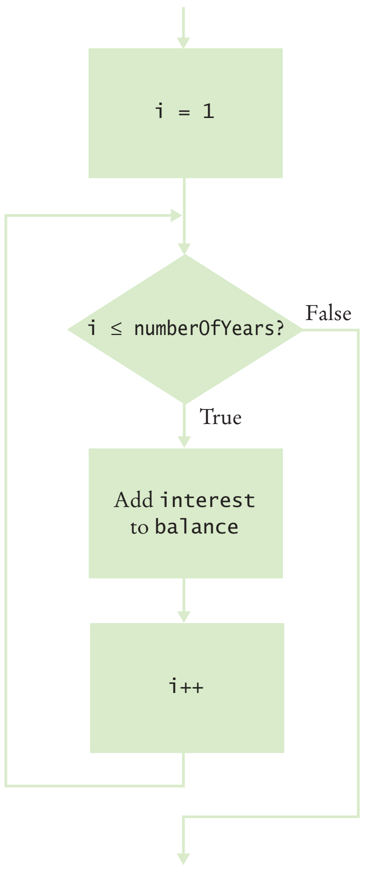
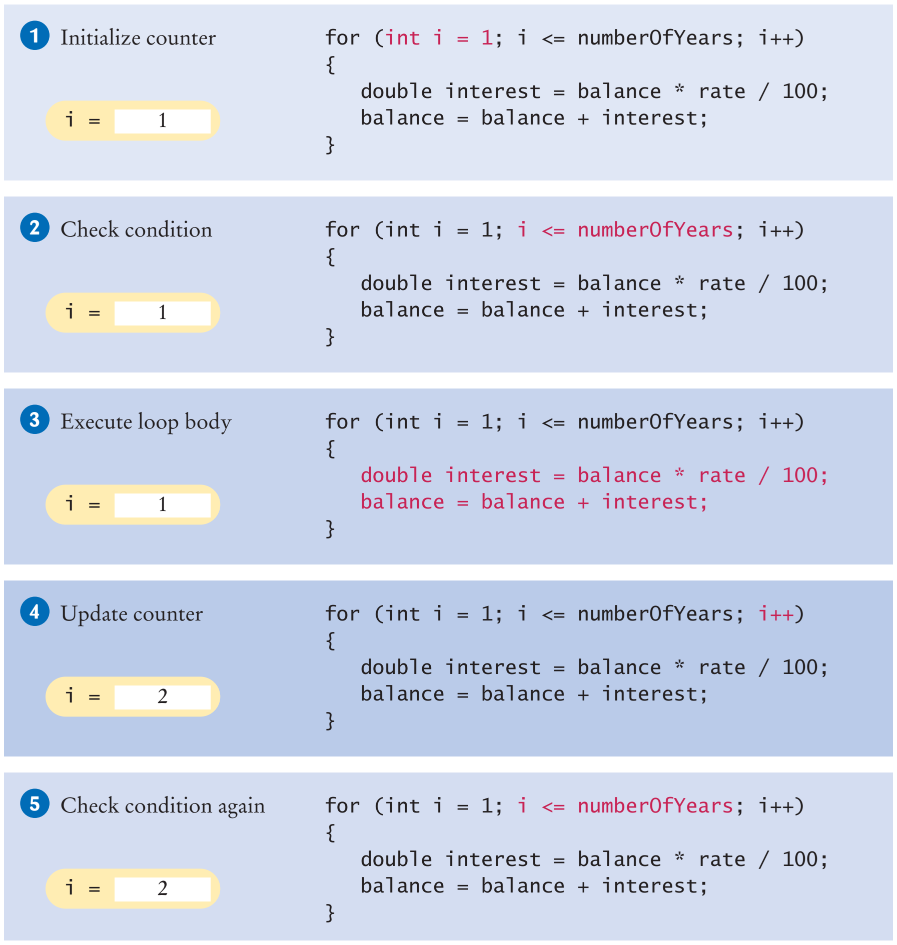


Figure 3
Flowchart of a for Loop



```
for (int i = 1; i <= numberOfYears; i++)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

Figure 4 Execution of a for Loop

Another common use of the `for` loop is to traverse all characters of a string:

```
for (int i = 0; i < str.length(); i++)
{
   char ch = str.charAt(i);
   Process ch
}
```

Note that the counter variable `i` starts at `0`, and the loop is terminated when `i` reaches the length of the string. For example, if `str` has length 5, `i` takes on the values `0`, 1, 2, 3, and 4. These are the valid positions in the string.

Note too that the three slots in the `for` header can contain any three expressions. You can count down instead of up:

ANIMATION
The `for` *Loop*

```
for (int i = 10; i > 0; i--)
```

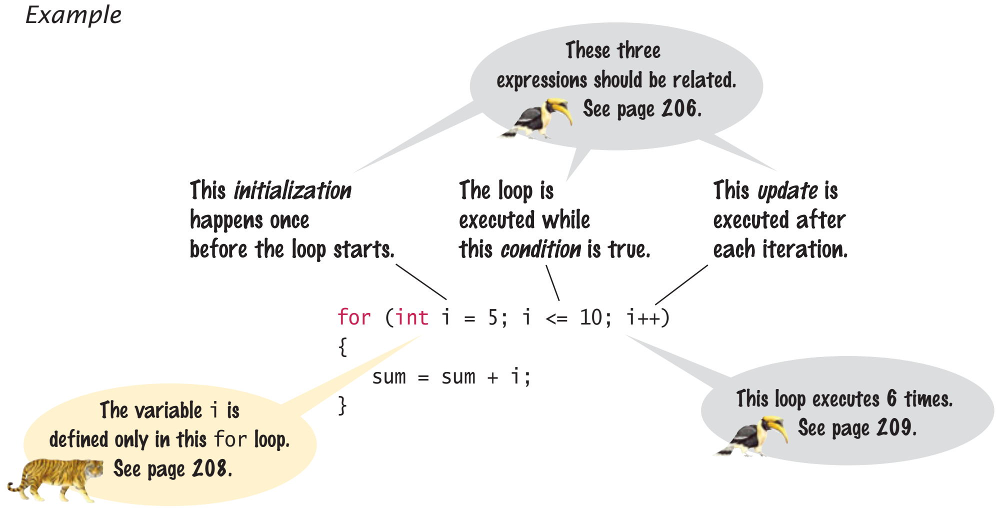
The increment or decrement need not be in steps of 1:

```
for (int i = -10; i <= 10; i = i + 2) . . .
```

Syntax 6.2 The for Statement

Syntax `for (`*initialization*`;` *condition*`;` *update*`)`
statement

Example


These three expressions should be related. See page 206.
This *initialization* happens once before the loop starts.
The loop is executed while this *condition* is true.
This *update* is executed after each iteration.
The variable i is defined only in this for loop. See page 208.
This loop executes 6 times. See page 209.

```
for (int i = 5; i <= 10; i++)
{
   sum = sum + i;
}
```

It is possible—but a sign of unbelievably bad taste—to put unrelated conditions into the loop header:

```
for (rate = 5; years-- > 0; System.out.println(balance))
   . . . // Bad taste
```

We won't even begin to decipher what that might mean. You should stick with `for` loops that initialize, test, and update a single variable.

Table 2 for Loop Examples

Loop	Values of i	Comment
`for (i = 0; i <= 5; i++)`	0 1 2 3 4 5	Note that the loop is executed 6 times. (See Quality Tip 6.4 on page 209.)
`for (i = 5; i >= 0; i--)`	5 4 3 2 1 0	Use `i--` for decreasing values.
`for (i = 0; i < 9; i = i + 2)`	0 2 4 6 8	Use `i = i + 2` for a step size of 2.
`for (i = 0; i != 9; i = i + 2)`	0 2 4 6 8 10 12 14 … (infinite loop)	You can use < or <= instead of != to avoid this problem.
`for (i = 1; i <= 20; i = i * 2)`	1 2 4 8 16	You can specify any rule for modifying `i`, such as doubling it in every step.
`for (i = 0; i < str.length(); i++)`	0 1 2 … until the last valid index of the string `str`	In the loop body, use the expression `str.charAt(i)` to get the `i`th character.

ch06/invest2/Investment.java

```
/**
   A class to monitor the growth of an investment that
   accumulates interest at a fixed annual rate.
*/
public class Investment
{
   private double balance;
   private double rate;
   private int years;

   /**
      Constructs an Investment object from a starting balance and
      interest rate.
      @param aBalance the starting balance
      @param aRate the interest rate in percent
   */
   public Investment(double aBalance, double aRate)
   {
      balance = aBalance;
      rate = aRate;
      years = 0;
   }

   /**
      Keeps accumulating interest until a target balance has
      been reached.
      @param targetBalance the desired balance
   */
   public void waitForBalance(double targetBalance)
   {
      while (balance < targetBalance)
      {
         years++;
         double interest = balance * rate / 100;
         balance = balance + interest;
      }
   }

   /**
      Keeps accumulating interest for a given number of years.
      @param numberOfYears the number of years to wait
   */
   public void waitYears(int numberOfYears)
   {
      for (int i = 1; i <= numberOfYears; i++)
      {
         double interest = balance * rate / 100;
         balance = balance + interest;
      }
      years = years + n;
   }

   /**
      Gets the current investment balance.
      @return the current balance
   */
   public double getBalance()
   {
```

```java
      return balance;
   }

   /**
      Gets the number of years this investment has accumulated
      interest.
      @return the number of years since the start of the investment
   */
   public int getYears()
   {
      return years;
   }
}
```

ch06/invest2/InvestmentRunner.java

```java
/**
   This program computes how much an investment grows in
   a given number of years.
*/
public class InvestmentRunner
{
   public static void main(String[] args)
   {
      final double INITIAL_BALANCE = 10000;
      final double RATE = 5;
      final int YEARS = 20;
      Investment invest = new Investment(INITIAL_BALANCE, RATE);
      invest.waitYears(YEARS);
      double balance = invest.getBalance();
      System.out.printf("The balance after %d years is %.2f\n",
            YEARS, balance);
   }
}
```

Program Run

```
The balance after 20 years is 26532.98
```

SELF CHECK

3. Rewrite the `for` loop in the `waitYears` method as a `while` loop.
4. How many times does the following `for` loop execute?

```java
for (i = 0; i <= 10; i++)
   System.out.println(i * i);
```

Quality Tip 6.1

Use `for` Loops for Their Intended Purpose

A `for` loop is an *idiom* for a `while` loop of a particular form. A counter runs from the start to the end, with a constant increment:

```
for (Set counter to start; Test whether counter at end; Update counter by increment)
{  . . .
   // counter, start, end, increment not changed here
}
```

If your loop doesn't match this pattern, don't use the `for` construction. The compiler won't prevent you from writing idiotic `for` loops:

```
// Bad style—unrelated header expressions
for (System.out.println("Inputs:");
      (x = in.nextDouble()) > 0;
      sum = sum + x)
   count++;

for (int i = 1; i <= years; i++)
{
   if (balance >= targetBalance)
      i = years;    // Bad style—modifies counter
   else
   {
      double interest = balance * rate / 100;
      balance = balance + interest;
   }
}
```

These loops will work, but they are plainly bad style. Use a `while` loop for iterations that do not fit the `for` pattern.

Common Error 6.3

Forgetting a Semicolon

Occasionally all the work of a loop is already done in the loop header. Suppose you ignored Quality Tip 6.1 on page 206; then you could write an investment doubling loop as follows:

```
for (years = 1;
      (balance = balance + balance * rate / 100) < targetBalance;
      years++)
   ;
System.out.println(years);
```

The body of the `for` loop is completely empty, containing just one empty statement terminated by a semicolon.

If you do run into a loop without a body, it is important that you make sure the semicolon is not forgotten. If the semicolon is accidentally omitted, then the next line becomes part of the loop statement!

```
for (years = 1;
      (balance = balance + balance * rate / 100) < targetBalance;
      years++)
System.out.println(years);
```

You can avoid this error by using an empty block `{ }` instead of an empty statement.

Common Error 6.4

A Semicolon Too Many

What does the following loop print?

```
sum = 0;
for (i = 1; i <= 10; i++);
```

```
    sum = sum + i;
System.out.println(sum);
```

Of course, this loop is supposed to compute 1 + 2 + ··· + 10 = 55. But actually, the print statement prints 11!

Why 11? Have another look. Did you spot the semicolon at the end of the `for` loop header? This loop is actually a loop with an empty body.

```
for (i = 1; i <= 10; i++)
   ;
```

The loop does nothing 10 times, and when it is finished, `sum` is still `0` and `i` is 11. Then the statement

```
sum = sum + i;
```

is executed, and `sum` is 11. The statement was indented, which fools the human reader. But the compiler pays no attention to indentation.

Of course, the semicolon at the end of the statement was a typing error. Someone's fingers were so used to typing a semicolon at the end of every line that a semicolon was added to the `for` loop by accident. The result was a loop with an empty body.

Quality Tip 6.2

Don't Use `!=` to Test the End of a Range

Here is a loop with a hidden danger:

```
for (i = 1; i != n; i++)
```

The test `i != n` is a poor idea. How does the loop behave if `n` happens to be zero or negative? The test `i != n` is never false, because `i` starts at 1 and increases with every step.

The remedy is simple. Use `<=` rather than `!=` in the condition:

```
for (i = 1; i <= n; i++)
```

Special Topic 6.2

Variables Declared in a `for` Loop Header

Special Topic 6.2 shows how to declare multiple variables in a `for` loop header, and it explains that such variables are not defined beyond the loop body.

Quality Tip 6.3

Symmetric and Asymmetric Bounds

It is easy to write a loop with `i` going from 1 to `n`:

```
for (i = 1; i <= n; i++) . . .
```

The values for `i` are bounded by the relation $1 \le$ `i` $\le$ `n`. Because there are $\le$ comparisons on both bounds, the bounds are called **symmetric**.

When traversing the characters in a string, the bounds are **asymmetric**.

```
for (i = 0; i < str.length(); i++) . . .
```

Make a choice between symmetric and asymmetric loop bounds.

The values for `i` are bounded by `0` $\le$ `i` $<$ `str.length()`, with a $\le$ comparison to the left and a $<$ comparison to the right. That is appropriate, because `str.length()` is not a valid position.

It is not a good idea to force symmetry artificially:

```
for (i = 0; i <= str.length() - 1; i++) . . .
```

That is more difficult to read and understand.

For every loop, consider which form is most natural for the problem, and use that.

Quality Tip 6.4

Count Iterations

Finding the correct lower and upper bounds for an iteration can be confusing. Should I start at `0`? Should I use `<= b` or `< b` as a termination condition?

Counting the number of iterations is a very useful device for better understanding a loop. Counting is easier for loops with asymmetric bounds. The loop

```
for (i = a; i < b; i++) . . .
```

is executed `b - a` times. For example, the loop traversing the characters in a string,

```
for (i = 0; i < str.length(); i++) . . .
```

runs `str.length()` times. That makes perfect sense, because there are `str.length()` characters in a string.

The loop with symmetric bounds,

```
for (i = a; i <= b; i++)
```

is executed `b - a + 1` times. That "`+ 1`" is the source of many programming errors. For example,

```
for (n = 0; n <= 10; n++)
```

Count the number of iterations to check that your `for` loop is correct.

runs 11 times. Maybe that is what you want; if not, start at `1` or use `< 10`.

One way to visualize this "`+ 1`" error is to think of the posts and sections of a fence. Suppose the fence has ten sections (`=`). How many posts (`|`) does it have?

```
|=|=|=|=|=|=|=|=|=|=|
```

A fence with ten sections has *eleven* posts. Each section has one post to the left, *and* there is one more post after the last section. Forgetting to count the last iteration of a "`<=`" loop is often called a "fence post error".

If the increment is a value `c` other than 1, and `c` divides `b - a`, then the counts are

`(b - a) / c`	for the asymmetric loop
`(b - a) / c + 1`	for the symmetric loop

For example, the loop `for (i = 10; i <= 40; i += 5)` executes $(40 - 10)/5 + 1 = 7$ times.

6.3 Common Loop Algorithms

In the following sections, we discuss some of the most common algorithms that are implemented as loops. You can use them as starting points for your loop designs.

6.3.1 Computing a Total

Computing the sum of a number of inputs is a very common task. Keep a *running total:* a variable to which you add each input value. Of course, the total should be initialized with `0`.

```
double total = 0;
while (in.hasNextDouble())
{
   double input = in.nextDouble();
   total = total + input;
}
```

6.3.2 Counting Matches

You often want to know how many values fulfill a particular condition. For example, you may want to count how many uppercase letters are in a string. Keep a *counter*, a variable that is initialized with `0` and incremented whenever there is a match.

```
int upperCaseLetters = 0;
for (int i = 0; i < str.length(); i++)
{
   char ch = str.charAt(i);
   if (Character.isUpperCase(ch))
   {
      upperCaseLetters++;
   }
}
```

For example, if `str` is the string `"Hello, World!"`, `upperCaseLetters` is incremented twice (when `i` is `0` and `7`).

6.3.3 Finding the First Match

When you count the values that fulfill a condition, you need to look at all values. However, if your task is to find a match, then you can stop as soon as the condition is fulfilled.

Here is a loop that finds the first lowercase letter in a string. Because we do not visit all elements in a string, a `while` loop is a better choice than a `for` loop:

```
boolean found = false;
char ch = '?';
int position = 0;
```

```
while (!found && position < str.length())
{
   ch = str.charAt(position);
   if (Character.isLowerCase(ch)) { found = true; }
   else { position++; }
}
```

If a match was found, then `found` is `true`, `ch` is the first matching character, and its index is stored in the variable `position`. If the loop did not find a match, then `found` remains `false` and the loop continues until `position` reaches `str.length()`.

Note that the variable `ch` is declared *outside* the `while` loop because you may want to use it after the loop has finished.

6.3.4 Prompting Until a Match is Found

In the preceding example, we searched a string for a character that matches a condition. You can apply the same process to user input. Suppose you are asking a user to enter a positive value < 100. Keep asking until the user provides a correct input:

```
boolean valid = false;
double input = 0;
while (!valid)
{
   System.out.print("Please enter a positive value < 100: ");
   input = in.nextDouble();
   if (0 < input && input < 100) { valid = true; }
   else { System.out.println("Invalid input."); }
}
```

As in the preceding example, the variable `input` is declared outside the `while` loop so that you can use it after the loop has finished.

6.3.5 Comparing Adjacent Values

When processing a sequence of values in a loop, you sometimes need to compare a value with the value that just preceded it. For example, suppose you want to check whether a sequence of inputs contains adjacent duplicates such as `1 7 2 9 9 4 9`.

Now you face a challenge. Consider the typical loop for reading a value:

```
double input = 0;
while (in.hasNextDouble())
{
   input = in.nextDouble();
   . . .
}
```

How can you compare the current input with the preceding one? At any time, `input` contains the current input, overwriting the previous one.

The answer is to store the previous input, like this:

```
double input = 0;
while (in.hasNextDouble())
{
      double previous = input;
      input = in.nextDouble();
      if (input == previous) { System.out.println("Duplicate input"); }
   }
```

One problem remains. When the loop is entered for the first time, there is no previous `input` value. You can solve this problem with an initial input operation outside the loop:

```
double input = in.nextDouble();
while (in.hasNextDouble())
{
   double previous = input;
   input = in.nextDouble();
   if (input == previous) { System.out.println("Duplicate input"); }
}
```

6.3.6 Processing Input with Sentinel Values

Suppose you want to process a set of values, for example a set of measurements. Your goal is to analyze the data and display properties of the data set, such as the average or the maximum value. You prompt the user for the first value, then the second value, then the third, and so on. When does the input end?

One common method for indicating the end of a data set is a **sentinel** value, a value that is not part of the data. Instead, the sentinel value indicates that the data has come to an end.

Some programmers choose numbers such as `0` or –1 as sentinel values. But that is not a good idea. These values may well be valid inputs. A better idea is to use an input that is not a number, such as the letter `Q`. Here is a typical program run:

```
Enter value, Q to quit: 1
Enter value, Q to quit: 2
Enter value, Q to quit: 3
Enter value, Q to quit: 4
Enter value, Q to quit: Q
Average = 2.5
Maximum = 4.0
```

Of course, we need to read each input as a string, not a number. Once we have tested that the input is not the letter `Q`, we convert the string into a number.

```
System.out.print("Enter value, Q to quit: ");
String input = in.next();
if (input.equalsIgnoreCase("Q"))
   We are done
else
{
   double x = Double.parseDouble(input);
   . . .
}
```

Now we have another problem. The test for loop termination occurs in the *middle* of the loop, not at the top or the bottom. You must first try to read input before you can test whether you have reached the end of input. In Java, there isn't a ready-made control structure for the pattern “do work, then test, then do more work”. Therefore, we use a combination of a `while` loop and a `boolean` variable.

Sometimes, the termination condition of a loop can only be evaluated in the middle of a loop. You can introduce a Boolean variable to control such a loop.

```
boolean done = false;
while (!done)
{
   Print prompt
   String input = read input;
   if (end of input indicated)
      done = true;
   else
   {
      Process input
   }
}
```

This pattern is sometimes called “loop and a half”. Some programmers find it clumsy to introduce a control variable for such a loop. Special Topic 6.3 shows several alternatives.

Here is a complete program that reads input and analyzes the data. We separate the input handling from the computation of the data set properties by using two classes, `DataAnalyzer` and `DataSet`. The `DataAnalyzer` class handles the input and adds values to a `DataSet` object with the `add` method. It then calls the `getAverage` method and the `getMaximum` method to obtain the average and maximum of all added data.

ch06/dataset/DataAnalyzer.java

```java
import java.util.Scanner;

/**
   This program computes the average and maximum of a set
   of input values.
*/
public class DataAnalyzer
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      DataSet data = new DataSet();

      boolean done = false;
      while (!done)
      {
         System.out.print("Enter value, Q to quit: ");
         String input = in.next();
         if (input.equalsIgnoreCase("Q"))
            done = true;
         else
         {
            double x = Double.parseDouble(input);
            data.add(x);
         }
      }

      System.out.println("Average = " + data.getAverage());
      System.out.println("Maximum = " + data.getMaximum());
   }
}
```

ch06/dataset/DataSet.java

```java
/**
   Computes information about a set of data values.
*/
public class DataSet
{
   private double sum;
   private double maximum;
   private int count;

   /**
      Constructs an empty data set.
   */
   public DataSet()
   {
      sum = 0;
      count = 0;
      maximum = 0;
   }

   /**
      Adds a data value to the data set.
      @param x  a data value
   */
   public void add(double x)
   {
      sum = sum + x;
      if (count == 0 || maximum < x) maximum = x;
      count++;
   }

   /**
      Gets the average of the added data.
      @return  the average or 0 if no data has been added
   */
   public double getAverage()
   {
      if (count == 0) return 0;
      else return sum / count;
   }

   /**
      Gets the largest of the added data.
      @return  the maximum or 0 if no data has been added
   */
   public double getMaximum()
   {
      return maximum;
   }
}
```

Program Run

```
Enter value, Q to quit: 10
Enter value, Q to quit: 0
Enter value, Q to quit: -1
Enter value, Q to quit: Q
Average = 3.0
Maximum = 10.0
```

5. How do you compute the total of all positive inputs?
6. What happens with the algorithm in Section 6.3.5 when no input is provided at all? How can you overcome that problem?
7. Why does the `DataAnalyzer` class call `in.next` and not `in.nextDouble`?
8. Would the `DataSet` class still compute the correct maximum if you simplified the update of the `maximum` variable in the `add` method to the following statement?

```
if (maximum < x) maximum = x;
```

How To 6.1 Writing a Loop

This How To walks you through the process of implementing a loop statement. We will illustrate the steps with the following example problem:

Read twelve temperature values (one for each month), and display the number of the month with the highest temperature. For example, according to `http://worldclimate.com`, the average maximum temperatures for Death Valley are (in order by month):

18.2 22.6 26.4 31.1 36.6 42.2
45.7 44.5 40.2 33.1 24.2 17.6

In this case, the month with the highest temperature (45.7 degrees Celsius) is July, and the program should display 7.

Step 1 Decide what work must be done *inside* the loop.

Every loop needs to do some kind of repetitive work, such as

- Reading another item.
- Updating a value (such as a bank balance or total).
- Incrementing a counter.

If you can't figure out what needs to go inside the loop, start by writing down the steps that you would take if you solved the problem by hand. For example, with the temperature reading problem, you might write

```
Read first value.
Read second value.
If second value is higher than the first, set highest temperature to that value, highest month to 2.
Read next value.
If value is higher than the first and second, set highest temperature to that value, highest month to 3.
Read next value.
If value is higher than the highest temperature seen so far, set highest temperature to that value,
    highest month to 4.
. . .
```

Now look at these steps and reduce them to a set of *uniform* actions that can be placed into the loop body. The first action is easy:

```
Read next value.
```

The next action is trickier. In our description, we used tests "higher than the first", "higher than the first and second", "higher than the highest temperature seen so far". We need to settle on one test that works for all iterations. The last formulation is the most general.

Similarly, we must find a general way of setting the highest month. We need a variable that stores the current month, running from 1 to 12. Then we can formulate the second loop action:

```
If value is higher than the highest temperature, set highest temperature to that value,
    highest month to current month.
```

Altogether our loop is

```
Loop
    Read next value.
    If value is higher than the highest temperature, set highest temperature to that value,
        highest month to current month.
    Increment current month.
```

Step 2 Specify the loop condition.

What goal do you want to reach in your loop? Typical examples are

- Has a counter reached its final value?
- Have you read the last input value?
- Has a value reached a given threshold?

In our example, we simply want the current month to reach 12.

Step 3 Determine the loop type.

We distinguish between two major loop types. A *definite* or *count-controlled* loop is executed a definite number of times. In an *indefinite* or *event-controlled* loop, the number of iterations is not known in advance—the loop is executed until some event happens. A typical example of the latter is a loop that reads data until a sentinel is encountered.

Definite loops can be implemented as `for` statements. When you have an indefinite loop, consider the loop condition. Does it involve values that are only set inside the loop body? In that case, you should choose a `do` loop to ensure that the loop is executed at least once before the loop condition is be evaluated. Otherwise, use a `while` loop.

Sometimes, the condition for terminating a loop changes in the middle of the loop body. In that case, you can use a Boolean variable that specifies when you are ready to leave the loop. Follow this pattern:

```
boolean done = false;
while (!done)
{
    Do some work
    If all work has been completed
    {
        done = true;
    }
    else
    {
        Do more work
    }
}
```

Such a variable is called a *flag*.

In summary,

- If you know in advance how many times a loop is repeated, use a `for` loop.
- If the loop must be executed at least once, use a `do` loop.
- Otherwise, use a `while` loop.

In our example, we read 12 temperature values. Therefore, we choose a `for` loop.

Step 4 Set up variables for entering the loop for the first time.

List all variables that are used and updated in the loop, and determine how to initialize them. Commonly, counters are initialized with `0` or `1`, totals with `0`.

In our example, the variables are

```
current month
highest value
highest month
```

We need to be careful how we set up the highest temperature value. We can't simply set it to `0`. After all, our program needs to work with temperature values from Antarctica, all of which may be negative.

A good option is to set the highest temperature value to the first input value. Of course, then we need to remember to only read in another 11 values, with the current month starting at 2.

We also need to initialize the highest month with 1. After all, in an Australian city, we may never find a month that is warmer than January.

Step 5 Process the result after the loop has finished.

In many cases, the desired result is simply a variable that was updated in the loop body. For example, in our temperature program, the result is the highest month. Sometimes, the loop computes values that contribute to the final result. For example, suppose you are asked to average the temperatures. Then the loop should compute the sum, not the average. After the loop has completed, you are ready compute the average: divide the sum by the number of inputs.

Here is our complete loop.

```
Read first value; store as highest value.
highest month = 1
for (current month = 2; current month <= 12; current month++)
    Read next value.
    If value is higher than the highest value, set highest value to that value,
        highest month to current month.
```

Step 6 Trace the loop with typical examples.

Hand trace your loop code, as described in Productivity Hint 6.1 on page 198. Choose example values that are not too complex—executing the loop 3–5 times is enough to check for the most common errors. Pay special attention when entering the loop for the first and last time.

Sometimes, you want to make a slight modification to make tracing feasible. For example, when hand tracing the investment doubling problem, use an interest rate of 20 percent rather than 5 percent. When hand tracing the temperature loop, use 4 data values, not 12.

Let's say the data are 22.6 36.6 44.5 24.2. Here is the walkthrough:

current month	current value	highest month	highest value
		~~1~~	~~22.6~~
~~2~~	~~36.6~~	~~2~~	~~36.6~~
~~3~~	~~44.5~~	3	44.5
4	24.2		

The trace demonstrates that **highest month** and **highest value** are properly set.

Step 7 Implement the loop in Java.

Here's the loop for our example. Exercise P6.1 asks you to complete the program.

```
double highestValue = in.nextDouble();
int highestMonth = 1;
for (int currentMonth = 2; currentMonth <= 12; currentMonth++)
{
   double nextValue = in.nextDouble();
   if (nextValue > highestValue)
   {
      highestValue = nextValue;
      highestMonth = currentMonth;
   }
}
```

Worked Example 6.1

Credit Card Processing

This Worked Example uses a loop to remove spaces from a credit card number.

Special Topic 6.3

The "Loop and a Half" Problem

Special Topic 6.3 discusses two alternate strategies for implementing a loop whose termination condition is determined halfway into the loop body.

Special Topic 6.4

The `break` and `continue` Statements

Special Topic 6.4 discusses the optional `break` and `continue` statements. Neither statement is necessary for implementing loops, but they can occasionally make a complex loop more concise.

6.4 Nested Loops

Sometimes, the body of a loop is again a loop. We say that the inner loop is **nested** inside an outer loop. This happens often when you process two-dimensional structures, such as tables.

Let's look at an example that looks a bit more interesting than a table of numbers.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

When the body of a loop contains another loop, the loops are nested. A typical use of nested loops is printing a table with rows and columns.

We want to generate the following triangular shape:

```
[]
[][]
[][][]
[][][][]
[][][][][]
[][][][][][]
[][][][][][][]
```

The basic idea is simple. We generate a sequence of rows:

```
for (int i = 1; i <= width; i++)
{
   // Make triangle row
   . . .
}
```

How do you make a triangle row? Use another loop to concatenate the squares `[]` for that row. Then add a newline character at the end of the row. The `i`th row has `i` symbols, so the loop counter goes from 1 to `i`.

```
for (int j = 1; j <= i; j++)
   r = r + "[]";
r = r + "\n";
```

Putting both loops together yields two *nested loops:*

```
String r = "";
for (int i = 1; i <= width; i++)
{
   // Make triangle row
   for (int j = 1; j <= i; j++)
      r = r + "[]";
   r = r + "\n";
}
return r;
```

For the full text of the program, see `ch06/triangle1/` in your source code, or view it in WileyPLUS.

Table 3 Nested Loop Examples

Nested Loops	Output	Explanation

`for (i = 1; i <= 3; i++)`
`{`
`   for (j = 1; j <= 4; j++) { Print "*" }`
`   System.out.println();`
`}`
	`****`
	`****`
	`****`
		Prints 3 rows of 4 asterisks each.

`for (i = 1; i <= 4; i++)`
`{`
`   for (j = 1; j <= 3; j++) { Print "*" }`
`   System.out.println();`
`}`
	`***`
	`***`
	`***`
	`***`
		Prints 4 rows of 3 asterisks each.

Table 3 Nested Loop Examples, continued

Nested Loops	Output	Explanation

`for (i = 1; i <= 4; i++)`
`{`
`   for (j = 1; j <= i; j++) { Print "*" }`
`   System.out.println();`
`}`
	`*`
	`**`
	`***`
	`****`
		Prints 4 rows of lengths 1, 2, 3, and 4.

`for (i = 1; i <= 3; i++)`
`{`
`   for (j = 1; j <= 5; j++)`
`   {`
`      if (j % 2 == 0) { Print "*" }`
`      else { Print "-" }`
`   }`
`   System.out.println();`
`}`
	`-*-*-`
	`-*-*-`
	`-*-*-`
		Prints asterisks in even columns, dashes in odd columns.

`for (i = 1; i <= 3; i++)`
`{`
`   for (j = 1; j <= 5; j++)`
`   {`
`      if ((i + j) % 2 == 0) { Print "*" }`
`      else { Print " " }`
`   }`
`   System.out.println();`
`}`
	`* * *`
	` * * `
	`* * *`
		Prints a checkerboard pattern.

SELF CHECK

9. How would you modify the nested loops so that you print a square instead of a triangle?

10. What is the value of `n` after the following nested loops?

```
int n = 0;
for (int i = 1; i <= 5; i++)
   for (int j = 0; j < i; j++)
      n = n + j;
```

Worked Example 6.2

Manipulating the Pixels in an Image

This Worked Example shows how to use nested loops for manipulating the pixels in an image. The outer loop traverses the rows of the image, and the inner loop accesses each pixel of a row.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

6.5 Application: Random Numbers and Simulations

In a simulation, you repeatedly generate random numbers and use them to simulate an activity.

A *simulation program* uses the computer to simulate an activity in the real world (or an imaginary one). Simulations are commonly used for predicting climate change, analyzing traffic, picking stocks, and many other applications in science and business. In many simulations, one or more loops are used to modify the state of a system and observe the changes.

Here is a typical problem that can be decided by running a simulation: the *Buffon needle experiment*, devised by Comte Georges-Louis Leclerc de Buffon (1707–1788), a French naturalist. On each *try*, a one-inch long needle is dropped onto paper that is ruled with lines 2 inches apart. If the needle drops onto a line, count it as a hit. (See Figure 5.) Buffon conjectured that the quotient *tries/hits* approximates π.

Now, how can you run this experiment in the computer? You don't actually want to build a robot that drops needles on paper. The `Random` class of the Java library implements a *random number generator*, which produces numbers that appear to be completely random. To generate random numbers, you construct an object of the `Random` class, and then apply one of the following methods:

Method	Returns
`nextInt(n)`	A random integer between the integers `0` (inclusive) and `n` (exclusive)
`nextDouble()`	A random floating-point number between `0` (inclusive) and 1 (exclusive)

For example, you can simulate the cast of a die as follows:

```
Random generator = new Random();
int d = 1 + generator.nextInt(6);
```

The call `generator.nextInt(6)` gives you a random number between `0` and 5 (inclusive). Add 1 to obtain a number between 1 and 6.

If you call `nextInt` ten times, you get a random sequence of numbers similar to the following:

```
6 5 6 3 2 6 3 4 4 1
```

Actually, the numbers are not completely random. They are drawn from very long sequences of numbers that don't repeat for a long time. These sequences are

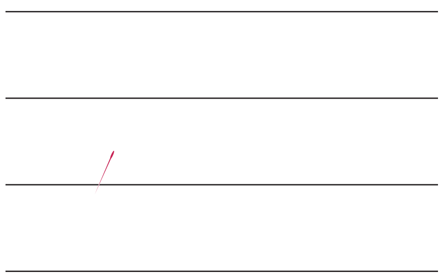


Figure 5 The Buffon Needle Experiment

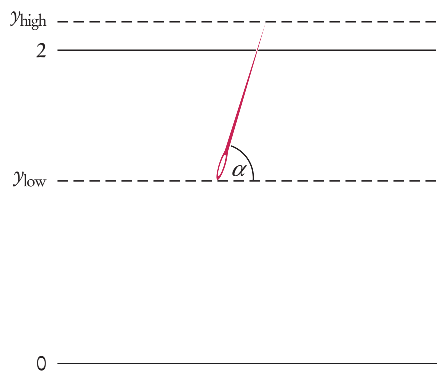


Figure 6 When Does the Needle Fall on a Line?

computed from fairly simple formulas; they just behave like random numbers. For that reason, they are often called **pseudorandom numbers**. Generating good sequences of numbers that behave like truly random sequences is an important and well-studied problem in computer science. We won't investigate this issue further, though; we'll just use the random numbers produced by the `Random` class.

To run the Buffon needle experiment, we have to work a little harder. When you throw a die, it has to come up with one of six faces. When throwing a needle, however, there are many possible outcomes. You must generate *two* random numbers: one to describe the starting position and one to describe the angle of the needle with the x-axis. Then you need to test whether the needle touches a grid line. Stop after 10,000 tries.

Let us agree to generate the *lower* point of the needle. Its x-coordinate is irrelevant, and you may assume its y-coordinate y_{low} to be any random number between 0 and 2. However, because it can be a random **floating-point number**, we use the `nextDouble` method of the `Random` class. It returns a random floating-point number between 0 and 1. Multiply by 2 to get a random number between 0 and 2.

The angle α between the needle and the x-axis can be any value between 0 degrees and 180 degrees. The upper end of the needle has y-coordinate

$$y_{high} = y_{low} + \sin(\alpha)$$

The needle is a hit if y_{high} is at least 2. See Figure 6.

For the program that carries out the simulation of the needle experiment, see `ch06/random2/` in your source code, or view it in WileyPLUS.

The point of this program is not to compute π—there are far more efficient ways to do that. Rather, the point is to show how a physical experiment can be simulated on the computer. Buffon had to physically drop the needle thousands of times and record the results, which must have been a rather dull activity. The computer can execute the experiment quickly and accurately.

Simulations are very common computer applications. Many simulations use essentially the same pattern as the code of this example: In a loop, a large number of sample values are generated, and the values of certain observations are recorded for each sample. When the simulation is completed, the averages, or other statistics of interest from the observed values are printed out.

A typical example of a simulation is the modeling of customer queues at a bank or a supermarket. Rather than observing real customers, one simulates their arrival and their transactions at the teller window or checkout stand in the computer. One can try different staffing or building layout patterns in the computer simply by making changes in the program. In the real world, making many such changes and measuring their effects would be impossible, or at least, very expensive.

SELF CHECK

11. How do you use a random number generator to simulate the toss of a coin?

12. Why is the `NeedleSimulator` program not an efficient method for computing π?

Special Topic 6.5

Loop Invariants

Special Topic 6.5 shows how you can use the technique of loop invariants to prove that a loop will always compute the correct result.

6.6 Using a Debugger

As you have undoubtedly realized by now, computer programs rarely run perfectly the first time. At times, it can be quite frustrating to find the bugs. Of course, you can insert print commands, run the program, and try to analyze the printout. If the printout does not clearly point to the problem, you may need to add and remove print commands and run the program again. That can be a time-consuming process.

A debugger is a program that you can use to execute another program and analyze its run-time behavior.

Modern development environments contain special programs, called **debuggers**, that help you locate bugs by letting you follow the execution of a program. You can stop and restart your program and see the contents of variables whenever your program is temporarily stopped. At each stop, you have the choice of what variables to inspect and how many program steps to run until the next stop.

Some people feel that debuggers are just a tool to make programmers lazy. Admittedly some people write sloppy programs and then fix them up with a debugger, but the majority of programmers make an honest effort to write the best program they can before trying to run it through a debugger. These programmers realize that a debugger, while more convenient than print commands, is not cost-free. It does take time to set up and carry out an effective debugging session.

In actual practice, you cannot avoid using a debugger. The larger your programs get, the harder it is to debug them simply by inserting print commands. You will find that the time investment to learn about a debugger is amply repaid in your programming career.

Like compilers, debuggers vary widely from one system to another. On some systems they are quite primitive and require you to memorize a small set of arcane commands; on others they have an intuitive window interface. The screen shots in this chapter show the debugger in the Eclipse development environment, downloadable for free from the Eclipse Foundation web site (`eclipse.org`). Other integrated environments, such as BlueJ, also include debuggers. A free standalone debugger called JSwat is available from `www.bluemarsh.com/java/jswat`.

✚ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

You can make effective use of a debugger by mastering just three concepts: breakpoints, single-stepping, and inspecting variables.

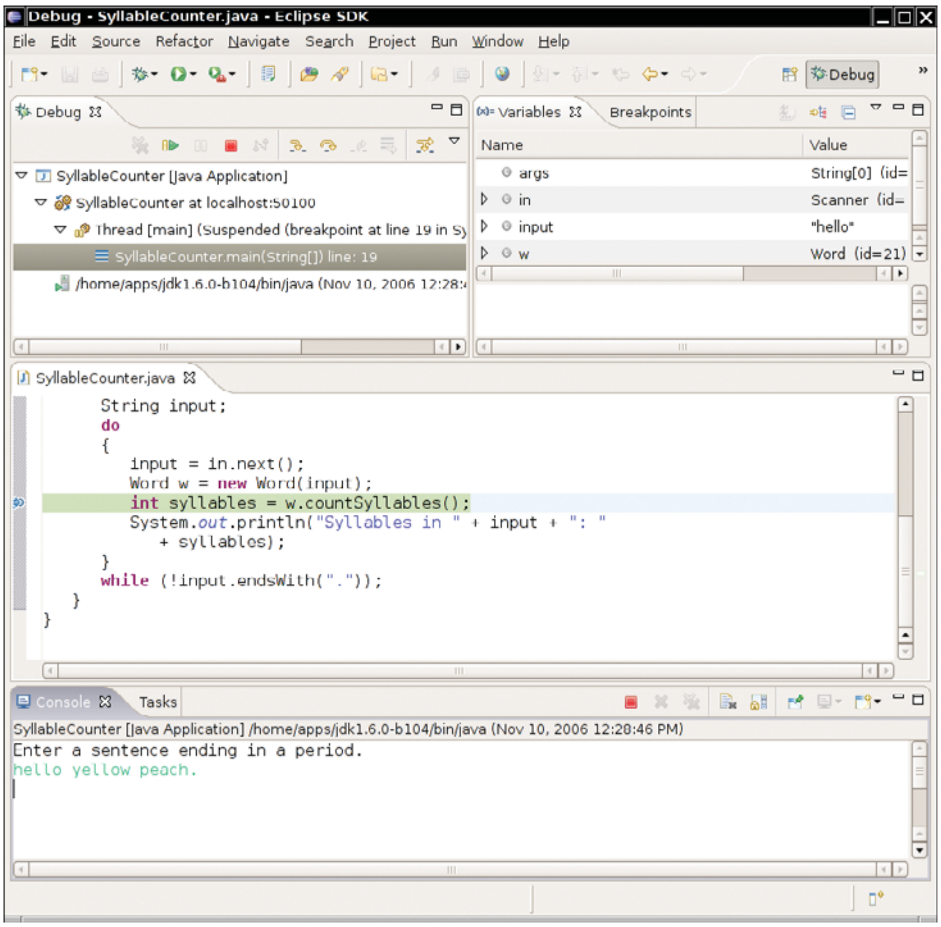
When a debugger executes a program, the execution is suspended whenever a breakpoint is reached.

You will have to find out how to prepare a program for debugging and how to start a debugger on your system. If you use an integrated development environment, which contains an editor, compiler, and debugger, this step is usually very easy. You just build the program in the usual way and pick a menu command to start debugging. On some systems, you must manually build a debug version of your program and invoke the debugger.

Once you have started the debugger, you can go a long way with just three debugging commands: "set breakpoint", "single step", and "inspect variable". The names and keystrokes or mouse clicks for these commands differ widely between debuggers, but all debuggers support these basic commands. You can find out how, either from the documentation or a lab manual, or by asking someone who has used the debugger before.

When you start the debugger, it runs at full speed until it reaches a **breakpoint**. Then execution stops, and the breakpoint that causes the stop is displayed (see Figure 7). You can now inspect variables and step through the program a line at a time, or continue running the program at full speed until it reaches the next breakpoint. When the program terminates, the debugger stops as well.

Breakpoints stay active until you remove them, so you should periodically clear the breakpoints that you no longer need.


Debug - SyllableCounter.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
Debug
Variables
Breakpoints
Name
Value
SyllableCounter.java
Console
Tasks

SyllableCounter [Java Application]
SyllableCounter at localhost:50100
Thread [main] (Suspended (breakpoint at line 19 in Sy
SyllableCounter.main(String[]) line: 19
/home/apps/jdk1.6.0-b104/bin/java (Nov 10, 2006 12:28:

Name	Value
args	String[0] (id=
in	Scanner (id=
input	"hello"
w	Word (id=21)

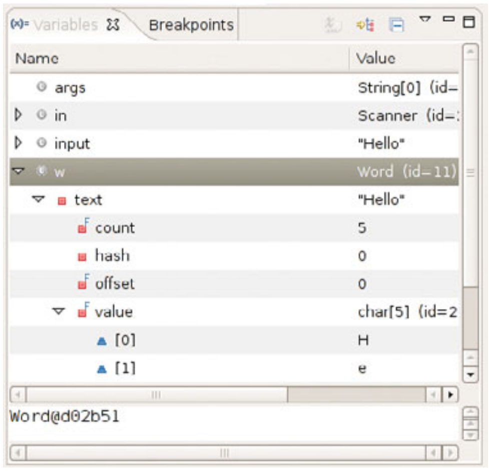
```
         String input;
         do
         {
            input = in.next();
            Word w = new Word(input);
            int syllables = w.countSyllables();
            System.out.println("Syllables in " + input + ": "
               + syllables);
         }
         while (!input.endsWith("."));
      }
   }
```

SyllableCounter [Java Application] /home/apps/jdk1.6.0-b104/bin/java (Nov 10, 2006 12:28:46 PM)

```
Enter a sentence ending in a period.
hello yellow peach.
```

Figure 7 Stopping at a Breakpoint

Figure 8
Inspecting Variables



Name	Value
args	String[0] (id=
in	Scanner (id=
input	"Hello"
w	Word (id=11)
text	"Hello"
count	5
hash	0
offset	0
value	char[5] (id=2
[0]	H
[1]	e

```
Word@d02b51
```

Once the program has stopped, you can look at the current values of variables. Again, the method for selecting the variables differs among debuggers. Some debuggers always show you a window with the current local variables. On other debuggers you issue a command such as “inspect variable” and type in or click on the variable. The debugger then displays the contents of the variable. If all variables contain what you expected, you can run the program until the next point where you want to stop.

The single-step command executes the program one line at a time.

When inspecting objects, you often need to give a command to “open up” the object, for example by clicking on a tree node. Once the object is opened up, you see its instance variables (see Figure 8).

Running to a breakpoint gets you there speedily, but you don’t know how the program got there. You can also step through the program a line at a time. Then you know how the program flows, but it can take a long time to step through it. The *single-step command* executes the current line and stops at the next program line. Most debuggers have two single-step commands, one called *step into*, which steps inside method calls, and one called *step over*, which skips over method calls.

For example, suppose the current line is

```
String input = in.next();
Word w = new Word(input);
int syllables = w.countSyllables();
System.out.println("Syllables in " + input + ": " + syllables);
```

When you step over method calls, you get to the next line:

```
String input = in.next();
Word w = new Word(input);
int syllables = w.countSyllables();
System.out.println("Syllables in " + input + ": " + syllables);
```

However, if you step into method calls, you enter the first line of the `countSyllables` method.

```
public int countSyllables()
{
   int count = 0;
   int end = text.length() - 1;
   . . .
}
```

You should step *into* a method to check whether it carries out its job correctly. You should step *over* a method if you know it works correctly.

Finally, when the program has finished running, the debug session is also finished. To run the program again, you may be able to reset the debugger, or you may need to exit the debugging program and start over. Details depend on the particular debugger.

A debugger can be used only to analyze the presence of bugs, not to show that a program is bug-free.

A debugger can be an effective tool for finding and removing bugs in your program. However, it is no substitute for good design and careful programming. If the debugger does not find any errors, it does not mean that your program is bug-free. Testing and debugging can only show the presence of bugs, not their absence.

SELF CHECK

13. In the debugger, you are reaching a call to `System.out.println`. Should you step into the method or step over it?

14. In the debugger, you are reaching the beginning of a method with a couple of loops inside. You want to find out the return value that is computed at the end of the method. Should you set a breakpoint, or should you step through the method?

How To 6.2 Debugging

Now you know about the mechanics of debugging, but all that knowledge may still leave you helpless when you fire up a debugger to look at a sick program. There are a number of strategies that you can use to recognize bugs and their causes.

Step 1 Reproduce the error.

As you test your program, you notice that it sometimes does something wrong. It gives the wrong output, it seems to print something completely random, it goes in an infinite loop, or it crashes. Find out exactly how to reproduce that behavior. What numbers did you enter? Where did you click with the mouse?

Run the program again; type in exactly the same numbers, and click with the mouse on the same spots (or as close as you can get). Does the program exhibit the same behavior? If so, then it makes sense to fire up a debugger to study this particular problem. Debuggers are good for analyzing particular failures. They aren't terribly useful for studying a program in general.

Step 2 Simplify the error.

Before you fire up a debugger, it makes sense to spend a few minutes trying to come up with a simpler input that also produces an error. Can you use shorter words or simpler numbers and still have the program misbehave? If so, use those values during your debugging session.

Step 3 Divide and conquer.

Use the divide-and-conquer technique to locate the point of failure of a program.

Now that you have a particular failure, you want to get as close to the failure as possible. The key point of debugging is to locate the code that produces the failure. Just as with real insect pests, finding the bug can be hard, but once you find it, squashing it is usually the easy part. Suppose your program dies with a division by `0`. Because there are many division operations in a typical program, it is often not feasible to set breakpoints to all of them. Instead, use a technique of divide and conquer. Step over the methods in `main`, but don't step inside them. Eventually, the failure will happen again. Now you know which method contains the bug: It is the last method that was called from `main` before the program died. Restart the debugger and go back to that line in `main`, then step inside that method. Repeat the process.

Eventually, you will have pinpointed the line that contains the bad division. Maybe it is completely obvious from the code why the denominator is not correct. If not, you need to find the location where it is computed. Unfortunately, you can't go back in the debugger. You need to restart the program and move to the point where the denominator computation happens.

Step 4 Know what your program should do.

During debugging, compare the actual contents of variables against the values you know they should have.

A debugger shows you what the program does. You must know what the program *should* do, or you will not be able to find bugs. Before you trace through a loop, ask yourself how many iterations you expect the program to make. Before you inspect a variable, ask yourself what you expect to see. If you have no clue, set aside some time and think first. Have a calculator handy to make independent computations. When you know what the value should be, inspect the variable. This is the moment of truth. If the program is still on the right track, then that value is what you expected, and you must look further for the bug. If the value is different, you may be on to something. Double-check your computation. If you are sure your value is correct, find out why your program comes up with a different value.

In many cases, program bugs are the result of simple errors such as loop termination conditions that are off by one. Quite often, however, programs make computational errors. Maybe they are supposed to add two numbers, but by accident the code was written to subtract them. Unlike your calculus instructor, programs don't make a special effort to ensure that everything is a simple integer (and neither do real-world problems). You will need to make some calculations with large integers or nasty floating-point numbers. Sometimes these calculations can be avoided if you just ask yourself, "Should this quantity be positive? Should it be larger than that value?" Then inspect variables to verify those theories.

Step 5 Look at all details.

When you debug a program, you often have a theory about what the problem is. Nevertheless, keep an open mind and look around at all details. What strange messages are displayed? Why does the program take another unexpected action? These details count. When you run a debugging session, you really are a detective who needs to look at every clue available.

If you notice another failure on the way to the problem that you are about to pin down, don't just say, "I'll come back to it later". That very failure may be the original cause for your current problem. It is better to make a note of the current problem, fix what you just found, and then return to the original mission.

Step 6 Make sure you understand each bug before you fix it.

Once you find that a loop makes too many iterations, it is very tempting to apply a "Band-Aid" solution and subtract 1 from a variable so that the particular problem doesn't appear again. Such a quick fix has an overwhelming probability of creating trouble elsewhere. You really need to have a thorough understanding of how the program should be written before you apply a fix.

It does occasionally happen that you find bug after bug and apply fix after fix, and the problem just moves around. That usually is a symptom of a larger problem with the program logic. There is little you can do with the debugger. You must rethink the program design and reorganize it.

Worked Example 6.3

A Sample Debugging Session

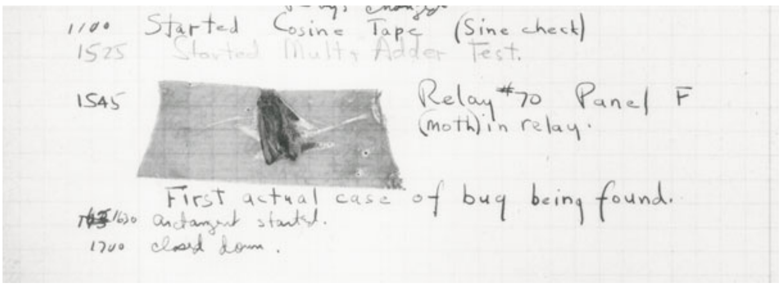
This Worked Example shows how to find bugs in an algorithm for counting the syllables of a word.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Random Fact 6.1

The First Bug

According to legend, the first bug was one found in 1947 in the Mark II, a huge electro-mechanical computer at Harvard University. It really was caused by a bug—a moth was trapped in a relay switch. Actually, from the note that the operator left in the log book next to the moth (see the figure), it appears as if the term “bug” had already been in active use at the time.



1100 Started Cosine Tape (Sine check)
1525 Started Mult + Adder Test.
1545 Relay #70 Panel F (moth) in relay.
First actual case of bug being found.
1630 Arctangent started.
1700 closed down.

The First Bug

The pioneering computer scientist Maurice Wilkes wrote: “Somehow, at the Moore School and afterwards, one had always assumed there would be no particular difficulty in getting programs right. I can remember the exact instant in time at which it dawned on me that a great part of my future life would be spent finding mistakes in my own programs.”

Summary of Learning Objectives

Explain the flow of execution in a loop.

- A `while` statement executes a block of code repeatedly. A condition controls for how long the loop is executed.
- An off-by-one error is a common error when programming loops. Think through simple test cases to avoid this type of error.

Use `for` loops to implement counting loops.

- You use a `for` loop when a variable runs from a starting to an ending value with a constant increment or decrement.
- Make a choice between symmetric and asymmetric loop bounds.
- Count the number of iterations to check that your `for` loop is correct.

Implement loops that process a data set until a sentinel value is encountered.

- Sometimes, the termination condition of a loop can only be evaluated in the middle of a loop. You can introduce a Boolean variable to control such a loop.

Use nested loops to implement multiple levels of iterations.

- When the body of a loop contains another loop, the loops are nested. A typical use of nested loops is printing a table with rows and columns.

Apply loops to the implementation of simulations that involve random values.

- In a simulation, you repeatedly generate random numbers and use them to simulate an activity.

Use a debugger to locate errors in a running program.

- A debugger is a program that you can use to execute another program and analyze its run-time behavior.
- You can make effective use of a debugger by mastering just three concepts: breakpoints, single-stepping, and inspecting variables.
- When a debugger executes a program, the execution is suspended when-ever a breakpoint is reached.
- The single-step command executes the program one line at a time.
- A debugger can be used only to analyze the presence of bugs, not to show that a program is bug-free.
- Use the divide-and-conquer technique to locate the point of failure of a program.
- During debugging, compare the actual contents of variables against the values you know they should have.

Classes, Objects, and Methods Introduced in this Chapter

```
java.util.Random
   nextDouble
   nextInt
```

Media Resources

www.wiley.com/ college/ horstmann

- ***Worked Example*** Credit Card Processing
- ***Worked Example*** Manipulating the Pixels in an Image
- ***Worked Example*** A Sample Debugging Session
- Lab Exercises
- ***Animation*** Tracing a Loop
- ***Animation*** The `for` Loop
- Practice Quiz
- Code Completion Exercises

Review Exercises

★★ **R6.1** Which loop statements does Java support? Give simple rules when to use each loop type.

★★ **R6.2** What does the following code print?

```
for (int i = 0; i < 10; i++)
{
      for (int j = 0; j < 10; j++)
         System.out.print(i * j % 10);
      System.out.println();
   }
```

★★ **R6.3** How many iterations do the following loops carry out? Assume that `i` is an integer variable that is not changed in the loop body.

a. `for (i = 1; i <= 10; i++) . . .`
b. `for (i = 0; i < 10; i++) . . .`
c. `for (i = 10; i > 0; i--) . . .`
d. `for (i = -10; i <= 10; i++) . . .`
e. `for (i = 10; i >= 0; i++) . . .`
f. `for (i = -10; i <= 10; i = i + 2) . . .`
g. `for (i = -10; i <= 10; i = i + 3) . . .`

★ **R6.4** Rewrite the following `for` loop into a `while` loop.

```
int s = 0;
for (int i = 1; i <= 10; i++) s = s + i;
```

★★ **R6.5** Rewrite the following `do` loop into a `while` loop.

```
int n = 1;
double x = 0;
double s;
do
{
   s = 1.0 / (n * n);
   x = x + s;
   n++;
}
while (s > 0.01);
```

★ **R6.6** What is an infinite loop? On your computer, how can you terminate a program that executes an infinite loop?

★★★ **R6.7** Give three strategies for implementing the following “loop and a half”:

```
Loop
  Read name of bridge.
  If not OK, exit loop.
  Read length of bridge in feet.
  If not OK, exit loop.
  Convert length to meters.
  Print bridge data.
```

Use a Boolean variable, a `break` statement, and a method with multiple `return` statements. Which of these three approaches do you find clearest?

★ **R6.8** Implement a loop that prompts a user to enter a number between 1 and 10, giving three tries to get it right.

★ **R6.9** Sometimes students write programs with instructions such as “Enter data, 0 to quit” and that exit the data entry loop when the user enters the number 0. Explain why that is usually a poor idea.

★ **R6.10** How would you use a random number generator to simulate the drawing of a playing card?

★ **R6.11** What is an “off-by-one error”? Give an example from your own programming experience.

★★ **R6.12** Give an example of a `for` loop in which symmetric bounds are more natural. Give an example of a `for` loop in which asymmetric bounds are more natural.

★ **R6.13** What are nested loops? Give an example where a nested loop is typically used.

★T **R6.14** Explain the differences between these debugger operations:

- Stepping into a method
- Stepping over a method

★★T **R6.15** Explain in detail how to inspect the string stored in a `String` object in your debugger.

★★T **R6.16** Explain in detail how to inspect the information stored in a `Rectangle` object in your debugger.

★★T **R6.17** Explain in detail how to use your debugger to inspect the balance stored in a `BankAccount` object.

★★T **R6.18** Explain the divide-and-conquer strategy to get close to a bug in a debugger.

Programming Exercises

★ **P6.1** Complete the program in How To 6.1 on page 215. Your program should read twelve temperature values and print the month with the highest temperature.

★★★ **P6.2** *Credit Card Number Check*. The last digit of a credit card number is the *check digit*, which protects against transcription errors such as an error in a single digit or switching two digits. The following method is used to verify actual credit card numbers but, for simplicity, we will describe it for numbers with 8 digits instead of 16:

- Starting from the rightmost digit, form the sum of every other digit. For example, if the credit card number is 4358 9795, then you form the sum 5 + 7 + 8 + 3 = 23.
- Double each of the digits that were not included in the preceding step. Add all digits of the resulting numbers. For example, with the number given above, doubling the digits, starting with the next-to-last one, yields 18 18 10 8. Adding all digits in these values yields 1 + 8 + 1 + 8 + 1 + 0 + 8 = 27.
- Add the sums of the two preceding steps. If the last digit of the result is 0, the number is valid. In our case, 23 + 27 = 50, so the number is valid.

Write a program that implements this algorithm. The user should supply an 8-digit number, and you should print out whether the number is valid or not. If it is not valid, you should print out the value of the check digit that would make the number valid.

★ **P6.3** *Currency conversion.* Write a program `CurrencyConverter` that asks the user to enter today’s price of one dollar in euro. Then the program reads U.S. dollar values and converts each to euro values. Stop when the user enters `Q`.

★★★ **P6.4** *Projectile flight.* Suppose a cannonball is propelled vertically into the air with a starting velocity v_0. Any calculus book will tell us that the position of the ball after t seconds is $s(t) = -0.5 \cdot g \cdot t^2 + v_0 \cdot t$, where $g = 9.81$ m/sec^2 is the gravitational force of the earth. No calculus book ever mentions why someone would want to carry out such an obviously dangerous experiment, so we will do it in the safety of the computer.

In fact, we will confirm the theorem from calculus by a simulation. In our simulation, we will consider how the ball moves in very short time intervals Δt. In a short time interval the velocity v is nearly constant, and we can compute the distance the ball moves as $\Delta s = v \cdot \Delta t$. In our program, we will simply set

```
double deltaT = 0.01;
```

and update the position by

```
s = s + v * deltaT;
```

The velocity changes constantly—in fact, it is reduced by the gravitational force of the earth. In a short time interval, v decreases by $g \cdot \Delta t$, and we must keep the velocity updated as

```
v = v - g * deltaT;
```

In the next iteration the new velocity is used to update the distance.

Now run the simulation until the cannonball falls back to the earth. Get the initial velocity as an input (100 m/sec is a good value). Update the position and velocity 100 times per second, but only print out the position every full second. Also print out the values from the exact formula $s(t) = -0.5 \cdot g \cdot t^2 + v_0 \cdot t$ for comparison. Use a class `Cannonball`.

What is the benefit of this kind of simulation when an exact formula is available? Well, the formula from the calculus book is *not* exact. Actually, the gravitational force diminishes the farther the cannonball is away from the surface of the earth. This complicates the algebra sufficiently that it is not possible to give an exact formula for the actual motion, but the computer simulation can simply be extended to apply a variable gravitational force. For cannonballs, the calculus-book formula is actually good enough, but computers are necessary to compute accurate trajectories for higher-flying objects such as ballistic missiles.

★★ **P6.5** Write a program that prints the powers of ten

```
1.0
10.0
100.0
1000.0
10000.0
100000.0
1000000.0
1.0E7
1.0E8
1.0E9
1.0E10
1.0E11
```

Implement a class

```
public class PowerGenerator
{
      /**
         Constructs a power generator.
         @param aFactor the number that will be multiplied by itself
      */
      public PowerGenerator(double aFactor) { . . . }

      /**
         Computes the next power.
      */
      public double nextPower() { . . . }
      . . .
   }
```

Then supply a test class `PowerGeneratorRunner` that calls `System.out.println( myGenerator.nextPower())` twelve times.

★★ **P6.6** The *Fibonacci sequence* is defined by the following rule. The first two values in the sequence are 1 and 1. Every subsequent value is the sum of the two values preceding it. For example, the third value is $1 + 1 = 2$, the fourth value is $1 + 2 = 3$, and the fifth is $2 + 3 = 5$. If f_n denotes the nth value in the Fibonacci sequence, then

$$\begin{aligned} f_1 &= 1 \\ f_2 &= 1 \\ f_n &= f_{n-1} + f_{n-2} \quad \text{if } n > 2 \end{aligned}$$

Write a program that prompts the user for n and prints the first n values in the Fibonacci sequence. Use a class `FibonacciGenerator` with a method `nextNumber`.

Hint: There is no need to store all values for f_n. You only need the last two values to compute the next one in the series:

```
   fold1 = 1;
   fold2 = 1;
   fnew = fold1 + fold2;
```

After that, discard `fold2`, which is no longer needed, and set `fold2` to `fold1` and `fold1` to `fnew`.

Your generator class will be tested with this runner program:

```
   public class FibonacciRunner
   {
      public static void main(String[] args)
      {
         Scanner in = new Scanner(System.in);

         System.out.println("Enter n:");
         int n = in.nextInt();

         FibonacciGenerator fg = new FibonacciGenerator();

         for (int i = 1; i <= n; i++)
            System.out.println(fg.nextNumber());
      }
   }
```

★★ **P6.7** *Mean and standard deviation.* Write a program that reads a set of floating-point data values from the input. When the user indicates the end of input, print out the count of the values, the average, and the standard deviation. The average of a data set $x_1, \ldots, x_n$ is

$$\overline{x} = \frac{\sum x_i}{n}$$

where $\sum x_i = x_1 + \cdots + x_n$ is the sum of the input values. The standard deviation is

$$s = \sqrt{\frac{\sum \left(x_i - \overline{x}\right)^2}{n - 1}}$$

However, that formula is not suitable for our task. By the time you have computed the mean, the individual x_i are long gone. Until you know how to save these values, use the numerically less stable formula

$$s = \sqrt{\frac{\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2}{n - 1}}$$

You can compute this quantity by keeping track of the count, the sum, and the sum of squares in the `DataSet` class as you process the input values.

★★ **P6.8** *Factoring of integers.* Write a program that asks the user for an integer and then prints out all its factors in increasing order. For example, when the user enters 150, the program should print

```
2
3
5
5
```

Use a class `FactorGenerator` with a constructor `FactorGenerator(int numberToFactor)` and methods `nextFactor` and `hasMoreFactors`. Supply a class `FactorPrinter` whose `main` method reads a user input, constructs a `FactorGenerator` object, and prints the factors.

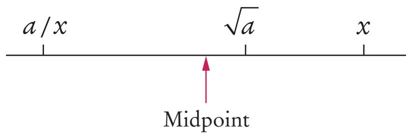
★★ **P6.9** *Prime numbers.* Write a program that prompts the user for an integer and then prints out all prime numbers up to that integer. For example, when the user enters 20, the program should print

```
2
3
5
7
11
13
17
19
```

Recall that a number is a prime number if it is not divisible by any number except 1 and itself.

Supply a class `PrimeGenerator` with a method `nextPrime`.

★★ **P6.10** The *Heron method* is a method for computing square roots that was known to the ancient Greeks. If x is a guess for the value $\sqrt{a}$, then the average of x and a/x is a better guess.



Implement a class `RootApproximator` that starts with an initial guess of 1 and whose `nextGuess` method produces a sequence of increasingly better guesses. Supply a method `hasMoreGuesses` that returns `false` if two successive guesses are sufficiently close to each other (that is, they differ by no more than a small value ε). Then test your class like this:

```
RootApproximator approx = new RootApproximator(a, EPSILON);
while (approx.hasMoreGuesses())
   System.out.println(approx.nextGuess());
```

★★ **P6.11** The best known iterative method for computing the roots of a function f (that is, the x-values for which $f(x)$ is 0) is Newton–Raphson approximation. To find the zero of a function whose derivative is also known, compute

$$x_{\text{new}} = x_{\text{old}} - f\left(x_{\text{old}}\right)/f'\left(x_{\text{old}}\right).$$

For this exercise, write a program to compute nth roots of floating-point numbers. Prompt the user for a and n, then obtain $\sqrt[n]{a}$ by computing a zero of the function $f(x) = x^n - a$. Follow the approach of Exercise P6.10.

★★ **P6.12** The value of e^x can be computed as the power series

$$e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!}$$

where $n! = 1 \cdot 2 \cdot 3 \cdot \ldots \cdot n$.

Write a program that computes e^x using this formula. Of course, you can't compute an infinite sum. Just keep adding values until an individual summand (term) is less than a certain threshold. At each step, you need to compute the new term and add it to the total. Update these terms as follows:

```
term = term * x / n;
```

Follow the approach of the preceding two exercises, by implementing a class `ExpApproximator`. Its first guess should be 1.

★ **P6.13** Write a program `RandomDataAnalyzer` that generates 100 random numbers between 0 and 1000 and adds them to a `DataSet`. Print out the average and the maximum.

★★ **P6.14** Program the following simulation: Darts are thrown at random points onto the square with corners (1,1) and (–1,–1). If the dart lands inside the unit circle (that is, the circle with center (0,0) and radius 1), it is a hit. Otherwise it is a miss. Run this simulation and use it to determine an approximate value for π. Extra credit if you explain why this is a better method for estimating π than the Buffon needle program.

★★★G **P6.15** *Random walk.* Simulate the wandering of an intoxicated person in a square street grid. Draw a grid of 20 streets horizontally and 20 streets vertically. Represent the simulated drunkard by a dot, placed in the middle of the grid to start. For 100 times, have the simulated drunkard randomly pick a direction (east, west, north, south), move one block in the chosen direction, and draw the dot. (One might expect that on average the person might not get anywhere because the moves to different directions cancel one another out in the long run, but in fact it can be shown with probability 1 that the person eventually moves outside any finite region. Use classes for the grid and the drunkard.

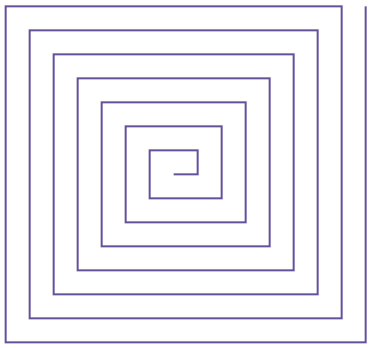
★★★G **P6.16** This exercise is a continuation of Exercise P6.4. Most cannonballs are not shot upright but at an angle. If the starting velocity has magnitude v and the starting angle is α, then the velocity is a vector with components $v_x = v \cdot \cos(\alpha)$, $v_y = v \cdot \sin(\alpha)$. In the x-direction the velocity does not change. In the y-direction the gravitational force takes its toll. Repeat the simulation from the previous exercise, but update the x and y components of the location and the velocity separately. In every iteration, plot the location of the cannonball on the graphics display as a tiny circle. Repeat until the cannonball has reached the earth again.

This kind of problem is of historical interest. The first computers were designed to carry out just such ballistic calculations, taking into account the diminishing gravity for high-flying projectiles and wind speeds.

★G **P6.17** Write a graphical application that displays a checkerboard with 64 squares, alternating white and black.

★★G **P6.18** Write a graphical application that prompts a user to enter a number `n` and that draws `n` circles with random diameter and random location. The circles should be completely contained inside the window.

★★★G **P6.19** Write a graphical application that draws a spiral, such as the following:



★★G **P6.20** It is easy and fun to draw graphs of curves with the Java graphics library. Simply draw 100 line segments joining the points $(x, f(x))$ and $(x + d, f(x + d))$, where x ranges from x_{min} to x_{max} and $d = (x_{\text{max}} - x_{\text{min}})/100$.

Draw the curve $f(x) = 0.00005x^3 - 0.03x^2 + 4x + 200$, where x ranges from 0 to 400 in this fashion.

★★★G **P6.21** Draw a picture of the “four-leaved rose” whose equation in polar coordinates is $r = \cos(2\theta)$. Let θ go from 0 to 2π in 100 steps. Each time, compute `r` and then compute the (x,y) coordinates from the polar coordinates by using the formula

$$x = r \cdot \cos(\theta),\ y = r \cdot \sin(\theta)$$

Programming Projects

Project 6.1 *Flesch Readability Index.* The following index was invented by Rudolf Flesch as a tool to gauge the legibility of a document without linguistic analysis.

- Count all words in the file. A *word* is any sequence of characters delimited by white space, whether or not it is an actual English word.
- Count all syllables in each word. To make this simple, use the following rules: Each *group* of adjacent vowels (a, e, i, o, u, y) counts as one syllable (for example, the "ea" in "real" contributes one syllable, but the "e . . . a" in "regal" count as two syllables). However, an "e" at the end of a word doesn't count as a syllable. Also, each word has at least one syllable, even if the previous rules give a count of 0.
- Count all sentences. A sentence is ended by a period, colon, semicolon, question mark, or exclamation mark.
- The index is computed by

$$\begin{aligned}\text{Index} = {} & 206.835 \\ & - 84.6 \times (\text{Number of syllables}/\text{Number of words}) \\ & - 1.015 \times (\text{Number of words}/\text{Number of sentences})\end{aligned}$$

  rounded to the nearest integer.

The purpose of the index is to force authors to rewrite their text until the index is high enough. This is achieved by reducing the length of sentences and by removing long words. For example, the sentence

> The following index was invented by Flesch as a simple tool to estimate the legibility of a document without linguistic analysis.

can be rewritten as

> Flesch invented an index to check whether a text is easy to read. To compute the index, you need not look at the meaning of the words.

This index is a number, usually between 0 and 100, indicating how difficult the text is to read. Some example indices for random material from various publications are:

Comics	95
Consumer ads	82
Sports Illustrated	65
Time	57
New York Times	39
Auto insurance policy	10
Internal Revenue Code	−6

Translated into educational levels, the indices are:

91–100	5th grader
81–90	6th grader
71–80	7th grader
66–70	8th grader
61–65	9th grader
51–60	High school student
31–50	College student
0–30	College graduate
Less than 0	Law school graduate

Your program should read a text file in, compute the legibility index, and print out the equivalent educational level. Use classes `Word` and `Document`.

Project 6.2 *The game of Nim.* This is a well-known game with a number of variants. We will consider the following variant, which has an interesting winning strategy. Two players alternately take marbles from a pile. In each move, a player chooses how many marbles to take. The player must take at least one but at most half of the marbles. Then the other player takes a turn. The player who takes the last marble loses.

Write a program in which the computer plays against a human opponent. Generate a random integer between 10 and 100 to denote the initial size of the pile. Generate a random integer between 0 and 1 to decide whether the computer or the human takes the first turn. Generate a random integer between 0 and 1 to decide whether the computer plays *smart* or *stupid*. In stupid mode, the computer simply takes a random legal value (between 1 and $n/2$) from the pile whenever it has a turn. In smart mode the computer takes off enough marbles to make the size of the pile a power of 2 minus 1—that is, 3, 7, 15, 31, or 63. That is always a legal move, except if the size of the pile is currently one less than a power of 2. In that case, the computer makes a random legal move.

Note that the computer cannot be beaten in smart mode when it has the first move, unless the pile size happens to be 15, 31, or 63. Of course, a human player who has the first turn and knows the winning strategy can win against the computer.

When you implement this program, be sure to use classes `Pile`, `Player`, and `Game`. A player can be either stupid, smart, or human. (Human `Player` objects prompt for input.)

Answers to Self-Check Questions

1. Never.
2. The `waitForBalance` method would never return due to an infinite loop.
3.
```
int i = 1;
while (i <= numberOfYears)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
   i++;
}
```
4. 11 times.
5.
```
double total = 0;
while (in.hasNextDouble())
{
   double input = in.nextDouble();
   if (value > 0) total = total + input;
}
```
6. The initial call to `in.nextDouble()` fails, terminating the program. One solution is to do all input in the loop and introduce a Boolean variable that checks whether the loop is entered for the first time.
```
double input = 0;
boolean first = true;
while (in.hasNextDouble())
{
   double previous = input;
   input = in.nextDouble();
   if (first) { first = false; }
   else if (input == previous) { System.out.println("Duplicate input"); }
}
```
7. Because we don't know whether the next input is a number or the letter `Q`.
8. No. If *all* input values are negative, the maximum is also negative. However, the `maximum` variable is initialized with `0`. With this simplification, the maximum would be falsely computed as `0`.
9. Change the inner loop to `for (int j = 1; j <= width; j++)`.
10. 20.
11. `int n = generator.nextInt(2); // 0 = heads, 1 = tails`
12. The program repeatedly calls `Math.toRadians(angle)`. You could simply call `Math.toRadians(180)` to compute π.
13. You should step over it because you are not interested in debugging the internals of the `println` method.
14. You should set a breakpoint. Stepping through loops can be tedious.

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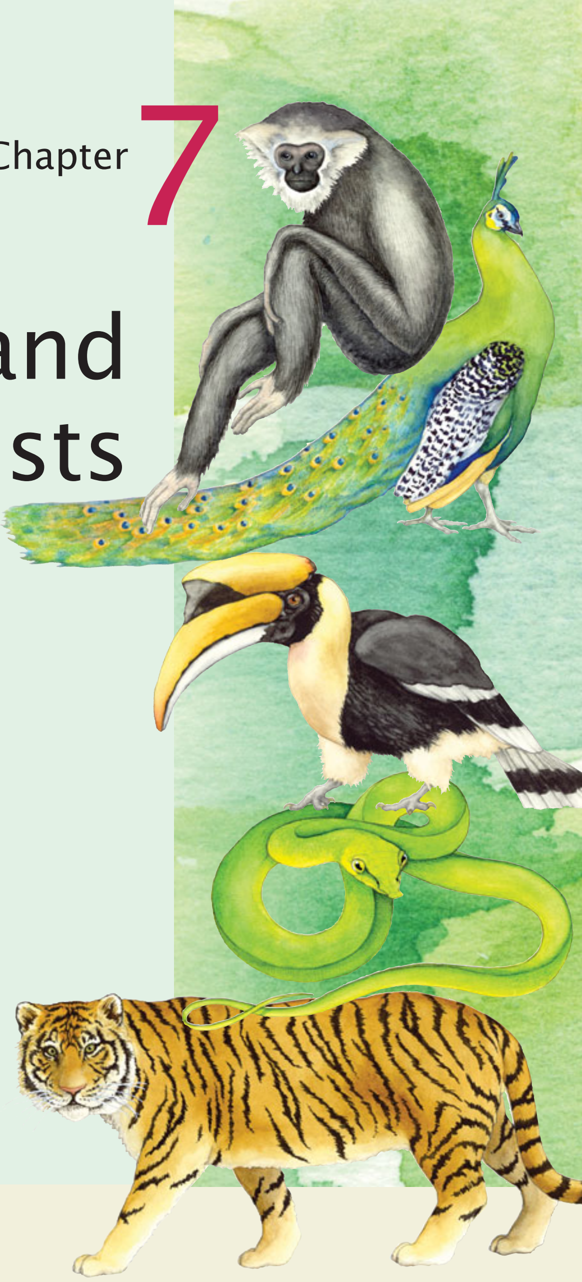
Chapter 7

Arrays and Array Lists



CHAPTER GOALS

- To become familiar with using arrays and array lists
- To learn about wrapper classes, auto-boxing, and the enhanced `for` loop
- To study common array algorithms
- To learn how to use two-dimensional arrays
- To understand when to choose array lists and arrays in your programs
- To implement partially filled arrays

T To understand the concept of regression testing

In order to process large quantities of data, you need to have a mechanism for collecting values. In Java, arrays and array lists serve this purpose. In this chapter, you will learn how to construct arrays and array lists, fill them with values, and access the stored values. We introduce the enhanced `for` loop, a convenient statement for processing all elements of a collection. You will see how to use the enhanced `for` loop, as well as ordinary loops, to implement common array algorithms. The chapter concludes with a discussion of two-dimensional arrays, which are useful for handling rows and columns of data.

Chapter Contents

7.1 Arrays 242
Syntax 7.1: Arrays 245
Common Error 7.1: Bounds Errors 245
Common Error 7.2: Uninitialized and Unfilled Arrays 246
Quality Tip 7.1: Use Arrays for Sequences of Related Values 246
Quality Tip 7.2: Make Parallel Arrays into Arrays of Objects 246
Special Topic 7.1: Methods with a Variable Number of Parameters ⊕
Random Fact 7.1: An Early Internet Worm ⊕

7.2 Array Lists 248
Syntax 7.2: Array Lists 250
Common Error 7.3: Length and Size 253
Special Topic 7.2: ArrayList Syntax Enhancements in Java 7 253

7.3 Wrappers and Auto-boxing 254

7.4 The Enhanced for Loop 255
Syntax 7.3: The "for each" Loop 256

7.5 Partially Filled Arrays 257
Common Error 7.4: Underestimating the Size of a Data Set 259

7.6 Common Array Algorithms 259
Productivity Hint 7.1: Easy Printing of Arrays and Array Lists 268
How To 7.1: Working with Arrays and Array Lists 269
Worked Example 7.1: Rolling the Dice ⊕

7.7T Regression Testing 271
Productivity Hint 7.2: Batch Files and Shell Scripts ⊕
Random Fact 7.2: The Therac-25 Incidents ⊕

7.8 Two-Dimensional Arrays 274
Worked Example 7.2: A World Population Table ⊕
Special Topic 7.3: Two-Dimensional Arrays with Variable Row Lengths ⊕
Special Topic 7.4: Multidimensional Arrays ⊕

7.1 Arrays

In many programs, you need to manipulate collections of related values. It would be impractical to use a sequence of variables such as `value1`, `value2`, `value3`, . . . , and so on. The array construct provides a better way of storing a collection of values.

An array is a sequence of values of the same type.

An **array** is a sequence of values of the same type. The values that are stored in an array are called its "elements". For example, here is how you construct an array of 10 floating-point numbers:

```
new double[10]
```

The number of elements (here, 10) is called the length of the array.

The `new` operator merely constructs the array. You will want to store a reference to the array in a variable so that you can access it later.

The type of an array variable is the element type, followed by `[]`. In this example, the type is `double[]`, because the element type is `double`. Here is the declaration of an array variable:

```
double[] values = new double[10];
```

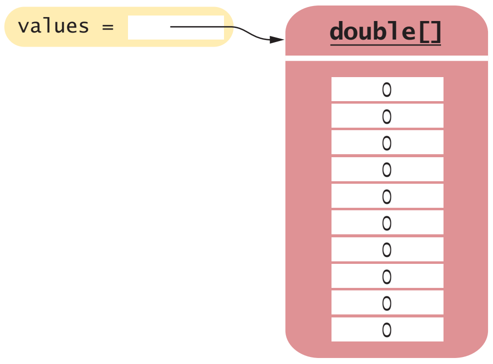
That is, `values` is a reference to an array of floating-point numbers. It is initialized with an array of 10 numbers (see Figure 1).

You can also form arrays of objects, for example

```
BankAccount[] accounts = new BankAccount[10];
```

When an array is first created, all elements are initialized with `0` (for an array of numbers such as `int[]` or `double[]`), `false` (for a `boolean[]` array), or `null` (for an array of object references).

Figure 1
An Array Reference and an Array



Alternatively, you can initialize an array with other values. List all elements that you want to include in the array, enclosed in braces and separated by commas:

```
int[] primes = { 2, 3, 5, 7, 11 };
```

The Java compiler counts how many elements you want to place in the array, allocates an array of the correct size, and fills it with the elements that you specify.

Each element in the array is specified by an integer index that is placed inside square brackets ([]). For example, the expression

```
values[4]
```

denotes the element of the values array with index 4.

You can store a value at a location with an assignment statement, such as the following.

```
values[2] = 29.95;
```

You access an array element with an integer index, using the [] operator.

Now the position with index 2 of values is filled with 29.95 (see Figure 2).

To read the element at index 2, simply use the expression values[2] as you would any variable of type double:

```
System.out.println("The element at index 2 is " + values[2]);
```

If you look closely at Figure 2, you will notice that the index values start at 0. That is,

values[0] is the first element

values[1] is the second element

values[2] is the third element

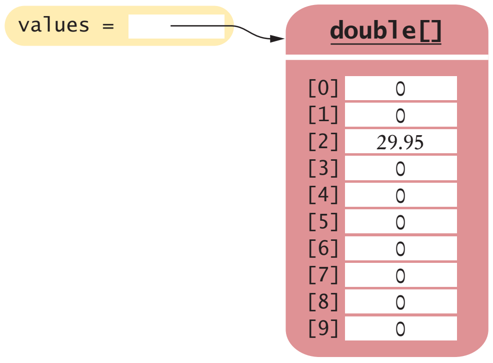


Figure 2
Modifying an Array Element

Index values of an array range from 0 to `length - 1`.

and so on. This convention can be a source of grief for the newcomer, so you should pay close attention to the index values. In particular, the *last* element in the array has an index *one less than* the array length. For example, `values` refers to an array with length 10. The last element is `values[9]`.

Accessing a nonexistent element results in a bounds error.

If you try to access an element that does not exist, then an "array index out of bounds" exception occurs. For example, the statement

```
values[10] = 29.95; // ERROR
```

is a **bounds error**.

To avoid bounds errors, you will want to know how many elements are in an array. The expression

The expression *array*`.length` yields the number of elements in an array.

```
values.length
```

is the length of the `values` array. Note that there are no parentheses following `length`—it is an instance variable of the array object, not a method. However, you cannot modify this instance variable. In other words, `length` is a `final public` instance variable. This is quite an anomaly. Normally, Java programmers use a method to inquire about the properties of an object. You just have to remember to omit the parentheses in this case.

The following code ensures that you only access the array when the index variable `i` is within the legal bounds:

```
if (0 <= i && i < values.length) values[i] = value;
```

Arrays suffer from a significant limitation: *their length is fixed*. If you start out with an array of 10 elements and later decide that you need to add additional elements, then you need to make a new array and copy all elements of the existing array into the new array. We will discuss this process in detail in Section 7.6.

Table 1 Declaring Arrays

`int[] numbers = new int[10];`	An array of ten integers. All elements are initialized with zero.

`final int NUMBERS_LENGTH = 10;`
`int[] numbers = new int[NUMBERS_LENGTH];`
	It is a good idea to use a named constant instead of a "magic number".

`int valuesLength = in.nextInt();`
`double[] values = new double[valuesLength];`
	The length need not be a constant.

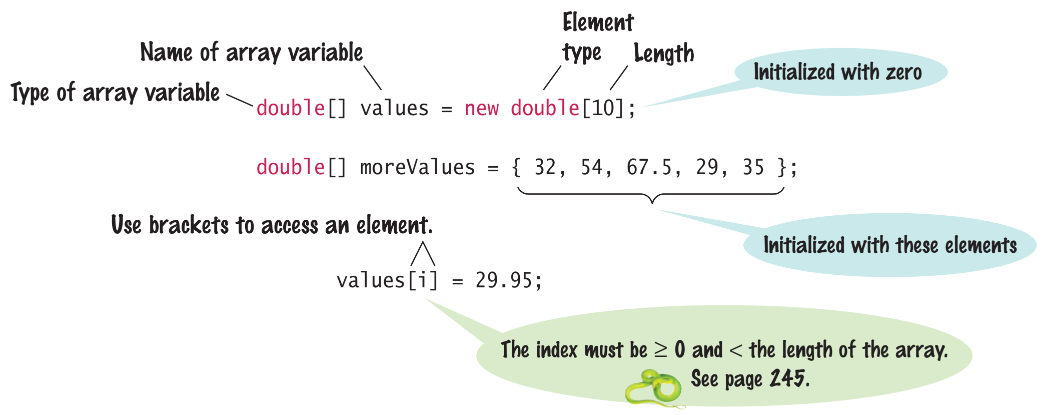
`int[] squares = { 0, 1, 4, 9, 16 };`	An array of five integers, with initial values.
`String[] names = new String[3];`	An array of three string references, all initially `null`.
`String[] friends = { "Emily", "Bob", "Cindy" };`	Another array of three strings.
`double[] values = new int[10]`	**Error:** You cannot initialize a `double[]` variable with an array of type `int[]`.

Syntax 7.1 Arrays

Syntax To construct an array: `new` *typeName*[*length*]

To access an element: *arrayReference*[*index*]

Example


Name of array variable
Element type
Length
Type of array variable
Initialized with zero
Initialized with these elements
Use brackets to access an element.
The index must be ≥ 0 and < the length of the array. See page 245.

```
double[] values = new double[10];

double[] moreValues = { 32, 54, 67.5, 29, 35 };

values[i] = 29.95;
```

SELF CHECK

1. What elements does the `values` array contain after the following statements?

```
double[] values = new double[10];
for (int i = 0; i < values.length; i++) values[i] = i * i;
```

2. What do the following program segments print? Or, if there is an error, describe the error and specify whether it is detected at compile-time or at run-time.

   a.
   ```
   double[] a = new double[10];
   System.out.println(a[0]);
   ```
   b.
   ```
   double[] b = new double[10];
   System.out.println(b[10]);
   ```
   c.
   ```
   double[] c;
   System.out.println(c[0]);
   ```

Common Error 7.1

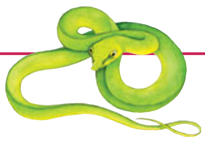
Bounds Errors

A very common array error is attempting to access a nonexistent position.

```
double[] data = new double[10];
data[10] = 29.95;   // Error—only have elements with index values 0 . . . 9
```

When the program runs, an out-of-bounds index generates an exception and terminates the program.

This is a great improvement over languages such as C and C++. With those languages there is no error message; instead, the program will quietly (or not so quietly) corrupt the memory location that is 10 elements away from the start of the array. Sometimes that corruption goes unnoticed, but at other times, the program will act flaky or die a horrible death many instructions later. These are serious problems that make C and C++ programs difficult to debug. Bounds errors in C and C++ programs are a major cause of security vulnerabilities—see Random Fact 7.1 on page 248.



Common Error 7.2

Uninitialized and Unfilled Arrays

A common error is to allocate an array reference, but not an actual array.

```
double[] values;
values[0] = 29.95; // Error—values not initialized
```

Array variables work exactly like object variables—they are only references to the actual array. To construct the actual array, you must use the `new` operator:

```
double[] values = new double[10];
```

Another common error is to allocate an array of objects and expect it to be filled with objects.

```
BankAccount[] accounts = new BankAccount[10]; // Contains ten null references
```

This array contains `null` references, not default bank accounts. You need to remember to fill the array, for example:

```
for (int i = 0; i < 10; i++)
{
   accounts[i] = new BankAccount();
}
```

Quality Tip 7.1

Use Arrays for Sequences of Related Values

Arrays are intended for storing sequences of values with the same meaning. For example, an array of test scores makes perfect sense:

```
int[] scores = new int[NUMBER_OF_SCORES];
```

But it is a bad design to use an array

```
double[] personalData = new double[3];
```

that holds a person's age, bank balance, and shoe size as `personalData[0]`, `personalData[1]`, and `personalData[2]`. It would be tedious for the programmer to remember which of these data items is stored in which array location. In this situation, it is far better to use three variables

```
int age;
double bankBalance;
double shoeSize;
```

Quality Tip 7.2

Make Parallel Arrays into Arrays of Objects

Programmers who are familiar with arrays, but unfamiliar with object-oriented programming, sometimes distribute information across separate arrays. Here is a typical example. A program needs to manage bank data, consisting of account numbers and balances. Don't store the account numbers and balances in separate arrays.

```
// Don't do this
int[] accountNumbers;
double[] balances;
```

Arrays such as these are called parallel arrays (see Figure 3). The `i`th slice (`accountNumbers[i]` and `balances[i]`) contains data that need to be processed together.

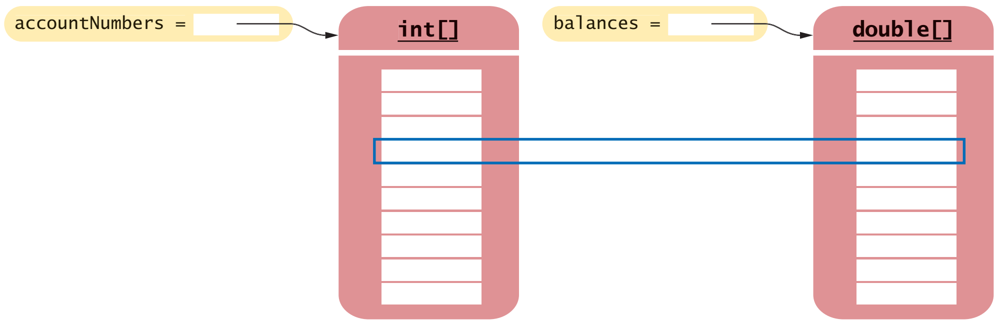


Figure 3 Avoid Parallel Arrays

Avoid parallel arrays by changing them into arrays of objects.

If you find yourself using two arrays that have the same length, ask yourself whether you couldn't replace them with a single array of a class type. Look at a slice and find the concept that it represents. Then make the concept into a class. In our example each slice contains an account number and a balance, describing a bank account. Therefore, it is an easy matter to use a single array of objects

```
BankAccount[] accounts;
```

(See Figure 4.)

Why is this beneficial? Think ahead. Maybe your program will change and you will need to store the owner of the bank account as well. It is a simple matter to update the `BankAccount` class. It may well be quite complicated to add a new array and make sure that all methods that accessed the original two arrays now also correctly access the third one.

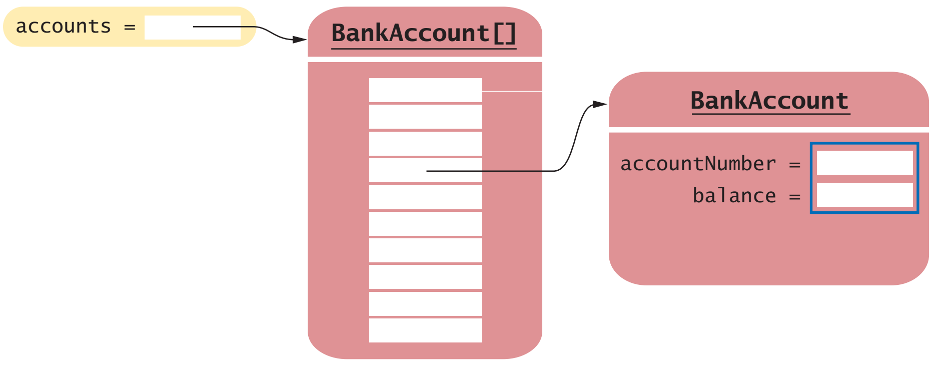


Figure 4 Reorganizing Parallel Arrays into an Array of Objects

Special Topic 7.1

Methods with a Variable Number of Parameters

Special Topic 7.1 shows how to implement a method that takes a variable number of parameters, and how to retrieve the parameter values from an array.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Random Fact 7.1

An Early Internet Worm

Random Fact 7.1 tells the story of the first serious Internet virus, launched by a graduate student at Cornell University. The virus exploited an array overrun vulnerability that is present in the C programming language but not in Java.

7.2 Array Lists

The `ArrayList` class manages a sequence of objects whose size can change.

The array construct is rather primitive. In this section, we introduce the `ArrayList` class. It lets you collect objects, just like an array does, but array lists offer two significant benefits:

- Array lists can grow and shrink as needed.
- The `ArrayList` class supplies methods for many common tasks, such as inserting and removing elements.

You declare an array list of strings as follows:

```
ArrayList<String> names = new ArrayList<String>();
```

The `ArrayList` class is a generic class: `ArrayList<`*`TypeName`*`>` collects objects of the given type.

The type `ArrayList<String>` denotes an array list of strings. The angle brackets around the `String` type tell you that `String` is a **type parameter**. You can replace `String` with any other class and get a different array list type. For that reason, `ArrayList` is called a **generic class**. You will learn more about generic classes in Chapter 17. For now, simply use an `ArrayList<T>` whenever you want to collect objects of type `T`. However, keep in mind that you cannot use primitive types as type parameters—there is no `ArrayList<int>` or `ArrayList<double>`. You will see in Section 7.4 how to overcome that limitation.

When you construct an `ArrayList` object, it has size `0`. You use the `add` method to add an object to the end of the array list. The size increases after each call to `add` (see Figure 5). The `size` method yields the current size of the array list.

```
names.add("Emily"); // Now names has size 1 and element "Emily"
names.add("Bob"); // Now names has size 2 and elements "Emily", "Bob"
names.add("Cindy"); // names has size 3 and elements "Emily", "Bob", and "Cindy"
```

To obtain the value of an array list element, use the `get` method, not the `[]` operator. As with arrays, index values start at `0`. For example, `names.get(2)` retrieves the element with index 2, the third element in the array list:

```
String name = names.get(2);
```

As with arrays, it is an error to access a nonexistent element. A very common bounds error is to use the following:

```
int i = names.size();
name = names.get(i);  // Error
```

The last valid index is `names.size() - 1`.

To set an array list element to a new value, use the `set` method.

```
names.set(2, “Carolyn”);
```

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

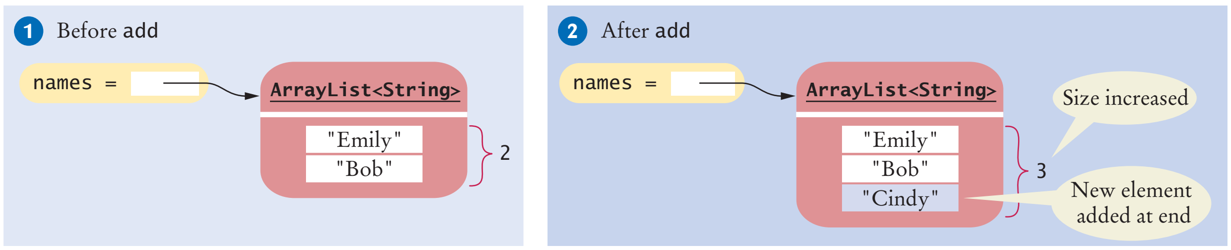


Figure 5 Adding an Element with `add`

This call sets position 2 of the `names` array list to `"Carolyn"`, overwriting whatever value was there before.

The `set` method can only overwrite existing values. It is different from the `add` method, which adds a new object to the end of the array list.

You can also insert an object in the middle of an array list. The call `names.add(1, "Ann")` moves all elements with index 1 or larger by one position and adds the string `"Ann"` at index 1 (see Figure 6). After each call to the `add` method, the size of the array list increases by 1.

Conversely, the `remove` method removes the element at a given index, moves all elements after the removed element to the next lower index, and reduces the size of the array list by 1. Part 3 of Figure 6 illustrates the call `names.remove(1)`.

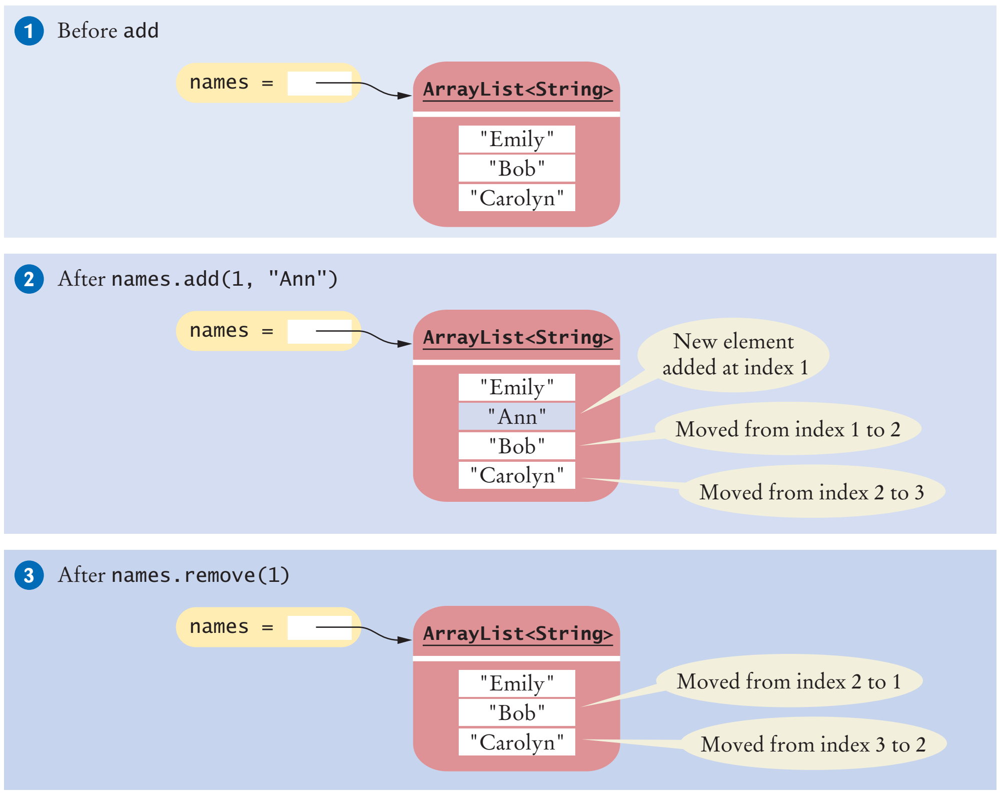


Figure 6 Adding and Removing Elements in the Middle of an Array List

Syntax 7.2 Array Lists

Syntax

To construct an array list: `new ArrayList<`*typeName*`>()`

To access an element: *arraylistReference*`.get(index)`
arraylistReference`.set(index, value)`

Example

Variable type

Variable name

An array list object of size 0

```
ArrayList<String> friends = new ArrayList<String>();
```

```
friends.add("Cindy");
String name = friends.get(i);
friends.set(i, "Harry");
```

The `add` method appends an element to the array list, increasing its size.

Use the `get` and `set` methods to access an element.

The index must be ≥ 0 and < `friends.size()`. See page 245.

The following program demonstrates how to use `ArrayList` class for collecting `BankAccount` objects. The `BankAccount` class has been enhanced from the version in Chapter 3. Each bank account has an account number. Note that you import the generic class `java.util.ArrayList`, without the type parameter.

Table 2 Working with Array Lists

`ArrayList<String> names = new ArrayList<String>();`	Constructs an empty array list that can hold strings.

`names.add("Ann");`
`names.add("Cindy");`
	Adds elements to the end.

`System.out.println(names);`	Prints `[Ann, Cindy]`.
`names.add(1, "Bob");`	Inserts an element at index 1. `names` is now `[Ann, Bob, Cindy]`.
`names.remove(0);`	Removes the element at index `0`. `names` is now `[Bob, Cindy]`.
`names.set(0, "Bill");`	Replaces an element with a different value. `names` is now `[Bill, Cindy]`.
`String name = names.get(i);`	Gets an element.
`String last = names.get(names.size() - 1);`	Gets the last element.

`ArrayList<Integer> squares = new ArrayList<Integer>();`
`for (int i = 0; i < 10; i++)`
`{`
`   squares.add(i * i);`
`}`
	Constructs an array list holding the first ten squares.

ch07/arraylist/ArrayListTester.java

```java
import java.util.ArrayList;

/**
   This program tests the ArrayList class.
*/
public class ArrayListTester
{
   public static void main(String[] args)
   {
      ArrayList<BankAccount> accounts = new ArrayList<BankAccount>();
      accounts.add(new BankAccount(1001));
      accounts.add(new BankAccount(1015));
      accounts.add(new BankAccount(1729));
      accounts.add(1, new BankAccount(1008));
      accounts.remove(0);

      System.out.println("Size: " + accounts.size());
      System.out.println("Expected: 3");
      BankAccount first = accounts.get(0);
      System.out.println("First account number: "
            + first.getAccountNumber());
      System.out.println("Expected: 1008");
      BankAccount last = accounts.get(accounts.size() - 1);
      System.out.println("Last account number: "
            + last.getAccountNumber());
      System.out.println("Expected: 1729");
   }
}
```

ch07/arraylist/BankAccount.java

```java
/**
   A bank account has a balance that can be changed by
   deposits and withdrawals.
*/
public class BankAccount
{
   private int accountNumber;
   private double balance;

   /**
      Constructs a bank account with a zero balance.
      @param anAccountNumber the account number for this account
   */
   public BankAccount(int anAccountNumber)
   {
      accountNumber = anAccountNumber;
      balance = 0;
   }

   /**
      Constructs a bank account with a given balance.
      @param anAccountNumber the account number for this account
      @param initialBalance the initial balance
   */
   public BankAccount(int anAccountNumber, double initialBalance)
   {
      accountNumber = anAccountNumber;
      balance = initialBalance;
   }

   /**
      Gets the account number of this bank account.
      @return the account number
   */
   public int getAccountNumber()
   {
      return accountNumber;
   }

   /**
      Deposits money into the bank account.
      @param amount the amount to deposit
   */
   public void deposit(double amount)
   {
      double newBalance = balance + amount;
      balance = newBalance;
   }

   /**
      Withdraws money from the bank account.
      @param amount the amount to withdraw
   */
   public void withdraw(double amount)
   {
      double newBalance = balance - amount;
      balance = newBalance;
   }

   /**
      Gets the current balance of the bank account.
      @return the current balance
   */
   public double getBalance()
   {
      return balance;
   }
}
```

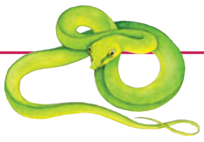
Program Run

```
Size: 3
Expected: 3
First account number: 1008
Expected: 1008
Last account number: 1729
Expected: 1729
```

SELF CHECK

3. How do you construct an array of 10 strings? An array list of strings?
4. What is the content of `names` after the following statements?

```java
ArrayList<String> names = new ArrayList<String>();
names.add("A");
names.add(0, "B");
names.add("C");
names.remove(1);
```

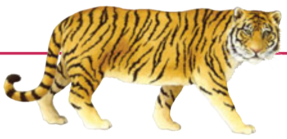


Common Error 7.3

Length and Size

Unfortunately, the Java syntax for determining the number of elements in an array, an array list, and a string is not at all consistent. It is a common error to confuse these. You just have to remember the correct syntax for every data type.

Data Type	Number of Elements
Array	`a.length`
Array list	`a.size()`
String	`a.length()`



Special Topic 7.2

`ArrayList` Syntax Enhancements in Java 7

Java 7 introduces several convenient syntax enhancements for array lists.

When you declare and construct an array list, you need not repeat the type parameter in the constructor. That is, you can write

```
ArrayList<String> names = new ArrayList<>();
```

instead of

```
ArrayList<String> names = new ArrayList<String>();
```

This shortcut is called the "diamond syntax" because the empty brackets `<>` look like a diamond shape.

You can supply initial values as follows:

```
ArrayList<String> names = new ArrayList<>(["Ann", "Cindy", "Bob"]);
```

In Java 7, you can access array list elements with the `[]` operator instead of the `get` and `put` methods. That is, the compiler translates

```
String name = names[i];
```

into

```
String name = names.get(i);
```

and

```
names[i] = "Fred";
```

into

```
names.set(i, "Fred");
```

7.3 Wrappers and Auto-boxing

To treat primitive type values as objects, you must use wrapper classes.

Because numbers are not objects in Java, you cannot directly insert them into array lists. For example, you cannot form an `ArrayList<double>`. To store sequences of numbers in an array list, you must turn them into objects by using **wrapper classes**. There are wrapper classes for all eight primitive types:

Primitive Type	Wrapper Class
`byte`	`Byte`
`boolean`	`Boolean`
`char`	`Character`
`double`	`Double`
`float`	`Float`
`int`	`Integer`
`long`	`Long`
`short`	`Short`

Note that the wrapper class names start with uppercase letters, and that two of them differ from the names of the corresponding primitive type: `Integer` and `Character`.

Each wrapper class object contains a value of the corresponding primitive type. For example, an object of the class `Double` contains a value of type `double` (see Figure 7).

Wrapper objects can be used anywhere that objects are required instead of primitive type values. For example, you can collect a sequence of floating-point numbers in an `ArrayList<Double>`.

Conversion between primitive types and the corresponding wrapper classes is automatic. This process is called **auto-boxing** (even though *auto-wrapping* would have been more consistent).

For example, if you assign a number to a `Double` object, the number is automatically "put into a box", namely a wrapper object.

```
Double d = 29.95; // Auto-boxing; same as Double d = new Double(29.95);
```

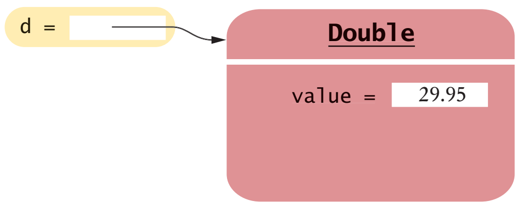


Figure 7 An Object of a Wrapper Class

Conversely, wrapper objects are automatically "unboxed" to primitive types.

```
double x = d; // Auto-unboxing; same as double x = d.doubleValue();
```

Auto-boxing even works inside arithmetic expressions. For example, the statement

```
d = d + 1;
```

is perfectly legal. It means:

- Auto-unbox `d` into a `double`
- Add 1
- Auto-box the result into a new `Double`
- Store a reference to the newly created wrapper object in `d`

In order to collect numbers in an array list, simply remember to use the wrapper type as the type parameter, and then rely on auto-boxing.

```
ArrayList<Double> values = new ArrayList<Double>();
values.add(29.95);
double x = values.get(0);
```

Keep in mind that storing wrapped numbers is quite inefficient. The use of wrappers is acceptable if you only collect a few numbers, but you should use arrays for long sequences of numbers or characters.

SELF CHECK

5. What is the difference between the types `double` and `Double`?
6. Suppose `values` is an `ArrayList<Double>` of size > `0`. How do you increment the element with index `0`?

7.4 The Enhanced for Loop

The enhanced `for` loop traverses all elements of a collection.

Java version 5.0 introduces a very convenient shortcut for a common loop type. Often, you need to iterate through a sequence of elements—such as the elements of an array or array list. The enhanced `for` loop makes this process particularly easy to program.

Suppose you want to total up all elements in an array `values`. Here is how you use the enhanced `for` loop to carry out that task.

```
double[] values = . . .;
double sum = 0;
for (double element : values)
{
   sum = sum + element;
}
```

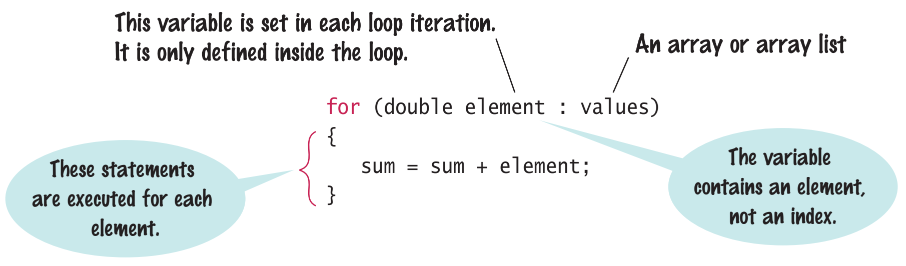
The loop body is executed for each element in the array `values`. At the beginning of each loop iteration, the next element is assigned to the variable `element`. Then the loop body is executed. You should read this loop as "`for` each `element` in `values`".

You may wonder why Java doesn't let you write "`for each (element in values)`". Unquestionably, this would have been neater, and the Java language designers seriously considered this. However, the "for each" construct was added to Java several

Syntax 7.3 The “for each” Loop

Syntax `for` (*typeName variable* : *collection*)
statement

Example



```
for (double element : values)
{
   sum = sum + element;
}
```

This variable is set in each loop iteration. It is only defined inside the loop.
An array or array list
These statements are executed for each element.
The variable contains an element, not an index.

years after its initial release. Had new reserved words `each` and `in` been added to the language, then older programs that happened to use those identifiers as variable or method names (such as `System.in`) would no longer have compiled correctly.

You don’t have to use the “for each” construct to loop through all elements in an array. You can implement the same loop with a straightforward `for` loop and an explicit index variable:

```
double[] values = . . .;
double sum = 0;
for (int i = 0; i < values.length; i++)
{
   double element = values[i];
   sum = sum + element;
}
```

In an enhanced `for` loop, the loop variable contains an element, not an index.

Note an important difference between the “for each” loop and the ordinary `for` loop. In the “for each” loop, the loop variable `e` is assigned *elements:* `values[0]`, `values[1]`, and so on. In the ordinary `for` loop, the loop variable `i` is assigned *index values:* `0`, `1`, and so on.

You can also use the enhanced `for` loop to visit all elements of an array list. For example, the following loop computes the total of the balances of all accounts:

```
ArrayList<BankAccount> accounts = . . . ;
double sum = 0;
for (BankAccount account : accounts)
{
   sum = sum + account.getBalance();
}
```

This loop is equivalent to the following ordinary `for` loop:

```
double sum = 0;
for (int i = 0; i < accounts.size(); i++)
{
   BankAccount account = accounts.get(i);
   sum = sum + account.getBalance();
}
```

Keep in mind that the “for each” loop has a very specific purpose: getting the elements of a collection, from the beginning to the end. It is not suitable for all array algorithms. In particular, the “for each” loop does not allow you to modify the contents of an array. The following loop does *not* fill an array with zeroes:

```
for (double element : values)
{
   element = 0; // ERROR—this assignment does not modify array elements
}
```

When the loop is executed, the variable `element` is first set to `values[0]`. Then `element` is set to `0`, then to `values[1]`, then to `0`, and so on. The `values` array is not modified. The remedy is simple: Use an ordinary `for` loop

```
for (int i = 0; i < values.length; i++)
{
   values[i] = 0; // OK
}
```

SELF CHECK

7. Write a “for each” loop that prints all elements in the array `values`.

8. What does this “for each” loop do?

```
int counter = 0;
for (BankAccount a : accounts)
{
   if (a.getBalance() == 0) { counter++; }
}
```

7.5 Partially Filled Arrays

Suppose you write a program that reads a sequence of numbers into an array. How many numbers will the user enter? You can’t very well ask the user to count the items before entering them—that is just the kind of work that the user expects the computer to do. Unfortunately, you now run into a problem. You need to set the size of the array before you know how many elements you need. Once the array size is set, it cannot be changed.

To solve this problem, make an array that is guaranteed to be larger than the largest possible number of entries, and partially fill it. For example, you can decide that the user will never provide more than 100 input values. Then allocate an array of size 100:

```
final int VALUES_LENGTH = 100;
double[] values = new double[VALUES_LENGTH];
```

With a partially filled array, keep a companion variable to track how many elements are used.

Then keep a companion variable that tells how many elements in the array are actually used. It is an excellent idea always to name this companion variable by adding the suffix `Size` to the name of the array.

```
int valuesSize = 0;
```

Now `values.length` is the capacity of the array `values`, and `valuesSize` is the current size of the array (see Figure 8). Keep adding elements into the array, incrementing the `valuesSize` variable each time.

```
values[valuesSize] = x;
valuesSize++;
```

This way, `valuesSize` always contains the correct element count.

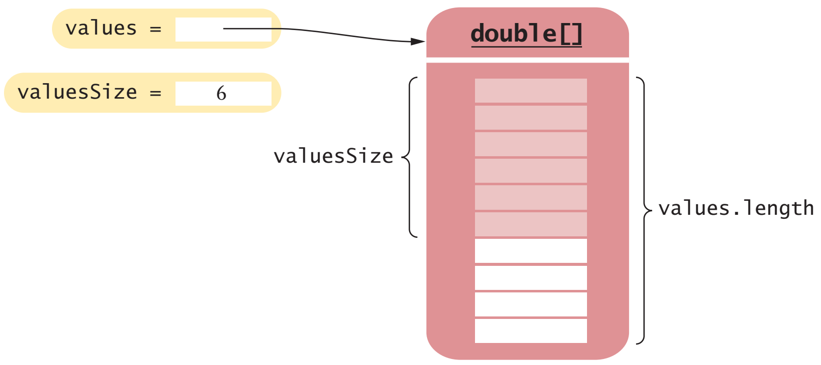


Figure 8 A Partially Filled Array

The following code segment shows how to read numbers into a partially filled array.

```
int valuesSize = 0;
Scanner in = new Scanner(System.in);
while (in.hasNextDouble())
{
   if (valuesSize < values.length)
   {
      values[valuesSize] = in.nextDouble();
      valuesSize++;
   }
}
```

At the end of this loop, `valuesSize` contains the actual number of elements in the array. Note that you have to stop accepting inputs if the `valuesSize` companion variable reaches the array length. Section 7.6 shows how you can overcome that limitation by growing the array.

To process the gathered array elements, you again use the companion variable, not the array length. This loop prints the partially filled array:

```
for (int i = 0; i < valuesSize; i++)
{
   System.out.println(values[i]);
}
```

Array lists use this technique behind the scenes. An array list contains an array of objects. When the array runs out of space, the array list allocates a larger array and copies the elements. However, all of this happens inside the array list methods, so you never need to think about it.

SELF CHECK

9. Write a loop to print the elements of the partially filled array `values` in reverse order, starting with the last element.

10. How do you remove the last element of the partially filled array `values`?

11. Why would a programmer use a partially filled array of numbers instead of an array list?

Common Error 7.4

Underestimating the Size of a Data Set

Programmers frequently underestimate the amount of input data that a user will pour into an unsuspecting program. A common problem results from the use of fixed-sized arrays. Suppose you write a program to search for text in a file. You store each line in a string, and keep an array of strings. How big do you make the array? Surely nobody is going to challenge your program with an input that is more than 100 lines. Really? It is easy to feed in the entire text of *Alice in Wonderland* or *War and Peace* (which are available on the Internet). All of a sudden, your program has to deal with tens or hundreds of thousands of lines. What will it do? Will it handle the input? Will it politely reject the excess input? Will it crash and burn?

A famous article (Barton P. Miller, Louis Fericksen, and Bryan So, "An Empirical Study of the Reliability of Unix Utilities", *Communications of the ACM*, vol. 33, no. 12, pp. 32–44) analyzed how several UNIX programs reacted when they were fed large or random data sets. Sadly, about a quarter didn't do well at all, crashing or hanging without a reasonable error message. For example, in some older versions of UNIX the tape backup program tar was not able to handle file names longer than 100 characters, which is a pretty unreasonable limitation. Many of these shortcomings are caused by features of the C language that, unlike Java, make it difficult to store strings and collections of arbitrary size.

7.6 Common Array Algorithms

In the following sections, we discuss some of the most common algorithms for working with arrays and array lists.

In the examples, we show a mixture of arrays and array lists so that you become familiar with the syntax for both constructs.

7.6.1 Filling

This loop fills an array with zeroes:

```
for (int i = 0; i < values.length; i++)
{
   values[i] = 0;
}
```

Here, we fill an array list with squares (0, 1, 4, 9, 16, …). Note that the element with index 0 contains 0^2, the element with index 1 contains 1^2, and so on.

```
for (int i = 0; i < values.size(); i++)
{
   values.set(i, i * i);
}
```

7.6.2 Computing Sum and Average Values

To compute the sum of all elements, simply keep a running total.

```
double total = 0;
for (double element : values)
{
      total = total + element;
   }
```

To obtain the average, divide by the number of elements:

```
   double average = total / values.size(); // For an array list
```

Be sure to check that the size is not zero.

7.6.3 Counting Matches

To count values, check all elements and count the matches until you reach the end.

Suppose you want to find how many accounts of a certain type you have. Then you must go through the entire collection and increment a counter each time you find a match. Here we count the number of accounts whose balance is at least as much as a given threshold:

```
   public class Bank
   {
      private ArrayList<BankAccount> accounts;

      public int count(double atLeast)
      {
         int matches = 0;
         for (BankAccount account : accounts)
         {
            if (account.getBalance() >= atLeast) matches++; // Found a match
         }
         return matches;
      }
      . . .
   }
```

7.6.4 Finding the Maximum or Minimum

To compute the maximum or minimum value, initialize a candidate with the starting element. Then compare the candidate with the remaining elements and update it if you find a larger or smaller value.

Suppose you want to find the account with the largest balance in the bank. Keep a candidate for the maximum. If you find an element with a larger value, then replace the candidate with that value. When you have reached the end of the sequence, you have found the maximum.

There is just one problem. When you visit the starting element, you don't yet have a candidate for the maximum. One way to overcome that is to set the candidate to the starting element and make the first comparison with the next element.

```
   BankAccount largestYet = accounts.get(0);
   for (int i = 1; i < accounts.size(); i++)
   {
      BankAccount a = accounts.get(i);
      if (a.getBalance() > largestYet.getBalance())
         largestYet = a;
   }
   return largestYet;
```

Here we use an explicit `for` loop because the loop no longer visits all elements—it skips the starting element.

Of course, this approach works only if there is at least one element. It doesn't make a lot of sense to ask for the largest element of an empty collection. We can return `null` in that case:

```
if (accounts.size() == 0) return null;
BankAccount largestYet = accounts.get(0);
. . .
```

See Exercises R7.5 and R7.6 for slight modifications to this algorithm.

To compute the minimum of a data set, keep a candidate for the minimum and replace it whenever you encounter a *smaller* value. At the end of the sequence, you have found the minimum.

7.6.5 Searching for a Value

To find a value, check all elements until you have found a match.

Suppose you want to know whether there is a bank account with a particular account number in your bank. Simply inspect each element until you find a match or reach the end of the sequence. Note that the loop might fail to find an answer, namely if none of the accounts match. This search process is called a **linear search**.

```
public class Bank
{
   . . .
   public BankAccount find(int accountNumber)
   {
      for (BankAccount account : accounts)
      {
         if (account.getAccountNumber() == accountNumber) // Found a match
            return account;
      }
      return null; // No match in the entire array list
   }
   . . .
}
```

Note that the method returns `null` if no match is found.

7.6.6 Locating the Position of an Element

You often need to locate the position of an element so that you can replace or remove it. Use a variation of the linear search algorithm, but remember the position instead of the matching element. Here we locate the position of the first element that is larger than 100.

```
int pos = 0;
boolean found = false;
while (pos < values.size() && !found)
{
   if (values.get(pos) > 100)
   {
      found = true;
   }
   else
   {
      pos++;
   }
}
if (found) { System.out.println("Position: " + pos); }
else { System.out.println("Not found"); }
```

7.6.7 Removing an Element

Removing an element from an array list is very easy—simply use the remove method. With an array, you have to work harder.

Suppose you want to remove the element with index pos from the array values. First off, you need to keep a companion variable for tracking the number of elements in the array, as explained in Section 7.5.

If the elements in the array are not in any particular order, simply overwrite the element to be removed with the *last* element of the array, then decrement the variable tracking the size of the array. (See Figure 9.)

```
values[pos] = values[valuesSize - 1];
valuesSize--;
```

ANIMATION
Removing from an Array

The situation is more complex if the order of the elements matters. Then you must move all elements following the element to be removed to a lower index, and then decrement the variable holding the size of the array. (See Figure 10.)

```
for (int i = pos; i < valuesSize - 1; i++)
{
   values[i] = values[i + 1];
}
valuesSize--;
```

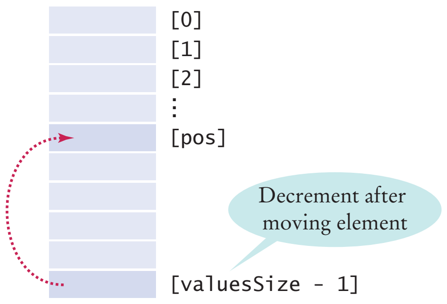


Figure 9
Removing an Element in an Unordered Array

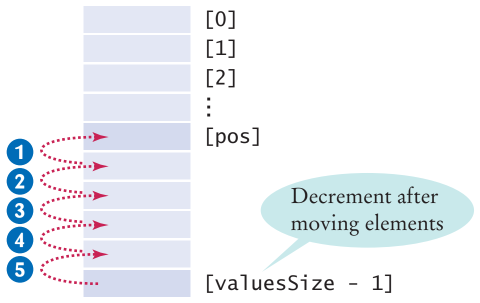


Figure 10
Removing an Element in an Ordered Array

7.6.8 Inserting an Element

To insert an element into an array list, simply use the add method.

In this section, you will see how to insert an element into an array. Note that you need a companion variable for tracking the array size, as explained in Section 7.5. If the order of the elements does not matter, you can simply insert new elements at the end, incrementing the variable tracking the size.

```
if (valuesSize < values.length)
{
   values[valuesSize] = newElement;
   valuesSize++;
}
```

ANIMATION
Inserting into an Array

It is more work to insert an element at a particular position in the middle of an array. First, move all elements above the insertion location to a higher index. Then insert the new element.

Note the order of the movement: When you remove an element, you first move the next element down to a lower index, then the one after that, until you finally get to the end of the array. When you insert an element, you start at the end of the array, move that element to a higher index, then move the one before that, and so on until you finally get to the insertion location (see Figure 12).

```
if (valuesSize < values.length)
{
   for (int i = valuesSize; i > pos; i--)
   {
      values[i] = values[i - 1];
   }
   values[pos] = newElement;
   valuesSize++;
}
```

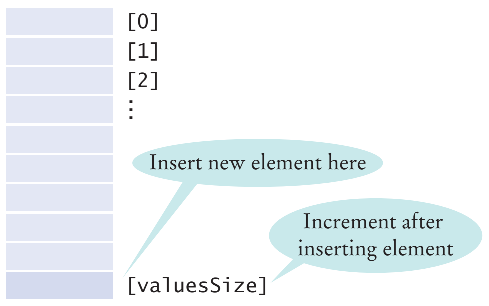


Figure 11
Inserting an Element in an Unordered Array

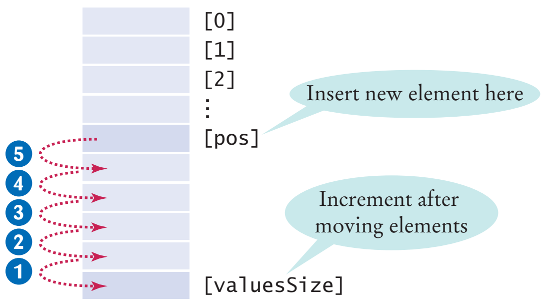


Figure 12
Inserting an Element in an Ordered Array

7.6.9 Copying and Growing Arrays

An array variable stores a reference to the array. Copying the variable yields a second reference to the same array.

Array variables work just like object variables—they hold a reference to the actual array. If you copy the reference, you get another reference to the same array (see Figure 13):

```
double[] values = new double[6];
. . . // Fill array
double[] prices = values; 1
```

Use the `Arrays.copyOf` method to copy the elements of an array.

If you want to make a true copy of an array, call the `Arrays.copyOf` method.

```
double[] prices = Arrays.copyOf(values, values.length); 2
```

Another use for `Arrays.copyOf` is to grow an array that has run out of space. The following statement has the effect of doubling the length of an array:

```
values = Arrays.copyOf(values, 2 * values.length);
```

See Figure 14.

For example, here is how you can read an arbitrarily long sequence numbers into an array, without running out of space:

```
int valuesSize = 0;
while (in.hasNextDouble())
{
   if (valuesSize == values.length)
      values = Arrays.copyOf(values, 2 * values.length);
   values[valuesSize] = in.nextDouble();
   valuesSize++;
}
```

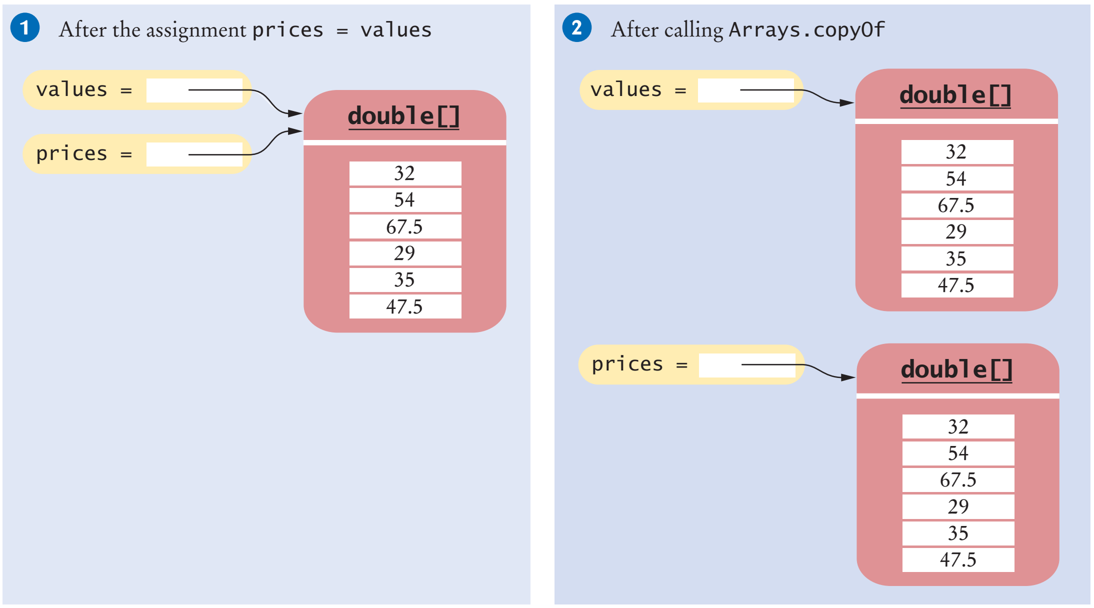


Figure 13 Copying an Array Reference vs. Copying an Array

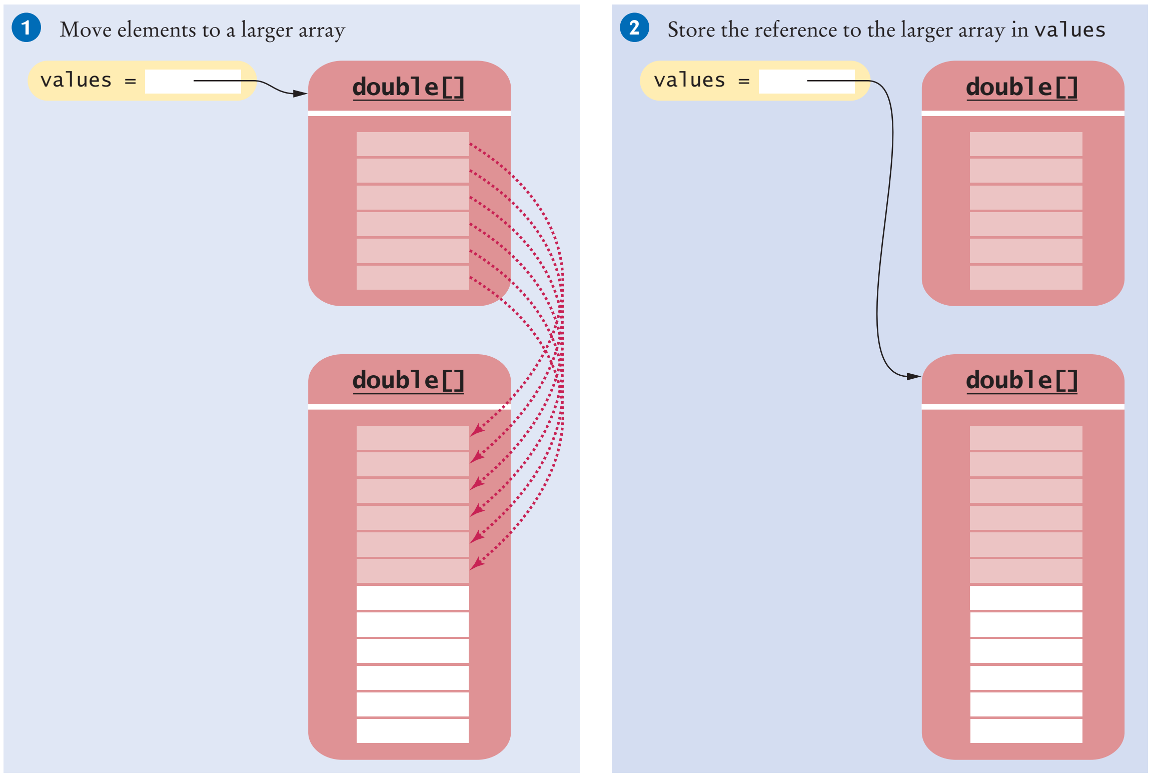

1 Move elements to a larger array
values =
double[]
double[]
2 Store the reference to the larger array in values
values =
double[]
double[]

Figure 14 Growing an Array

7.6.10 Printing Element Separators

When you display the elements of an array or array list, you usually want to separate them, often with commas or vertical lines, like this:

```
Ann | Bob | Cindy
```

Note that there is one fewer separator than there are elements. Print the separator before each element *except the initial one* (with index `0`):

```
for (int i = 0; i < names.size(); i++)
{
   if (i > 0)
   {
      System.out.print(" | ");
   }
   System.out.print(names.get(i));
}
```

The following sample program implements a `Bank` class that stores an array list of bank accounts. The methods of the `Bank` class use some of the algorithms that we have discussed in this section.

ch07/bank/Bank.java

```java
import java.util.ArrayList;

/**
   This bank contains a collection of bank accounts.
*/
public class Bank
{
   private ArrayList<BankAccount> accounts;

   /**
      Constructs a bank with no bank accounts.
   */
   public Bank()
   {
      accounts = new ArrayList<BankAccount>();
   }

   /**
      Adds an account to this bank.
      @param a the account to add
   */
   public void addAccount(BankAccount a)
   {
      accounts.add(a);
   }

   /**
      Gets the sum of the balances of all accounts in this bank.
      @return the sum of the balances
   */
   public double getTotalBalance()
   {
      double total = 0;
      for (BankAccount a : accounts)
      {
         total = total + a.getBalance();
      }
      return total;
   }

   /**
      Counts the number of bank accounts whose balance is at
      least a given value.
      @param atLeast the balance required to count an account
      @return the number of accounts having at least the given balance
   */
   public int countBalancesAtLeast(double atLeast)
   {
      int matches = 0;
      for (BankAccount a : accounts)
      {
         if (a.getBalance() >= atLeast) matches++; // Found a match
      }
      return matches;
   }

   /**
      Finds a bank account with a given number.
      @param accountNumber the number to find
      @return the account with the given number, or null if there
      is no such account
   */
   public BankAccount find(int accountNumber)
   {
      for (BankAccount a : accounts)
      {
         if (a.getAccountNumber() == accountNumber) // Found a match
            return a;
      }
      return null; // No match in the entire array list
   }

   /**
      Gets the bank account with the largest balance.
      @return the account with the largest balance, or null if the
      bank has no accounts
   */
   public BankAccount getMaximum()
   {
      if (accounts.size() == 0) return null;
      BankAccount largestYet = accounts.get(0);
      for (int i = 1; i < accounts.size(); i++)
      {
         BankAccount a = accounts.get(i);
         if (a.getBalance() > largestYet.getBalance())
            largestYet = a;
      }
      return largestYet;
   }
}
```

ch07/bank/BankTester.java

```
/**
   This program tests the Bank class.
*/
public class BankTester
{
   public static void main(String[] args)
   {
      Bank firstBankOfJava = new Bank();
      firstBankOfJava.addAccount(new BankAccount(1001, 20000));
      firstBankOfJava.addAccount(new BankAccount(1015, 10000));
      firstBankOfJava.addAccount(new BankAccount(1729, 15000));

      double threshold = 15000;
      int count = firstBankOfJava.countBalancesAtLeast(threshold);
      System.out.println("Count: " + count);
      System.out.println("Expected: 2");

      int accountNumber = 1015;
      BankAccount account = firstBankOfJava.find(accountNumber);
      if (account == null)
         System.out.println("No matching account");
      else
         System.out.println("Balance of matching account: "
            + account.getBalance());
      System.out.println("Expected: 10000");

      BankAccount max = firstBankOfJava.getMaximum();
      System.out.println("Account with largest balance: "
            + max.getAccountNumber());
      System.out.println("Expected: 1001");
   }
}
```

Program Run

```
Count: 2
Expected: 2
Balance of matching account: 10000.0
Expected: 10000
Account with largest balance: 1001
Expected: 1001
```

SELF CHECK

12. What does the `find` method do if there are two bank accounts with a matching account number?
13. Would it be possible to use a "for each" loop in the `getMaximum` method?
14. When printing separators, we skipped the separator before the initial element. Rewrite the loop so that the separator is printed *after* each element, except for the last element.
15. The following replacement has been suggested for the algorithm in Section 7.6.10.

    ```
    System.out.print(names.get(0));
    for (int i = 1; i < names.size(); i++) System.out.print(" | " + names.get(i));
    ```

    What is problematic about this suggestion?

Productivity Hint 7.1

Easy Printing of Arrays and Array Lists

If `values` is an array, the expression

```
Arrays.toString(values)
```

returns a string describing the elements, using a format that looks like this:

```
[32, 54, 67.5, 29, 35, 47.5]
```

The elements are surrounded by a pair of brackets and separated by commas. This can be convenient for debugging:

```
System.out.println("values=" + Arrays.toString(values));
```

With an array list, it is even easier to get a quick printout. Simply pass the array list to the `println` method:

```
System.out.println(names); // Prints [Ann, Bob, Cindy]
```

How To 7.1 Working with Arrays and Array Lists

When you process a sequence of values, you usually need to use array lists or arrays. (In some very simple situations, you can process data as you read them in, without storing them.) This How To walks you through the necessary steps.

Consider this example problem: You are given the quiz scores of a student. You are to compute the final quiz score, which is the sum of all scores after dropping the lowest one. For example, if the scores are

```
8  7  8.5  9.5  7  5  10
```

then the final score is 50.

However, if there is only one score, it would seem cruel to remove it. In that case, that score will be the final score. If there is no score, the final score should be `0`.

Step 1 Decompose your task into steps.

You will usually want to break down your task into multiple steps, such as

- Reading the data into an array list or array.
- Processing the data in one or more steps.
- Displaying the results.

When deciding how to process the data, you should be familiar with the array algorithms in Section 7.6. Most processing tasks can be solved by using one or more of these algorithms.

In our sample problem, we will want to read the data. Then we will remove the minimum and compute the total. For example, if the input is `8 7 8.5 9.5 7 5 10`, we will remove the minimum of `5`, yielding `8 7 8.5 9.5 7 10`. The sum of those values is the final score of `50`.

Thus, we have identified three steps:

```
Read inputs.
Remove the minimum.
Calculate the sum.
```

Step 2 Choose between array lists and arrays.

Generally, array lists are more convenient than arrays. You would choose arrays if one of the following applies:

- You know in advance how many elements you will collect, and the size will not change.
- You collect a large sequence of numbers.

None of these cases applies here, so we will store the scores in an array list. An alternate solution using arrays is included with the companion code for the book (`ch07/scores2` directory).

Step 3 Determine which algorithm(s) you need.

Sometimes, a step corresponds to exactly one of the basic array algorithms. That is the case with calculating the sum. At other times, you need to combine several algorithms. To remove the minimum value, you can find the minimum value (Section 7.6.4), find its position (Section 7.6.6), and remove the element at that position (Section 7.6.7).

We have now refined our plan as follows:

```
Read inputs.
Find the minimum.
Find its position.
Remove the minimum.
Calculate the sum.
```

This plan will work, but it is possible to do a bit better. It is easier to compute the sum and subtract the minimum. Then we don't have to find its position. The revised plan is

```
Read inputs.
Find the minimum.
Calculate the sum.
Subtract the minimum.
```

Step 4 Use classes and methods to structure the program.

Even though it may be possible to put all steps into the `main` method, this is rarely a good idea. It is better to carry out each processing step in a separate method. It is also a good idea to come up with a class that is responsible for collecting and processing the data, such as the `DataSet` class in Chapter 6 or the `Bank` class in the preceding section.

In our example, let's collect the scores in a `GradeBook` class.

```
public class GradeBook
{
   private ArrayList<Double> scores;
   . . .
   public void addScore(double score) { . . . }
   public double finalScore() { . . . }
}
```

A second class, `ScoreAnalyzer`, is responsible for reading the user input and displaying the result. Its `main` method simply calls the `GradeBook` methods:

```
GradeBook book = new GradeBook();
System.out.println("Please enter values, Q to quit:");
while (in.hasNextDouble())
{
   book.addScore(in.nextDouble());
}
System.out.println("Final score: " + book.finalScore());
```

Now the `finalScore` method must do the heavy lifting. It too should not have to do all the work. Instead, we will supply helper methods

```
public double sum()
public double minimum()
```

These methods simply implement the algorithms in Section 7.6.2 and Section 7.6.4.
Then the `finalScore` method becomes

```
public double finalScore()
{
   if (scores.size() == 0)
      return 0;
   else if (scores.size() == 1)
      return scores.get(0);
   else
      return sum() - minimum();
}
```

Step 5 Assemble and test the program.

Implement your classes and test them, as described in How To 3.1. Review your code and check that you handle both normal and exceptional situations. What happens with an empty array or array list? One that contains a single element? When no match is found? When there are multiple matches? Consider these boundary conditions and make sure that your program works correctly.

In our example, it is impossible to compute the minimum if the array list is empty. In that case, we should determine the special score of `0` *before* attempting to call the `minimum` method.

What if the minimum value occurs more than once? That means that a student had more than one test with the same low score. We subtract only one of the occurrences of that low score, and that is the desired behavior.

The following table shows test cases and their expected output:

Test Case	Expected Output	Comment
`8 7 8.5 9.5 7 5 10`	`50`	See Step 1.
`8 7 7 9`	`24`	Only one instance of the low score should be removed.
`8`	`8`	Don't remove the lowest score if there is only one.
(no inputs)	`0`	An empty grade book has score `0`.

The complete program is in the `ch07/scores` directory of the book's companion code.

Worked Example 7.1

Rolling the Dice

This Worked Example shows how to analyze a set of die tosses to see whether the die is "fair".

7.7 Regression Testing

A test suite is a set of tests for repeated testing.

Regression testing involves repeating previously run tests to ensure that known failures of prior versions do not appear in new versions of the software.

It is a common and useful practice to make a new test whenever you find a program bug. You can use that test to verify that your bug fix really works. Don't throw the test away; feed it to the next version after that and all subsequent versions. Such a collection of test cases is called a **test suite**.

You will be surprised how often a bug that you fixed will reappear in a future version. This is a phenomenon known as *cycling*. Sometimes you don't quite understand the reason for a bug and apply a quick fix that appears to work. Later, you apply a different quick fix that solves a second problem but makes the first problem appear again. Of course, it is always best to think through what really causes a bug and fix the root cause instead of doing a sequence of "Band-Aid" solutions. If you don't succeed in doing that, however, you at least want to have an honest appraisal of how well the program works. By keeping all old test cases around and testing them against every new version, you get that feedback. The process of checking each version of a program against a test suite is called **regression testing**.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

How do you organize a suite of tests? An easy technique is to produce multiple tester classes, such as `BankTester1`, `BankTester2`, and so on.

Another useful approach is to provide a generic tester, and feed it inputs from multiple files. Consider this tester for the `Bank` class of Section 7.6:

ch07/regression/BankTester.java

```java
import java.util.Scanner;

/**
   This program tests the Bank class.
*/
public class BankTester
{
   public static void main(String[] args)
   {
      Bank firstBankOfJava = new Bank();
      firstBankOfJava.addAccount(new BankAccount(1001, 20000));
      firstBankOfJava.addAccount(new BankAccount(1015, 10000));
      firstBankOfJava.addAccount(new BankAccount(1729, 15000));

      Scanner in = new Scanner(System.in);

      double threshold = in.nextDouble();
      int c = firstBankOfJava.count(threshold);
      System.out.println("Count: " + c);
      int expectedCount = in.nextInt();
      System.out.println("Expected: " + expectedCount);

      int accountNumber = in.nextInt();
      BankAccount a = firstBankOfJava.find(accountNumber);
      if (a == null)
         System.out.println("No matching account");
      else
      {
         System.out.println("Balance of matching account: " + a.getBalance());
         int matchingBalance = in.nextInt();
         System.out.println("Expected: " + matchingBalance);
      }
   }
}
```

Rather than using fixed values for the threshold and the account number to be found, the program reads these values, and the expected responses. By running the program with different inputs, we can test different scenarios, such as the ones for diagnosing off-by-one errors discussed in Common Error 6.2.

Of course, it would be tedious to type in the input values by hand every time the test is executed. It is much better to save the inputs in a file, such as the following:

ch07/regression/input1.txt

```
15000
2
1015
10000
```

The command line interfaces of most operating systems provide a way to link a file to the input of a program, as if all the characters in the file had actually been typed by a user. Type the following command into a shell window:

```
java BankTester < input1.txt
```

The program is executed, but it no longer reads input from the keyboard. Instead, the `System.in` object (and the `Scanner` that reads from `System.in`) gets the input from the file `input1.txt`. This process is called *input redirection*.

The output is still displayed in the console window:

Program Run

```
Count: 2
Expected: 2
Balance of matching account: 10000
Expected: 10000
```

You can also redirect output. To capture the output of a program in a file, use the command

```
java BankTester < input1.txt > output1.txt
```

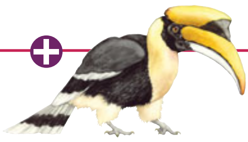
This is useful for archiving test cases.

SELF CHECK

16. Suppose you modified the code for a method. Why do you want to repeat tests that already passed with the previous version of the code?

17. Suppose a customer of your program finds an error. What action should you take beyond fixing the error?

18. Why doesn't the `BankTester` program contain prompts for the inputs?



Productivity Hint 7.2

Batch Files and Shell Scripts

Productivity Hint 7.1 shows how you can automate repetitive tasks by writing batch files or shell scripts.

Random Fact 7.2

The Therac-25 Incidents

Random Fact 7.2 tells the story of the Therac-25, a computerized device to deliver radiation treatment to cancer patients. Due to poor design and insufficient testing, the machine delivered serious overdoses, killing some patients and seriously maiming others.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

7.8 Two-Dimensional Arrays

Arrays and array lists can store linear sequences. Occasionally you want to store collections that have a two-dimensional layout. The traditional example is the tic-tac-toe board (see Figure 15).

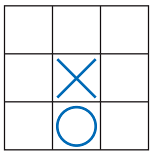


Figure 15
A Tic-Tac-Toe Board

Two-dimensional arrays form a tabular, two-dimensional arrangement. You access elements with an index pair `a[i][j]`.

Such an arrangement, consisting of rows and columns of values, is called a **two-dimensional array** or matrix. When constructing a two-dimensional array, you specify how many rows and columns you need. In this case, ask for 3 rows and 3 columns:

```
final int ROWS = 3;
final int COLUMNS = 3;
String[][] board = new String[ROWS][COLUMNS];
```

This yields a two-dimensional array with 9 elements

```
board[0][0]   board[0][1]   board[0][2]
board[1][0]   board[1][1]   board[1][2]
board[2][0]   board[2][1]   board[2][2]
```

To access a particular element, specify two index values in separate brackets. For example:

```
board[1][1] = "x";
board[2][1] = "o";
```

When filling or searching a two-dimensional array, it is common to use two nested loops. For example, this pair of loops sets all elements in the array to spaces.

```
for (int i = 0; i < ROWS; i++)
   for (int j = 0; j < COLUMNS; j++)
      board[i][j] = " ";
```

In this loop, we used constants for the number of rows and columns. You can also recover the array dimensions from the array variable:

- `board.length` is the number of rows.
- `board[0].length` is the number of columns. (See Special Topic 7.3 on page 277 for an explanation of this expression.)

You can rewrite the loop for filling the tic-tac-toe board as

```
for (int i = 0; i < board.length; i++)
   for (int j = 0; j < board[0].length; j++)
      board[i][j] = " ";
```

Here is a class and a test program for playing tic-tac-toe. This class does not check whether a player has won the game. That is left as an exercise—see Exercise P7.13.

ch07/twodim/TicTacToe.java

```java
/**
   A 3 x 3 tic-tac-toe board.
*/
public class TicTacToe
{
   private String[][] board;
   private static final int ROWS = 3;
   private static final int COLUMNS = 3;

   /**
      Constructs an empty board.
   */
   public TicTacToe()
   {
      board = new String[ROWS][COLUMNS];
      // Fill with spaces
      for (int i = 0; i < ROWS; i++)
         for (int j = 0; j < COLUMNS; j++)
            board[i][j] = " ";
   }

   /**
      Sets a field in the board. The field must be unoccupied.
      @param i the row index
      @param j the column index
      @param player the player ("x" or "o")
   */
   public void set(int i, int j, String player)
   {
      if (board[i][j].equals(" "))
         board[i][j] = player;
   }

   /**
      Creates a string representation of the board, such as
      |x o|
      | x |
      |  o|.
      @return the string representation
   */
   public String toString()
   {
      String r = "";
      for (int i = 0; i < ROWS; i++)
      {
         r = r + "|";
         for (int j = 0; j < COLUMNS; j++)
            r = r + board[i][j];
         r = r + "|\n";
      }
      return r;
   }
}
```

ch07/twodim/TicTacToeRunner.java

```java
import java.util.Scanner;

/**
   This program runs a TicTacToe game. It prompts the
   user to set positions on the board and prints out the
   result.
*/
public class TicTacToeRunner
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      String player = "x";
      TicTacToe game = new TicTacToe();
      boolean done = false;
      while (!done)
      {
         System.out.print(game.toString());
         System.out.print(
               "Row for " + player + " (-1 to exit): ");
         int row = in.nextInt();
         if (row < 0) done = true;
         else
         {
            System.out.print("Column for " + player + ": ");
            int column = in.nextInt();
            game.set(row, column, player);
            if (player.equals("x"))
               player = "o";
            else
               player = "x";
         }
      }
   }
}
```

Program Run

```
|   |
|   |
|   |
Row for x (-1 to exit): 1
Column for x: 2
|   |
|  x|
|   |
Row for o (-1 to exit): 0
Column for o: 0
|o  |
|  x|
|   |
Row for x (-1 to exit): -1
```

SELF CHECK

19. How do you declare and initialize a 4-by-4 array of integers?

20. How do you count the number of spaces in the tic-tac-toe board?

Worked Example 7.2

A World Population Table

This Worked Example shows how to print world population data in a table with row and column headers, and totals for each of the data columns.

Special Topic 7.3

Two-Dimensional Arrays with Variable Row Lengths

Special Topic 7.2 discusses two-dimensional arrays in which rows have different lengths.

Special Topic 7.4

Multidimensional Arrays

Special Topic 7.3 discusses arrays of three or more dimensions.

Summary of Learning Objectives

Use arrays for collecting values.

- An array is a sequence of values of the same type.
- You access an array element with an integer index, using the `[]` operator.
- Index values of an array range from `0` to `length - 1`.
- Accessing a nonexistent element results in a bounds error.
- The expression *array*`.length` yields the number of elements in an array.
- Avoid parallel arrays by changing them into arrays of objects.

Use array lists for managing collections whose size can change.

- The `ArrayList` class manages a sequence of objects whose size can change.
- The `ArrayList` class is a generic class: `ArrayList<`*TypeName*`>` collects objects of the given type.

Use wrapper classes when working with array lists of numbers.

- To treat primitive type values as objects, you must use wrapper classes.

Use the enhanced `for` loop to visit all elements of a collection.

- The enhanced `for` loop traverses all elements of a collection.
- In an enhanced `for` loop, the loop variable contains an element, not an index.

Work with arrays that are partially filled.

- With a partially filled array, keep a companion variable to track how many elements are used.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Be able to use common array algorithms.

- To count values, check all elements and count the matches until you reach the end.
- To compute the maximum or minimum value, initialize a candidate with the starting element. Then compare the candidate with the remaining elements and update it if you find a larger or smaller value.
- To find a value, check all elements until you have found a match.
- An array variable stores a reference to the array. Copying the variable yields a second reference to the same array.
- Use the `Arrays.copyOf` method to copy the elements of an array.

Describe the process of regression testing.

- A test suite is a set of tests for repeated testing.
- Regression testing involves repeating previously run tests to ensure that known failures of prior versions do not appear in new versions of the software.

Use two-dimensional arrays for data that is arranged in rows and columns.

- Two-dimensional arrays form a tabular, two-dimensional arrangement. You access elements with an index pair `a[i][j]`.

Classes, Objects, and Methods Introduced in this Chapter

```
java.lang.Boolean
   booleanValue
java.lang.Double
   doubleValue
java.lang.Integer
   intValue
java.util.Arrays
   copyOf
   toString
```

```
java.util.ArrayList<E>
   add
   get
   remove
   set
   size
```

Media Resources

www.wiley.com/ college/ horstmann

- ***Worked Example*** Rolling the Dice
- ***Worked Example*** A World Population Table
- Lab Exercises
- ***Animation*** Removing from an Array
- ***Animation*** Inserting into an Array
- Practice Quiz
- Code Completion Exercises

Review Exercises

★ **R7.1** What is an index? What are the bounds of an array or array list? What is a bounds error?

★ **R7.2** Write a program that contains a bounds error. Run the program. What happens on your computer? How does the error message help you locate the error?

★★ **R7.3** Write Java code for a loop that simultaneously computes the maximum and minimum values of an array list. Use an array list of accounts as an example.

★ **R7.4** Write a loop that reads 10 strings and inserts them into an array list. Write a second loop that prints out the strings in the opposite order from which they were entered.

★★ **R7.5** Consider the algorithm that we used for determining the maximum value in an array list. We set `largestYet` to the starting element, which meant that we were no longer able to use the "for each" loop. An alternate approach is to initialize `largestYet` with `null`, then loop through all elements. Of course, inside the loop you need to test whether `largestYet` is still `null`. Modify the loop that finds the bank account with the largest balance, using this technique. Is this approach more or less efficient than the one used in the text?

★★★ **R7.6** Consider another variation of the algorithm for determining the maximum value. Here, we compute the maximum value of an array of numbers.

```
double max = 0; // Contains an error!
for (double element : values)
{
   if (element > max) max = element;
}
```

However, this approach contains a subtle error. What is the error, and how can you fix it?

★ **R7.7** For each of the following sets of values, write code that fills an array a with the values.

a. 1 2 3 4 5 6 7 8 9 10

b. 0 2 4 6 8 10 12 14 16 18 20

c. 1 4 9 16 25 36 49 64 81 100

d. 0 0 0 0 0 0 0 0 0 0

e. 1 4 9 16 9 7 4 9 11

Use a loop when appropriate.

★★ **R7.8** Write a loop that fills an array a with 10 random numbers between 1 and 100. Write code (using one or more loops) to fill a with 10 different random numbers between 1 and 100.

★ **R7.9** What is wrong with the following loop?

```
double[] values = new double[10];
for (int i = 1; i <= 10; i++) values[i] = i * i;
```

Explain two ways of fixing the error.

★★★T **R7.10** Write a program that constructs an array of 20 integers and fills the first ten elements with the numbers 1, 4, 9, . . . , 100. Compile it and launch the debugger. After the array has been filled with three numbers, inspect it. What are the contents of the elements in the array beyond those that you filled?

★★ **R7.11** Rewrite the following loops without using the "for each" construct. Here, `values` has type `double`.

a. `for (double element : values) sum = sum + element;`

b. `for (double element : values) if (element == target) return true;`

c.
```
int i = 0;
for (double element : values) { values[i] = 2 * element; i++; }
```

★★ **R7.12** Rewrite the following loops, using the "for each" construct. Here, `values` has type `double`.

a. `for (int i = 0; i < values.length; i++) sum = sum + values[i];`

b. `for (int i = 1; i < values.length; i++) sum = sum + values[i];`

c.
```
for (int i = 0; i < values.length; i++)
   if (values[i] == target) return i;
```

★★ **R7.13** What is wrong with these statements for printing an array list with separators?

```
System.out.print(values.get(0));
for (int i = 1; i < values.size(); i++)
{
   System.out.print(", " + values.get(i));
}
```

★★ **R7.14** When finding the position of a match in Section 7.6.6, we used a `while` loop, not a `for` loop. What is wrong with using this loop instead?

```
for (pos = 0; pos < values.size() && !found; pos++)
{
   if (values.get(pos) > 100)
   {
      found = true;
   }
}
```

★★ **R7.15** When inserting an element into an array in Section 7.6.8, we moved the elements with larger index values, starting at the end of the array. Why is it wrong to start at the insertion location, like this?

```
for (int i = pos; i < size - 1; i++)
{
   values[i + 1] = values[i];
}
```

★★ **R7.16** In Section 7.6.9, we doubled the length of the array when growing it. Why didn't we just increase the size by one element?

★ **R7.17** What are parallel arrays? Why are parallel arrays indications of poor programming? How can they be avoided?

★ **R7.18** True or false?

a. All elements of an array are of the same type.

b. An array index must be an integer.

c. Arrays cannot contain string references as elements.

d. Arrays cannot contain `null` references as elements.

e. Parallel arrays must have equal length.

f. Two-dimensional arrays always have the same numbers of rows and columns.

g. Two parallel arrays can be replaced by a two-dimensional array.

h. Elements of different columns in a two-dimensional array can have different types.

★T **R7.19** Define the terms *regression testing* and *test suite*.

★T **R7.20** What is the debugging phenomenon known as *cycling*? What can you do to avoid it?

Programming Exercises

★ **P7.1** Implement a class `Purse`. A purse contains a collection of coins. For simplicity, we will only store the coin names in an `ArrayList<String>`. (We will discuss a better representation in Chapter 8.) Supply a method

```
void addCoin(String coinName)
```

Add a method `toString` to the `Purse` class that prints the coins in the purse in the format

```
Purse[Quarter,Dime,Nickel,Dime]
```

★ **P7.2** Write a method `reverse` that reverses the sequence of coins in a purse. Use the `toString` method of the preceding assignment to test your code. For example, if `reverse` is called with a purse

```
Purse[Quarter,Dime,Nickel,Dime]
```

then the purse is changed to

```
Purse[Dime,Nickel,Dime,Quarter]
```

★ **P7.3** Add a method to the `Purse` class

```
public void transfer(Purse other)
```

that transfers the contents of one purse to another. For example, if `a` is

```
Purse[Quarter,Dime,Nickel,Dime]
```

and `b` is

```
Purse[Dime,Nickel]
```

then after the call `a.transfer(b)`, `a` is

```
Purse[Quarter,Dime,Nickel,Dime,Dime,Nickel]
```

and `b` is empty.

★ **P7.4** Write a method for the `Purse` class

```
public boolean sameContents(Purse other)
```

that checks whether the other purse has the same coins in the same order.

★★ **P7.5** Write a method for the `Purse` class

```
public boolean sameCoins(Purse other)
```

that checks whether the other purse has the same coins, perhaps in a different order. For example, the purses

`Purse[Quarter,Dime,Nickel,Dime]` and `Purse[Nickel,Dime,Dime,Quarter]` should be considered equal.

You will probably need one or more helper methods.

★★ **P7.6** A `Polygon` is a closed curve made up from line segments that join the polygon's corner points. Implement a class `Polygon` with methods

```
public double perimeter()
```

and

```
public double area()
```

that compute the circumference and area of a polygon. To compute the perimeter, compute the distance between adjacent points, and total up the distances. The area of a polygon with corners $(x_0, y_0), \ldots, (x_{n-1}, y_{n-1})$ is

$$\frac{1}{2}\left(x_0y_1 + x_1y_2 + \cdots + x_{n-1}y_0 - y_0x_1 - y_1x_2 - \cdots - y_{n-1}x_0\right)$$

As test cases, compute the perimeter and area of a rectangle and of a regular hexagon. *Note:* You need not draw the polygon — that is done in Exercise P7.18.

★ **P7.7** Write a program that reads a sequence of integers into an array and that computes the alternating sum of all elements in the array. For example, if the program is executed with the input data

$$1 \quad 4 \quad 9 \quad 16 \quad 9 \quad 7 \quad 4 \quad 9 \quad 11$$

then it computes

$$1 - 4 + 9 - 16 + 9 - 7 + 4 - 9 + 11 = -2$$

★★ **P7.8** Write a program that produces random permutations of the numbers 1 to 10. To generate a random permutation, you need to fill an array with the numbers 1 to 10 so that no two entries of the array have the same contents. You could do it by brute force, by calling `Random.nextInt` until it produces a value that is not yet in the array. Instead, you should implement a smart method. Make a second array and fill it with the numbers 1 to 10. Then pick one of those at random, remove it, and append it to the permutation array. Repeat 10 times. Implement a class `PermutationGenerator` with a method

```
int[] nextPermutation
```

★★ **P7.9** A *run* is a sequence of adjacent repeated values. Write a program that generates a sequence of 20 random die tosses and that prints the die values, marking the runs by including them in parentheses, like this:

```
1 2 (5 5) 3 1 2 4 3 (2 2 2 2) 3 6 (5 5) 6 3 1
```

Use the following pseudocode:

```
Set a boolean variable inRun to false.
For each valid index i in the array list
    If inRun
        If values[i] is different from the preceding value
            Print )
            inRun = false
    Else
        If values[i] is the same as the following value
            Print (
            inRun = true
    Print values[i]
If inRun, print )
```

★★★ **P7.10** Write a program that generates a sequence of 20 random die tosses and that prints the die values, marking only the longest run, like this:

```
1 2 5 5 3 1 2 4 3 (2 2 2 2) 3 6 5 5 6 3 1
```

If there is more than one run of maximum length, mark the first one.

★★ **P7.11** It is a well-researched fact that men in a restroom generally prefer to maximize their distance from already occupied stalls, by occupying the middle of the longest sequence of unoccupied places.

For example, consider the situation where ten stalls are empty.

```
_ _ _ _ _ _ _ _ _ _
```

The first visitor will occupy a middle position:

```
_ _ _ _ _ X _ _ _ _
```

The next visitor will be in the middle of the empty area at the left.

```
_ _ X _ _ X _ _ _ _
```

Write a program that reads the number of stalls and then prints out diagrams in the format given above when the stalls become filled, one at a time. *Hint:* Use an array of `boolean` values to indicate whether a stall is occupied.

★★★ **P7.12** In this assignment, you will model the game of *Bulgarian Solitaire*. The game starts with 45 cards. (They need not be playing cards. Unmarked index cards work just as well.) Randomly divide them into some number of piles of random size. For example, you might start with piles of size 20, 5, 1, 9, and 10. In each round, you take one card from each pile, forming a new pile with these cards. For example, the sample starting configuration would be transformed into piles of size 19, 4, 8, 10, and 5. The solitaire is over when the piles have size 1, 2, 3, 4, 5, 6, 7, 8, and 9, in some order. (It can be shown that you always end up with such a configuration.)

In your program, produce a random starting configuration and print it. Then keep applying the solitaire step and print the result. Stop when the solitaire final configuration is reached.

★★ **P7.13** Add a method `getWinner` to the `TicTacToe` class of Section 7.8. It should return `"x"` or `"o"` to indicate a winner, or `" "` if there is no winner yet. Recall that a winning position has three matching marks in a row, column, or diagonal.

★★★ **P7.14** Write an application that plays tic-tac-toe. Your program should draw the game board, change players after every successful move, and pronounce the winner.

★★ **P7.15** *Magic squares*. An $n \times n$ matrix that is filled with the numbers $1, 2, 3, \ldots, n^2$ is a magic square if the sum of the elements in each row, in each column, and in the two diagonals is the same value. For example,

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

Write a program that reads in n^2 values from the keyboard and tests whether they form a magic square when arranged as a square matrix.

You need to test three features:

- Did the user enter n^2 numbers for some n?
- Do each of the numbers 1, 2, . . . , n^2 occur exactly once in the user input?
- When the numbers are put into a square, are the sums of the rows, columns, and diagonals equal to each other?

If the size of the input is a square, test whether all numbers between 1 and n^2 are present. Then compute the row, column, and diagonal sums. Implement a class `Square` with methods

```
public void add(int i)
public boolean isMagic()
```

★★ **P7.16** Implement the following algorithm to construct magic n-by-n^2 squares; it works only if n is odd. Place a 1 in the middle of the bottom row. After k has been placed in the (i, j) square, place $k + 1$ into the square to the right and down, wrapping around the borders. However, if the square to the right and down has already been filled, or if you are in the lower-right corner, then you must move to the square straight up instead. Here is the 5×5 square that you get if you follow this method:

11	18	25	2	9
10	12	19	21	3
4	6	13	20	22
23	5	7	14	16
17	24	1	8	15

Write a program whose input is the number n and whose output is the magic square of order n if n is odd. Implement a class `MagicSquare` with a constructor that constructs the square and a `toString` method that returns a representation of the square.

★G **P7.17** Implement a class `Cloud` that contains an array list of `Point2D.Double` objects. Support methods

```
public void add(Point2D.Double aPoint)
public void draw(Graphics2D g2)
```

Draw each point as a tiny circle.

Write a graphical application that draws a cloud of 100 random points.

★★G **P7.18** Implement a class `Polygon` that contains an array list of `Point2D.Double` objects. Support methods

```
public void add(Point2D.Double aPoint)
public void draw(Graphics2D g2)
```

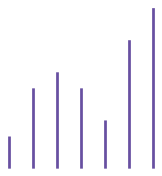
Draw the polygon by joining adjacent points with a line, and then closing it up by joining the end and start points.

Write a graphical application that draws a square and a pentagon using two `Polygon` objects.

★G **P7.19** Write a class `Chart` with methods

```
public void add(int value)
public void draw(Graphics2D g2)
```

that displays a stick chart of the added values, like this:



You may assume that the values are pixel positions.

★★G **P7.20** Write a class `BarChart` with methods

```
public void add(double value)
public void draw(Graphics2D g2)
```

that displays a chart of the added values. You may assume that all added values are positive. Stretch the bars so that they fill the entire area of the screen. You must figure out the maximum of the values, and then scale each bar.

★★★G **P7.21** Improve the `BarChart` class of Exercise P7.20 to work correctly when the data contains negative values.

★★G **P7.22** Write a class `PieChart` with methods

```
public void add(double value)
public void draw(Graphics2D g2)
```

that displays a pie chart of the added values. You may assume that all data values are positive.

Programming Projects

Project 7.1 *Poker Simulator.* In this assignment, you will implement a simulation of a popular casino game usually called video poker. The card deck contains 52 cards, 13 of each suit. At the beginning of the game, the deck is shuffled. You need to devise a fair method for shuffling. (It does not have to be efficient.) Then the top five cards of the deck are presented to the player. The player can reject none, some, or all of the cards. The rejected cards are replaced from the top of the deck. Now the hand is scored. Your program should pronounce it to be one of the following:

- No pair—The lowest hand, containing five separate cards that do not match up to create any of the hands below.
- One pair—Two cards of the same value, for example two queens.
- Two pairs—Two pairs, for example two queens and two 5's.
- Three of a kind—Three cards of the same value, for example three queens.
- Straight—Five cards with consecutive values, not necessarily of the same suit, such as 4, 5, 6, 7, and 8. The ace can either precede a 2 or follow a king.
- Flush—Five cards, not necessarily in order, of the same suit.
- Full House—Three of a kind and a pair, for example three queens and two 5's
- Four of a Kind—Four cards of the same value, such as four queens.

- Straight Flush—A straight and a flush: Five cards with consecutive values of the same suit.
- Royal Flush—The best possible hand in poker. A 10, jack, queen, king, and ace, all of the same suit.

If you are so inclined, you can implement a wager. The player pays a `JavaDollar` for each game, and wins according to the following payout chart:

Hand	Payout	Hand	Payout
Royal Flush	250	Straight	4
Straight Flush	50	Three of a Kind	3
Four of a Kind	25	Two Pair	2
Full House	6	Pair of Jacks or Better	1
Flush	5		

Project 7.2 *The Game of Life* is a well-known mathematical game that gives rise to amazingly complex behavior, although it can be specified by a few simple rules. (It is not actually a game in the traditional sense, with players competing for a win.) Here are the rules. The game is played on a rectangular board. Each square can be either empty or occupied. At the beginning, you can specify empty and occupied cells in some way; then the game runs automatically. In each *generation*, the next generation is computed. A new cell is born on an empty square if it is surrounded by exactly three occupied neighbor cells. A cell dies of overcrowding if it is surrounded by four or more neighbors, and it dies of loneliness if it is surrounded by zero or one neighbor. A neighbor is an occupant of an adjacent square to the left, right, top, or bottom or in a diagonal direction. Figure 16 shows a cell and its neighbor cells.

Many configurations show interesting behavior when subjected to these rules. Figure 17 shows a *glider*, observed over five generations. Note how it moves. After four generations, it is transformed into the identical shape, but located one square to the right and below.

One of the more amazing configurations is the glider gun: a complex collection of cells that, after 30 moves, turns back into itself and a glider (see Figure 18).

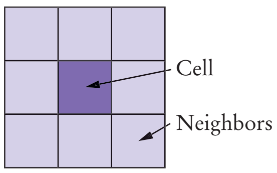


Figure 16
Neighborhood of a Cell

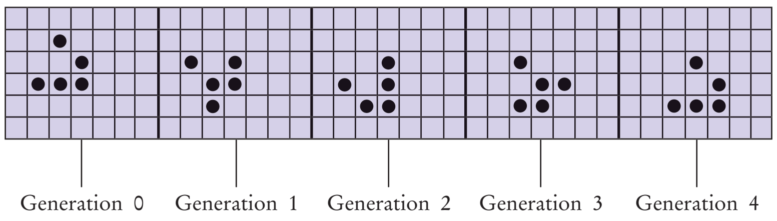


Figure 17
Glider

Program the game to eliminate the drudgery of computing successive generations by hand. Use a two-dimensional array to store the rectangular configuration. Write a program that shows successive generations of the game. You may get extra credit if you implement a graphical application that allows the user to add or remove cells by clicking with the mouse.

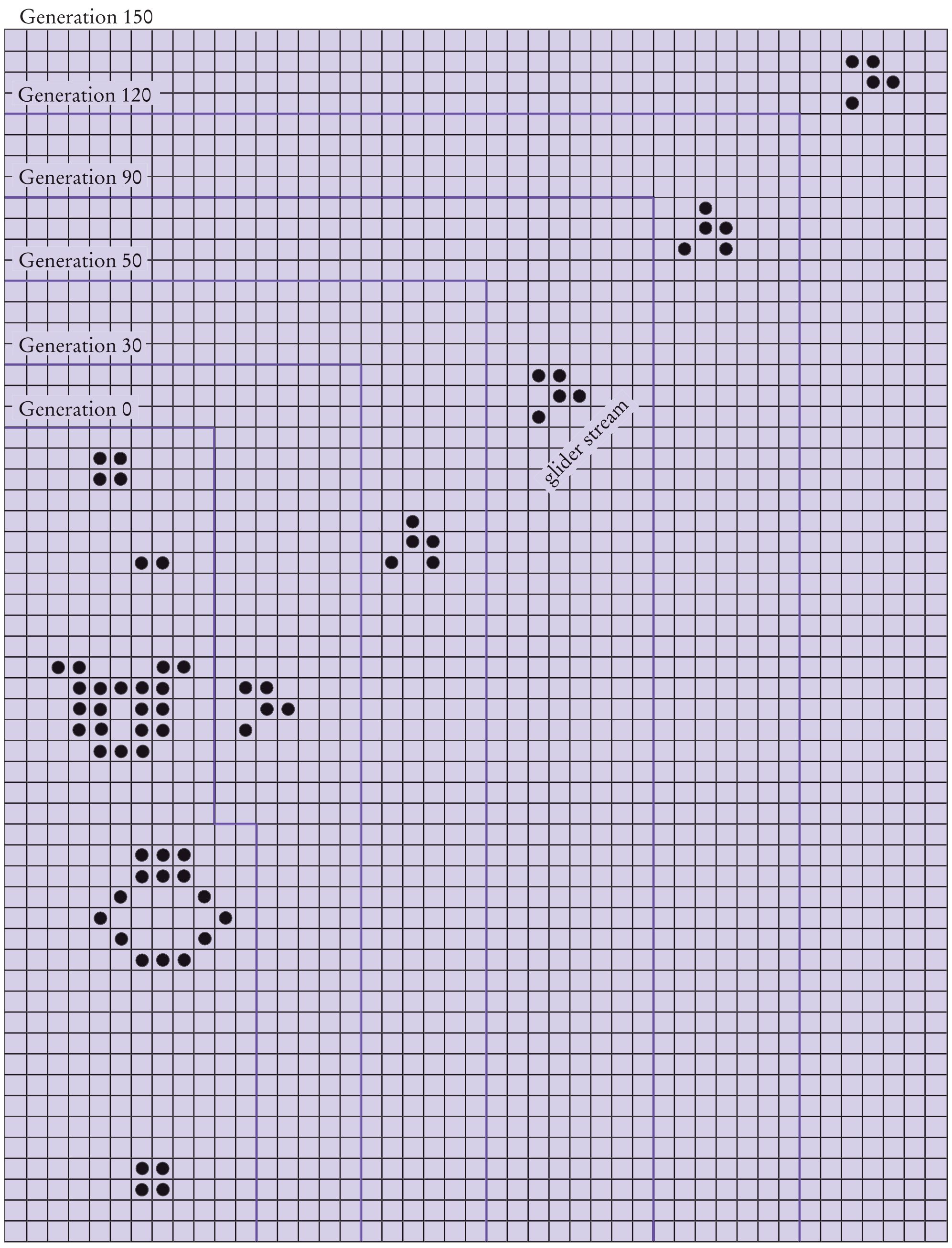


Figure 18 Glider Gun

Answers to Self-Check Questions

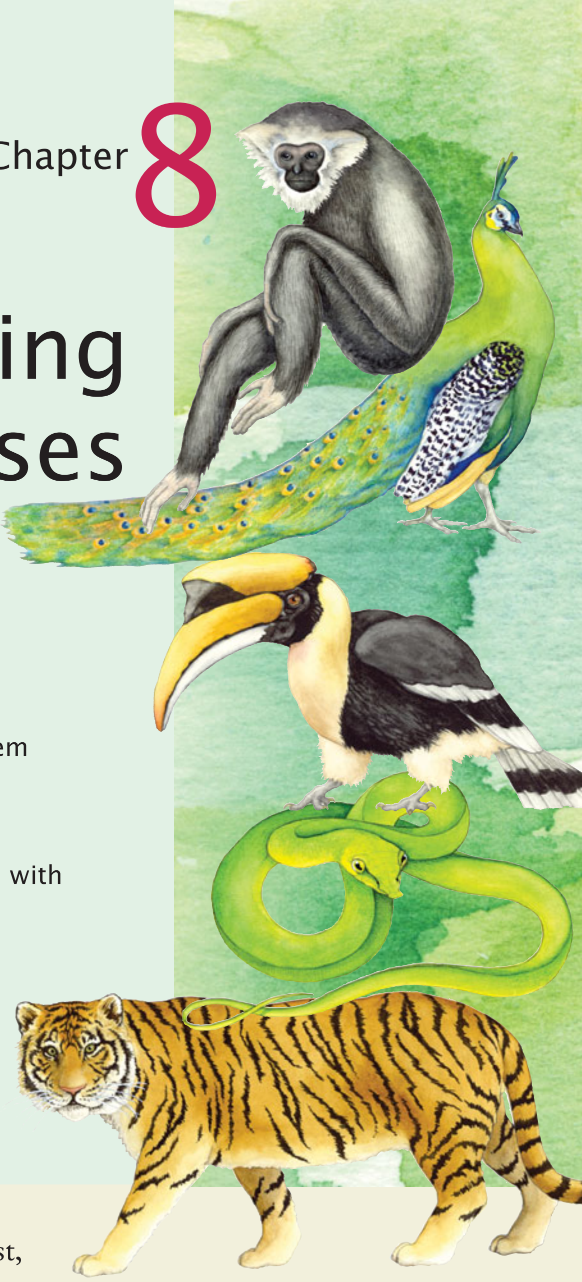
1. 0, 1, 4, 9, 16, 25, 36, 49, 64, 81, but *not* 100.
2. (a) 0; (b) a run-time error: array index out of bounds; (c) a compile-time error: `c` is not initialized.

3.
   ```
   new String[10];
   new ArrayList<String>();
   ```
4. `names` contains the strings `"B"` and `"C"` at positions 0 and 1.
5. `double` is one of the eight primitive types. `Double` is a class type.
6. `values.set(0, values.get(0) + 1);`
7. `for (double element : values) System.out.println(element);`
8. It counts how many accounts have a zero balance.
9. `for (int i = valuesSize - 1; i >= 0; i--) System.out.println(values[i]);`
10. `valuesSize--;`
11. You need to use wrapper objects in an `ArrayList<Double>`, which is less efficient.
12. It returns the first match that it finds.
13. Yes, but the first comparison would always fail.

14.
    ```
    for (int i = 0; i < values.size(); i++)
    {
       System.out.print(values.get(i));
       if (i < values.size() - 1)
       {
          System.out.print(" | ");
       }
    }
    ```
    Now you know why we set up the loop the other way.
15. If `names` happens to be empty, the first line causes a bounds error.
16. It is possible to introduce errors when modifying code.
17. Add a test case to the test suite that verifies that the error is fixed.
18. There is no human user who would see the prompts because input is provided from a file.
19. `int[][] array = new int[4][4];`

20.
    ```
    int count = 0;
    for (int i = 0; i < ROWS; i++)
       for (int j = 0; j < COLUMNS; j++)
          if (board[i][j].equals(" ")) count++;
    ```

Chapter 8 Designing Classes



CHAPTER GOALS

- To learn how to choose appropriate classes for a given problem
- To understand the concepts of cohesion and coupling
- To minimize the use of side effects
- To document the responsibilities of methods and their callers with preconditions and postconditions
- To understand static methods and variables
- To understand the scope rules for local variables and instance variables
- To learn about packages

T To learn about unit testing frameworks

In this chapter you will learn more about designing classes. First, we will discuss the process of discovering classes and declaring methods. Next, we will discuss how the concepts of pre- and postconditions enable you to specify, implement, and invoke methods correctly. You will also learn about several more technical issues, such as static methods and variables. Finally, you will see how to use packages to organize your classes.

CHAPTER CONTENTS

8.1 Discovering Classes 290

8.2 Cohesion and Coupling 291

QUALITY TIP 8.1: Consistency 293

8.3 Immutable Classes 294

8.4 Side Effects 295

COMMON ERROR 8.1: Trying to Modify Primitive Type Parameters 296

QUALITY TIP 8.2: Minimize Side Effects 298

QUALITY TIP 8.3: Don’t Change the Contents of Parameter Variables 298

SPECIAL TOPIC 8.1: Call by Value and Call by Reference ⊕

8.5 Preconditions and Postconditions 299

SYNTAX 8.1: Assertion 301

SPECIAL TOPIC 8.2: Class Invariants ⊕

8.6 Static Methods 302

QUALITY TIP 8.4: Minimize the Use of Static Methods 304

8.7 Static Variables 304

SPECIAL TOPIC 8.3: Static Imports ⊕

SPECIAL TOPIC 8.4: Alternative Forms of Instance and Static Variable Initialization ⊕

8.8 Scope 307

COMMON ERROR 8.2: Shadowing 309

QUALITY TIP 8.5: Minimize Variable Scope 310

8.9 Packages 310

SYNTAX 8.2: Package Specification 310

COMMON ERROR 8.3: Confusing Dots 314

SPECIAL TOPIC 8.5: Package Access 314

HOW TO 8.1: Programming with Packages 315

RANDOM FACT 8.1: The Explosive Growth of Personal Computers ⊕

8.10T Unit Test Frameworks 316

8.1 Discovering Classes

You have used a good number of classes in the preceding chapters and probably designed a few classes yourself as part of your programming assignments. Designing a class can be a challenge—it is not always easy to tell how to start or whether the result is of good quality.

A class should represent a single concept from a problem domain, such as business, science, or mathematics.

What makes a good class? Most importantly, a class should *represent a single concept* from a problem domain. Some of the classes that you have seen represent concepts from mathematics:

- `Point`
- `Rectangle`
- `Ellipse`

Other classes are abstractions of real-life entities:

- `BankAccount`
- `CashRegister`

For these classes, the properties of a typical object are easy to understand. A `Rectangle` object has a width and height. Given a `BankAccount` object, you can deposit and withdraw money. Generally, concepts from the part of the universe that a program concerns, such as science, business, or a game, make good classes. The name for such a class should be a noun that describes the concept. In fact, a simple rule of thumb for getting started with class design is to look for nouns in the problem description.

One useful category of classes can be described as *actors*. Objects of an actor class carry out certain tasks for you. Examples of actors are the `Scanner` class of

Chapter 4 and the Random class in Chapter 6. A Scanner object scans a stream for numbers and strings. A Random object generates random numbers. It is a good idea to choose class names for actors that end in "-er" or "-or". (A better name for the Random class might be RandomNumberGenerator.)

Very occasionally, a class has no objects, but it contains a collection of related static methods and constants. The Math class is a typical example. Such a class is called a *utility class*.

Finally, you have seen classes with only a main method. Their sole purpose is to start a program. From a design perspective, these are somewhat degenerate examples of classes.

What might not be a good class? If you can't tell from the class name what an object of the class is supposed to do, then you are probably not on the right track. For example, your homework assignment might ask you to write a program that prints paychecks. Suppose you start by trying to design a class PaycheckProgram. What would an object of this class do? An object of this class would have to do everything that the homework needs to do. That doesn't simplify anything. A better class would be Paycheck. Then your program can manipulate one or more Paycheck objects.

Another common mistake is to turn a single operation into a class. For example, if your homework assignment is to compute a paycheck, you may consider writing a class ComputePaycheck. But can you visualize a "ComputePaycheck" object? The fact that "ComputePaycheck" isn't a noun tips you off that you are on the wrong track. On the other hand, a Paycheck class makes intuitive sense. The word "paycheck" is a noun. You can visualize a paycheck object. You can then think about useful methods of the Paycheck class, such as computeTaxes, that help you solve the assignment.

SELF CHECK

1. What is a simple rule of thumb for finding classes?
2. Your job is to write a program that plays chess. Might ChessBoard be an appropriate class? How about MovePiece?

8.2 Cohesion and Coupling

In this section you will learn two useful criteria for analyzing the quality of a class—qualities of its public interface.

The public interface of a class is cohesive if all of its features are related to the concept that the class represents.

A class should represent a single concept. The public methods and constants that the public interface exposes should be *cohesive*. That is, all interface features should be closely related to the single concept that the class represents.

If you find that the public interface of a class refers to multiple concepts, then that is a good sign that it may be time to use separate classes instead. Consider, for example, the public interface of the CashRegister class in Chapter 4:

```
public class CashRegister
{
   public static final double NICKEL_VALUE = 0.05;
   public static final double DIME_VALUE = 0.1;
   public static final double QUARTER_VALUE = 0.25;
   . . .
```

```
      public void enterPayment(int dollars, int quarters,
            int dimes, int nickels, int pennies)
      . . .
   }
```

There are really two concepts here: a cash register that holds coins and computes their total, and the values of individual coins. (For simplicity, we assume that the cash register only holds coins, not bills. Exercise P8.1 discusses a more general solution.)

It makes sense to have a separate `Coin` class and have coins responsible for knowing their values.

```
public class Coin
{
   . . .
   public Coin(double aValue, String aName) { . . . }
   public double getValue() { . . . }
   . . .
}
```

Then the `CashRegister` class can be simplified:

```
public class CashRegister
{
   . . .
   public void enterPayment(int coinCount, Coin coinType) { . . . }
   . . .
}
```

Now the `CashRegister` class no longer needs to know anything about coin values. The same class can equally well handle euros or zorkmids!

This is clearly a better solution, because it separates the responsibilities of the cash register and the coins. The only reason we didn't follow this approach in Chapter 4 was to keep the `CashRegister` example simple.

A class depends on another class if it uses objects of that class.

Many classes need other classes in order to do their jobs. For example, the restructured `CashRegister` class now depends on the `Coin` class to determine the value of the payment.

To visualize relationships, such as dependence between classes, programmers draw class diagrams. In this book, we use the UML ("Unified Modeling Language") notation for objects and classes. UML is a notation for object-oriented analysis and design invented by Grady Booch, Ivar Jacobson, and James Rumbaugh, three leading researchers in object-oriented software development. The

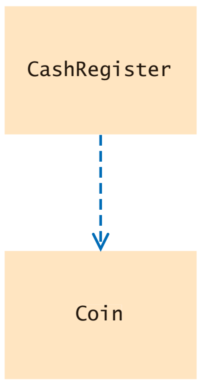


Figure 1
Dependency Relationship Between the `CashRegister` and `Coin` Classes

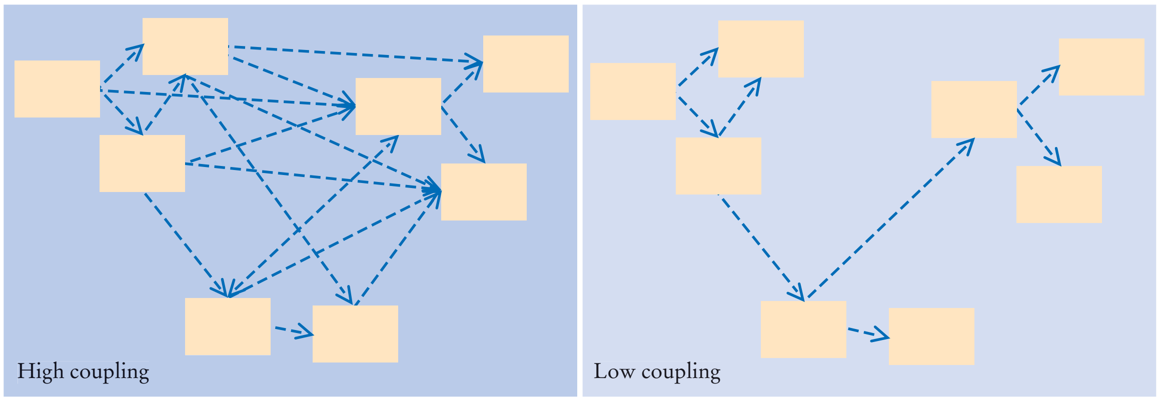


Figure 2 High and Low Coupling Between Classes

UML notation distinguishes between *object diagrams* and class diagrams. In an object diagram the class names are underlined; in a class diagram the class names are not underlined. In a class diagram, you denote dependency by a dashed line with a >-shaped open arrow tip that points to the dependent class. Figure 1 shows a class diagram indicating that the `CashRegister` class depends on the `Coin` class.

Note that the `Coin` class does *not* depend on the `CashRegister` class. Coins have no idea that they are being collected in cash registers, and they can carry out their work without ever calling any method in the `CashRegister` class.

If many classes of a program depend on each other, then we say that the **coupling** between classes is high. Conversely, if there are few dependencies between classes, then we say that the coupling is low (see Figure 2).

It is a good practice to minimize the coupling (i.e., dependency) between classes.

Why does coupling matter? If the `Coin` class changes in the next release of the program, all the classes that depend on it may be affected. If the change is drastic, the coupled classes must all be updated. Furthermore, if we would like to use a class in another program, we have to take with it all the classes on which it depends. Thus, we want to remove unnecessary coupling between classes.

SELF CHECK

3. Why is the `CashRegister` class from Chapter 4 not cohesive?
4. Why does the `Coin` class not depend on the `CashRegister` class?
5. Why should coupling be minimized between classes?

Quality Tip 8.1

Consistency

In this section you learned of two criteria for analyzing the quality of the public interface of a class. You should maximize cohesion and remove unnecessary coupling. There is another criterion that we would like you to pay attention to—*consistency*. When you have a set of methods, follow a consistent scheme for their names and parameters. This is simply a sign of good craftsmanship.

Sadly, you can find any number of inconsistencies in the standard library. Here is an example. To show an input dialog box, you call

```
JOptionPane.showInputDialog(promptString)
```

To show a message dialog box, you call

```
JOptionPane.showMessageDialog(null, messageString)
```

What's the `null` parameter? It turns out that the `showMessageDialog` method needs a parameter to specify the parent window, or `null` if no parent window is required. But the `showInputDialog` method requires no parent window. Why the inconsistency? There is no reason. It would have been an easy matter to supply a `showMessageDialog` method that exactly mirrors the `showInputDialog` method.

Inconsistencies such as these are not fatal flaws, but they are an annoyance, particularly because they can be so easily avoided.

8.3 Immutable Classes

When analyzing a program that consists of many classes, it is not only important to understand which parts of the program use a given class. We also want to understand who *modifies* objects of a class. The following sections are concerned with this aspect of class design.

Recall that a **mutator method** modifies the object on which it is invoked, whereas an **accessor method** merely accesses information without making any modifications. For example, in the `BankAccount` class, the `deposit` and `withdraw` methods are mutator methods. Calling

```
account.deposit(1000);
```

modifies the state of the `account` object, but calling

```
double balance = account.getBalance();
```

does not modify the state of `account`.

An immutable class has no mutator methods.

You can call an accessor method as many times as you like—you always get the same answer, and the method does not change the state of your object. That is clearly a desirable property, because it makes the behavior of such a method very predictable.

Some classes have been designed to have only accessor methods and no mutator methods at all. Such classes are called **immutable**. An example is the `String` class. Once a string has been constructed, its content never changes. No method in the `String` class can modify the contents of a string. For example, the `toUpperCase` method does not change characters from the original string. Instead, it constructs a *new* string that contains the uppercase characters:

```
String name = "John Q. Public";
String uppercased = name.toUpperCase(); // name is not changed
```

References to objects of an immutable class can be safely shared.

An immutable class has a major advantage: It is safe to give out references to its objects freely. If no method can change the object's value, then no code can modify the object at an unexpected time. In contrast, if you give out a `BankAccount` reference to any other method, you have to be aware that the state of your object may change—the other method can call the `deposit` and `withdraw` methods on the reference that you gave it.

SELF CHECK

6. Is the `substring` method of the `String` class an accessor or a mutator?
7. Is the `Rectangle` class immutable?

8.4 Side Effects

A side effect of a method is any externally observable data modification.

A **side effect** of a method is any kind of modification of data that is observable outside the method. Mutator methods have a side effect, namely the modification of the implicit parameter. For example, when you call

```
harrysChecking.deposit(1000);
```

you can tell that something changed by calling `harrysChecking.getBalance()`.

Now consider the explicit parameter of a method, such as `studentNames` here:

```
public class GradeBook
{
   . . .
   /**
      Adds student names to this grade book.
      @param studentNames a list of student names
   */
   public void addStudents(ArrayList<String> studentNames)
   {
      while (studentNames.size() > 0)
      {
         String name = studentNames.remove(0); // Not recommended
         Add name to gradebook
      }
   }
}
```

This method *removes* all names from the `studentNames` parameter as it adds them to the grade book. That too is a side effect. After a call

```
book.addStudents(listOfNames);
```

the call `listOfNames.size()` returns `0`. Such a side effect would not be what most programmers expect. It is better if the method reads the names from the list without modifying it.

Now consider the following method:

```
public class BankAccount
{
   . . .
   /**
      Transfers money from this account to another account.
      @param amount the amount of money to transfer
      @param other the account into which to transfer the money
   */
   public void transfer(double amount, BankAccount other)
   {
      balance = balance - amount;
      other.deposit(amount);
   }
}
```

This method modifies both the implicit parameter and the explicit parameter `other`. Neither side effect is surprising for a `transfer` method, and there is no reason to avoid them.

Another example of a side effect is output. Consider how we have always printed a bank balance:

```
System.out.println("The balance is now $" + momsSavings.getBalance());
```

Why don't we simply have a `printBalance` method?

```
public void printBalance() // Not recommended
{
   System.out.println("The balance is now $" + balance);
}
```

That would be more convenient when you actually want to print the value. But, of course, there are cases when you want the value for some other purpose. Thus, you can't simply drop the `getBalance` method in favor of `printBalance`.

More importantly, the `printBalance` method forces strong assumptions on the `BankAccount` class.

- The message is in English—you assume that the user of your software reads English. The majority of people on the planet don't.
- You rely on `System.out`. A method that relies on `System.out` won't work in an embedded system, such as the computer inside an automatic teller machine.

In other words, this design violates the rule of minimizing the coupling of the classes. The `printBalance` method couples the `BankAccount` class with the `System` and `PrintStream` classes. It is best to decouple input/output from the actual work of your classes.

SELF CHECK

8. If a refers to a bank account, then the call `a.deposit(100)` modifies the bank account object. Is that a side effect?
9. Consider the `DataSet` class of Chapter 6. Suppose we add a method

```
void read(Scanner in)
{
   while (in.hasNextDouble())
      add(in.nextDouble());
}
```

Does this method have a side effect other than mutating the data set?

Common Error 8.1

Trying to Modify Primitive Type Parameters

Methods can't update parameters of primitive type (numbers, `char`, and `boolean`). To illustrate this point, let's try to write a method that updates a number parameter:

```
public class BankAccount
{
   . . .
   /**
      Transfers money from this account and tries to add it to a balance.
      @param amount  the amount of money to transfer
      @param otherBalance  balance to add the amount to
   */
   void transfer(double amount, double otherBalance)  ❷
   {
      balance = balance - amount;
      otherBalance = otherBalance + amount;
         // Won't work
   }  ❸
}
```

This doesn't work. Let's consider a method call.

```
double savingsBalance = 1000;
harrysChecking.transfer(500, savingsBalance); 1
System.out.println(savingsBalance); 4
```

As the method starts, the parameter variable `otherBalance` is set to the same value as `savingsBalance` (see Figure 3). Then the value of the `otherBalance` value is modified, but that modification has no effect on `savingsBalance`, because `otherBalance` is a separate variable. When the method terminates, the `otherBalance` variable dies, and `savingsBalance` isn't increased.

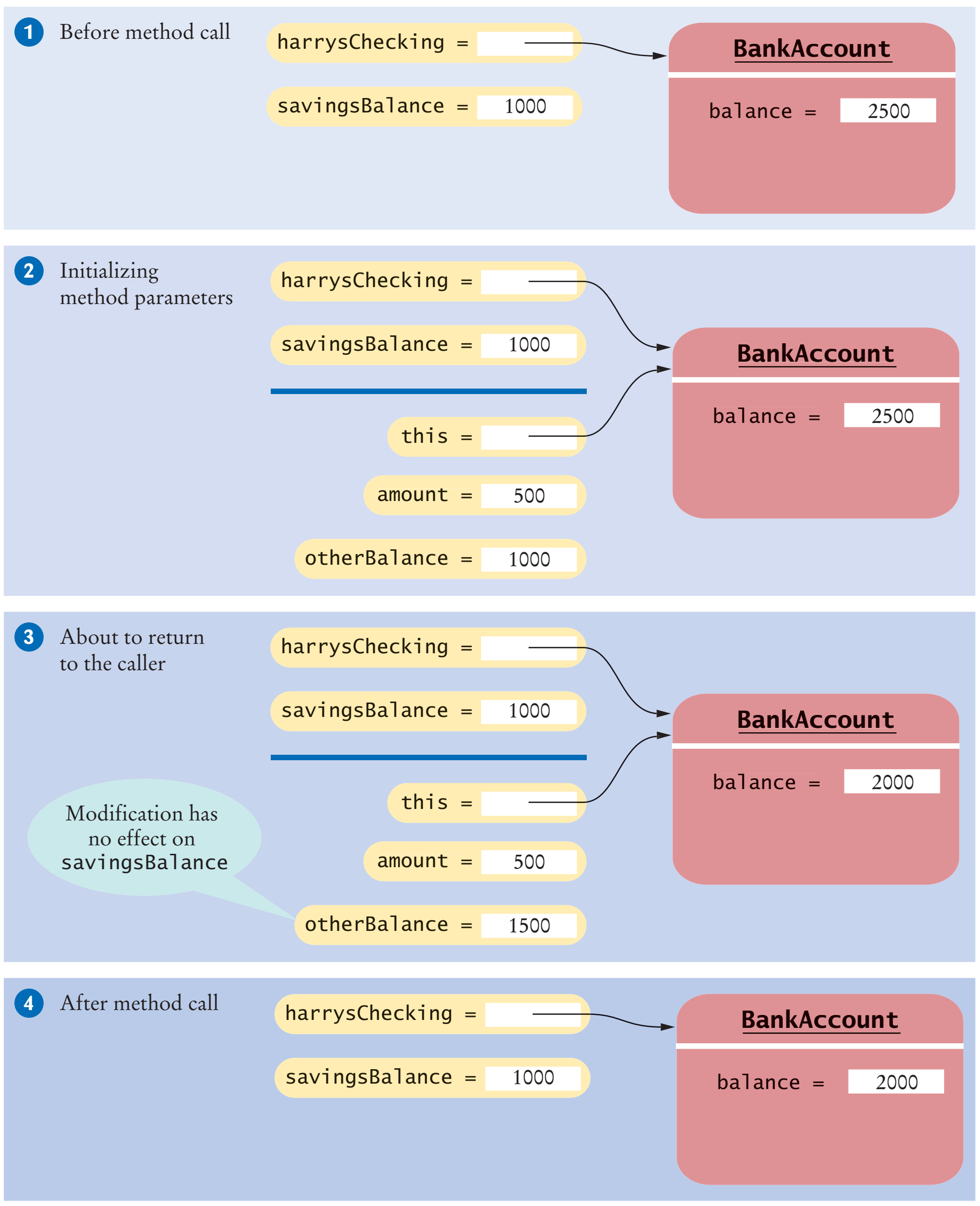


Figure 3 Modifying a Numeric Parameter Has No Effect on Caller

In Java, a method can never change parameters of primitive type.

Why did the example at the beginning of Section 8.4 work, where the second explicit parameter was a `BankAccount` reference? Then the parameter variable contained a *copy* of the object reference. Through that reference, the method is able to modify the object.

You already saw this difference between objects and primitive types in Chapter 2. As a consequence, a Java method can *never* modify numbers that are passed to it.

Quality Tip 8.2

Minimize Side Effects

In an ideal world, all methods would be accessors that simply return an answer without changing any value at all. (In fact, programs that are written in so-called *functional* programming languages, such as Scheme and ML, come close to this ideal.) Of course, in an object-oriented programming language, we use objects to remember state changes. Therefore, a method that just changes the state of its implicit parameter is certainly acceptable. Although side effects cannot be completely eliminated, they can be the cause of surprises and problems and should be minimized.

When designing methods, minimize side effects.

When analyzing side effects, we can categorize methods as follows:

- Accessor methods with no changes to any explicit parameters—no side effects. Example: `getBalance`.
- Mutator methods with no changes to any explicit parameters—an acceptable side effect. Example: `BankAccount.withdraw` is acceptable.
- Methods that change an explicit parameter—a side effect that should be avoided when possible. Example: `BankAccount.transfer` on page 295 is acceptable, but `GradeBook.addStudents` on page 295 should be changed.
- Methods that change another object (such as `System.out`)—a side effect that should be avoided. Example: `BankAccount.printBalance` on page 296 should not be implemented.

Quality Tip 8.3

Don’t Change the Contents of Parameter Variables

As explained in Common Error 8.1 on page 296 and Special Topic 8.1 on page 299, a method can treat its parameter variables like local variables and change their contents. However, that change affects only the parameter variable within the method itself—not any values supplied in the method call. Some programmers take “advantage” of the temporary nature of the parameter variables and use them as “convenient” holders for intermediate results, as in this example:

```
public void deposit(double amount)
{
   // Using the parameter variable to hold an intermediate value
   amount = balance + amount; // Poor style
   . . .
}
```

That code would produce errors if another statement in the method referred to `amount` expecting it to be the value of the parameter, and it will confuse later programmers maintaining this method. You should always treat the parameter variables as if they were constants. Don’t assign new values to them. Instead, introduce a new local variable.

```
public void deposit(double amount)
{
   double newBalance = balance + amount;
   . . .
}
```

Special Topic 8.1

Call by Value and Call by Reference

Special Topic 8.1 explains the theoretical concepts of "call by value" and "call by reference" and demonstrates that the Java programming language always uses "call by value".

8.5 Preconditions and Postconditions

A precondition is a requirement that the caller of a method must meet.

A **precondition** is a requirement that the caller of a method must obey. For example, the `deposit` method of the `BankAccount` class has a precondition that the amount to be deposited should not be negative. It is the responsibility of the caller never to call a method if one of its preconditions is violated. If the method is called anyway, it is not responsible for producing a correct result.

Therefore, a precondition is an important part of the method, and you must document it. Here we document the precondition that the `amount` parameter must not be negative.

```
/**
   Deposits money into this account.
   @param amount the amount of money to deposit
   (Precondition: amount >= 0)
*/
```

Some `javadoc` extensions support a `@precondition` or `@requires` tag, but it is not a part of the standard `javadoc` program. Because the standard `javadoc` tool skips all unknown tags, we simply add the precondition to the method explanation or the appropriate `@param` tag.

Preconditions are typically provided for one of two reasons:

1. To restrict the parameters of a method
2. To require that a method is only called when it is in the appropriate *state*

For example, once a `Scanner` has run out of input, it is no longer legal to call the `next` method. Thus, a precondition for the `next` method is that the `hasNext` method returns `true`.

If a method is called in violation of a precondition, the method is not responsible for computing the correct result.

A method is responsible for operating correctly only when its caller has fulfilled all preconditions. The method is free to do *anything* if a precondition is not fulfilled. What should a method actually do when it is called with inappropriate inputs? For example, what should `account.deposit(-1000)` do? There are two choices.

1. A method can check for the violation and **throw an exception**. Then the method does not return to its caller; instead, control is transferred to an

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

exception handler. If no handler is present, then the program terminates. We will discuss exceptions in Chapter 11.

2. A method can skip the check and work under the assumption that the preconditions are fulfilled. If they aren't, then any data corruption (such as a negative balance) or other failures are the caller's fault.

The first approach can be inefficient, particularly if the same check is carried out many times by several methods. The second approach can be dangerous. The *assertion mechanism* was invented to give you the best of both approaches.

An assertion is a logical condition in a program that you believe to be true.

An **assertion** is a condition that you believe to be true at all times in a particular program location. An assertion check tests whether an assertion is true. Here is a typical assertion check that tests a precondition:

```
public double deposit (double amount)
{
   assert amount >= 0;
   balance = balance + amount;
}
```

In this method, the programmer expects that the quantity `amount` can never be negative. When the assertion is correct, no harm is done, and the program works in the normal way. If, for some reason, the assertion fails, *and assertion checking is enabled*, then the program terminates with an `AssertionError`.

However, if assertion checking is disabled, then the assertion is never checked, and the program runs at full speed. By default, assertion checking is disabled when you execute a program. To execute a program with assertion checking turned on, use this command:

```
java -enableassertions MainClass
```

You can also use the shortcut `-ea` instead of `-enableassertions`. You definitely want to turn assertion checking on during program development and testing.

You don't have to use assertions for checking preconditions—throwing an exception is another reasonable option. But assertions have one advantage: You can turn them off after you have tested your program, so that it runs at maximum speed. That way, you never have to feel bad about putting lots of assertions into your code. You can also use assertions for checking conditions other than preconditions.

Many beginning programmers think that it isn't "nice" to abort the program when a precondition is violated. Why not simply return to the caller instead?

```
public void deposit(double amount)
{
   if (amount < 0)
      return; // Not recommended
   balance = balance + amount;
}
```

That is legal—after all, a method can do anything if its preconditions are violated. But it is not as good as an assertion check. If the program calling the `deposit` method has a few bugs that cause it to pass a negative amount as an input value, then the version that generates an assertion failure will make the bugs very obvious during testing—it is hard to ignore when the program aborts. The quiet version, on the other hand, will not alert you, and you may not notice that it performs some wrong calculations as a consequence. Think of assertions as the "tough love" approach to precondition checking.

Syntax 8.1 Assertion

Syntax `assert condition;`

Example

```
assert amount >= 0;
```

If the condition is false **and** assertion checking is enabled, an exception occurs.

Condition that is claimed to be true.

If a method has been called in accordance with its preconditions, then it must ensure that its postconditions are valid.

When a method is called in accordance with its preconditions, then the method promises to do its job correctly. A different kind of promise that the method makes is called a **postcondition**. There are two kinds of postconditions:

1. The return value is computed correctly.
2. The object is in a certain state after the method call is completed.

Here is a postcondition that makes a statement about the object state after the `deposit` method is called.

```
/**
   Deposits money into this account.
   (Postcondition: getBalance() >= 0)
   @param amount the amount of money to deposit
   (Precondition: amount >= 0)
*/
```

As long as the precondition is fulfilled, this method guarantees that the balance after the deposit is not negative.

Some `javadoc` extensions support a `@postcondition` or `@ensures` tag. However, just as with preconditions, we simply add postconditions to the method explanation or the `@return` tag, because the standard `javadoc` program skips all tags that it doesn't know.

Some programmers feel that they must specify a postcondition for every method. When you use `javadoc`, however, you already specify a part of the postcondition in the `@return` tag, and you shouldn't repeat it in a postcondition.

```
// This postcondition statement is overly repetitive.
/**
   Returns the current balance of this account.
   @return the account balance
   (Postcondition: The return value equals the account balance.)
*/
```

Note that we formulate pre- and postconditions only in terms of the *interface* of the class. Thus, we state the precondition of the `withdraw` method as `amount <= getBalance()`, not `amount <= balance`. After all, the caller, which needs to check the precondition, has access only to the public interface, not the private implementation.

Preconditions and postconditions are often compared to *contracts.* In real life, contracts spell out the obligations of the contracting parties. For example, a car dealer may promise you a car in good working order, and you promise in turn to pay a certain amount of money. If either party breaks the promise, then the other is not bound by the terms of the contract. In the same fashion, pre- and postconditions are contractual terms between a method and its caller. The method promises to fulfill the postcondition for all inputs that fulfill the precondition. The caller promises never to call the method with illegal inputs. If the caller fulfills its promise and gets a wrong answer, it can take the method to "programmer's court". If the caller doesn't fulfill its promise and something terrible happens as a consequence, it has no recourse.

SELF CHECK

10. Why might you want to add a precondition to a method that you provide for other programmers?

11. When you implement a method with a precondition and you notice that the caller did not fulfill the precondition, do you have to notify the caller?

Special Topic 8.2

Class Invariants

Special Topic 8.2 introduces the topic of class invariants, logical statements that are true after every constructor and method call. Class invariants can be used for correctness proofs.

8.6 Static Methods

A static method is not invoked on an object.

Sometimes you need a method that is not invoked on an object. Such a method is called a **static method** or a *class method.* In contrast, the methods that you have written up to now are often called **instance methods** because they operate on a particular instance of an object.

A typical example of a static method is the sqrt method in the Math class. When you call Math.sqrt(x), you don't supply any implicit parameter. (Recall that Math is the name of a class, not an object.)

Why would you want to write a method that does not operate on an object? The most common reason is that you want to encapsulate some computation that involves only numbers. Because numbers aren't objects, you can't invoke methods on them. For example, the call x.sqrt() can never be legal in Java.

Here is a typical example of a static method that carries out some simple algebra: to compute p percent of the amount a. Because the parameters are numbers, the method doesn't operate on any objects at all, so we make it into a static method:

```
/**
   Computes a percentage of an amount.
   @param p the percentage to apply
   @param a the amount to which the percentage is applied
   @return p percent of a
*/
public static double percentOf(double p, double a)
{
   return (p / 100) * a;
}
```

You need to find a home for this method. Let us come up with a new class (similar to the Math class of the standard Java library). Because the percentOf method has to

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When you design a static method, you must find a class into which it should be placed.

do with financial calculations, we'll design a class `Financial` to hold it. Here is the class:

```
public class Financial
{
   public static double percentOf(double p, double a)
   {
      return (p / 100) * a;
   }
   // More financial methods can be added here.
}
```

When calling a static method, you supply the name of the class containing the method so that the compiler can find it. For example,

```
double tax = Financial.percentOf(taxRate, total);
```

Note that you do not supply an object of type `Financial` when you call the method.

There is another reason why static methods are sometimes necessary. If a method manipulates a class that you do not own, you cannot add it to that class. Consider a method that computes the area of a rectangle. The `Rectangle` class in the standard library has no such feature, and we cannot modify that class. A static method solves this problem:

```
public class Geometry
{
   public static double area(Rectangle rect)
   {
      return rect.getWidth() * rect.getHeight();
   }
   // More geometry methods can be added here.
}
```

Now we can tell you why the `main` method is static. When the program starts, there aren't any objects. Therefore, the *first* method in the program must be a static method.

You may well wonder why these methods are called static. The normal meaning of the word *static* ("staying fixed at one place") does not seem to have anything to do with what static methods do. Indeed, it's used by accident. Java uses the `static` reserved word because C++ uses it in the same context. C++ uses `static` to denote class methods because the inventors of C++ did not want to invent another reserved word. Someone noted that there was a relatively rarely used reserved word, `static`, that denotes certain variables that stay in a fixed location for multiple method calls. (Java does not have this feature, nor does it need it.) It turned out that the reserved word could be reused to denote class methods without confusing the compiler. The fact that it can confuse humans was apparently not a big concern. You'll just have to live with the fact that "static method" means "class method": a method that has only explicit parameters.

SELF CHECK

12. Suppose that Java had no static methods. How would you use the `Math.sqrt` method for computing the square root of a number *x*?

13. The following method computes the average of an array list of numbers:

```
public static double average(ArrayList<Double> values)
```

Why must it be a static method?

Quality Tip 8.4

Minimize the Use of Static Methods

It is possible to solve programming problems by using classes with only static methods. In fact, before object-oriented programming was invented, that approach was quite common. However, it usually leads to a design that is not object-oriented and makes it hard to evolve a program.

Consider the task of How To 7.1. A program reads scores for a student and prints the final score, which is obtained by dropping the lowest one. We solved the problem by implementing a `GradeBook` class that stores student scores. Of course, we could have simply written a program with a few static methods:

```
public class ScoreAnalyzer
{
   public static double[] readInputs() { . . . }
   public static double sum(double[] values) { . . . }
   public static double minimum(double[] values) { . . . }
   public static double finalScore(double[] values)
   {
      if (values.length == 0) return 0;
      else if (values.length == 1) return 1;
      else return sum(values) - minimum(values);
   }

   public static void main(String[] args)
   {
      System.out.println(finalScore(readInputs()));
   }
}
```

That solution is fine if one's sole objective is to solve a simple homework problem. But suppose you need to modify the program so that it deals with multiple students. An object-oriented program can evolve the `GradeBook` class to store grades for many students. In contrast, adding more functionality to static methods gets messy quickly (see Exercise P8.7).

8.7 Static Variables

Sometimes, a value properly belongs to a class, not to any object of the class. You use a **static variable** for this purpose. Here is a typical example. We want to assign bank account numbers sequentially. That is, we want the bank account constructor to construct the first account with number 1001, the next with number 1002, and so on. Therefore, we must store the last assigned account number somewhere.

Of course, it makes no sense to make this value into an instance variable:

```
public class BankAccount
{
   private double balance;
   private int accountNumber;
   private int lastAssignedNumber = 1000; // NO—won't work
   . . .
}
```

In that case each *instance* of the BankAccount class would have its own value of lastAssignedNumber.

A static variable belongs to the class, not to any object of the class.

Instead, we need to have a single value of lastAssignedNumber that is the same for the entire *class*. Such a variable is called a static variable, because you declare it using the static reserved word.

```
public class BankAccount
{
   private double balance;
   private int accountNumber;
   private static int lastAssignedNumber = 1000;
   . . .
}
```

Every BankAccount object has its own balance and accountNumber instance variables, but there is only a single copy of the lastAssignedNumber variable (see Figure 4). That variable is stored in a separate location, outside any BankAccount objects.

A static variable is sometimes called a *class variable* because there is a single variable for the entire class.

Every method of a class can access its static variables. Here is the constructor of the BankAccount class, which increments the last assigned number and then uses it to initialize the account number of the object to be constructed:

```
public class BankAccount
{
   . . .
   public BankAccount()
   {
      lastAssignedNumber++; // Updates the static variable
      accountNumber = lastAssignedNumber; // Sets the instance variable
   }
}
```

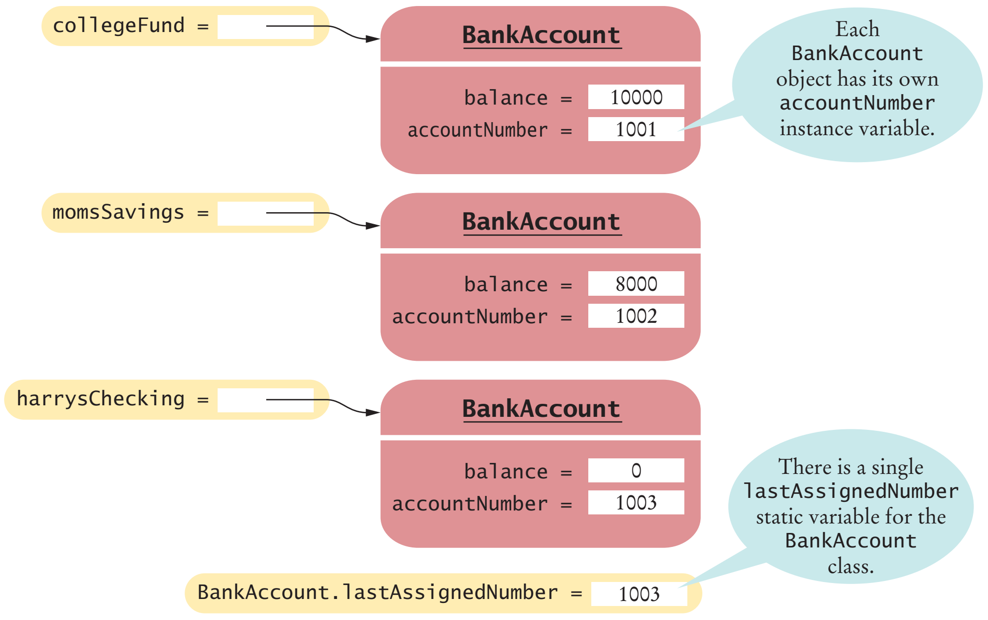

collegeFund =
BankAccount
balance = 10000
accountNumber = 1001
Each BankAccount object has its own accountNumber instance variable.
momsSavings =
BankAccount
balance = 8000
accountNumber = 1002
harrysChecking =
BankAccount
balance = 0
accountNumber = 1003
There is a single lastAssignedNumber static variable for the BankAccount class.
BankAccount.lastAssignedNumber = 1003

Figure 4 A Static Variable and Instance Variables

There are three ways to initialize a static variable:

1. Do nothing. The static variable is then initialized with `0` (for numbers), `false` (for `boolean` values), or `null` (for objects).
2. Use an explicit initializer, such as

   ```
   public class BankAccount
   {
      private static int lastAssignedNumber = 1000;
      . . .
   }
   ```
3. Use a static initialization block (see Special Topic 8.4).

Like instance variables, static variables should always be declared as `private` to ensure that methods of other classes do not change their values. The exception to this rule are static *constants*, which may be either private or public. For example, the `BankAccount` class may want to declare a public constant value, such as

```
public class BankAccount
{
   public static final double OVERDRAFT_FEE = 29.95;
   . . .
}
```

Methods from any class can refer to such a constant as `BankAccount.OVERDRAFT_FEE`.

It makes sense to declare constants as `static`—you wouldn't want every object of the `BankAccount` class to have its own set of variables with these constant values. It is sufficient to have one set of them for the class.

Why are class variables called `static`? As with static methods, the `static` reserved word itself is just a meaningless holdover from C++. But static variables and static methods have much in common: They apply to the entire *class*, not to specific instances of the class.

In general, you want to minimize the use of static methods and variables. If you find yourself using lots of static methods that access static variables, then that's an indication that you have not found the right classes to solve your problem in an object-oriented way.

SELF CHECK

14. Name two static variables of the `System` class.

15. Harry tells you that he has found a great way to avoid those pesky objects: Put all code into a single class and declare all methods and variables `static`. Then `main` can call the other static methods, and all of them can access the static variables. Will Harry's plan work? Is it a good idea?

Special Topic 8.3

Static Imports

Special Topic 8.3 introduces the "static import" syntax for importing static constants so that they can be used without a class prefix.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Special Topic 8.4

Alternative Forms of Instance and Static Variable Initialization

Special Topic 8.4 covers two less common mechanisms for instance variable initialization: specifying initial values for instance variables, and using initialization blocks.

8.8 Scope

The scope of a variable is the region of a program in which the variable can be accessed.

The **scope** of a variable is the part of the program in which the variable can be accessed. It is considered good design to minimize the scope of a variable. This reduces the possibility of accidental modification and name conflicts.

In the following sections, you will learn how to determine the scopes of local and instance variables, and how to resolve name conflicts if the scopes overlap.

8.8.1 Scope of Variables

The scope of a local variable extends from the point of its declaration to the end of the block or `for` loop that encloses it. The scope of a parameter variable is the entire method.

```
public static void process(double[] values) // values is a parameter variable
{
   for (int i = 0; i < 10; i++) // i is a local variable declared in a for loop
   {
      if (values[i] == 0)
      {
         double r = Math.random(); // r is a local variable declared in a block
         values[i] = r;
      } // Scope of r ends here
   } // Scope of i ends here
} // Scope of values ends here
```

The scope of a local variable cannot contain the declaration of another local variable with the same name.

In Java, the scope of a local variable can never contain the declaration of another local variable with the same name. For example, the following is an error:

```
public static void main(String[] args)
{
   double r = Math.random();
   if (r > 0.5)
   {
      Rectangle r = new Rectangle(5, 10, 20, 30);
      // Error—can't declare another variable called r here
      . . .
   }
}
```

However, you can have local variables with identical names if their scopes do not overlap, such as

```
if (Math.random() > 0.5)
{
      Rectangle r = new Rectangle(5, 10, 20, 30);
      . . .
   } // Scope of r ends here
   else
   {
      int r = 5;
      // OK—it is legal to declare another r here
      . . .
   }
```

These variables are independent from each other, or, in other words, their scopes are disjoint. You can have local variables with the same name `r` in different methods, just as you can have different motels with the same name "Bates Motel" in different cities.

In contrast, the scope of instance variables and static variables consists of the entire class in which they are declared.

8.8.2 Overlapping Scope

Problems arise if you have two identical variable names with overlapping scope. This can never occur with local variables, but the scopes of identically named local variables and instance variables can overlap. Here is a purposefully bad example.

```
public class Coin
{
   private String name;
   private double value; // Instance variable
   . . .
   public double getExchangeValue(double exchangeRate)
   {
      double value; // Local variable with the same name
      . . .
      return value;
   }
}
```

Inside the `getExchangeValue` method, the variable name `value` could potentially have two meanings: the **local variable** or the **instance variable**. The Java language specifies that in this situation the *local* variable wins out. It *shadows* the instance variable. This sounds pretty arbitrary, but there is actually a good reason: You can still refer to the instance variable as `this.value`.

A local variable can shadow an instance variable with the same name. You can access the shadowed variable name through the `this` reference.

```
value = this.value * exchangeRate;
```

Of course, it is not a good idea to write code like this. You can easily change the name of the local variable to something else, such as `result`.

However, there is one situation where overlapping scope is acceptable. When implementing constructors or setter methods, it can be awkward to come up with different names for instance variables and parameters. Here is how you can use the same name for both:

```
public Coin(double value, String name)
{
   this.value = value;
   this.name = name;
}
```

The expression `this.value` refers to the instance variable, and `value` is the parameter.

SELF CHECK

16. Consider the following program that uses two variables named `r`. Is this legal?

```
public class RectangleTester
{
   public static double area(Rectangle rect)
   {
      double r = rect.getWidth() * rect.getHeight();
      return r;
   }

   public static void main(String[] args)
   {
      Rectangle r = new Rectangle(5, 10, 20, 30);
      double a = area(r);
      System.out.println(r);
   }
}
```

17. What is the scope of the `balance` variable of the `BankAccount` class?

Common Error 8.2

Shadowing

Accidentally using the same name for a local variable and an instance variable is a surprisingly common error. As you saw in the preceding section, the local variable then *shadows* the instance variable. Even though you may have meant to access the instance variable, the local variable is quietly accessed. Look at this example of an incorrect constructor:

```
public class Coin
{
   private double value;
   private String name;
   . . .
   public Coin(double aValue, String aName)
   {
      value = aValue;
      String name = aName; // Oops . . .
   }
}
```

The programmer declared a local variable `name` in the constructor. In all likelihood, that was just a typo—the programmer's fingers were on autopilot and typed the reserved word `String`, even though the programmer all the time intended to access the instance variable. Unfortunately, the compiler gives no warning in this situation and quietly sets the local variable to the value of `aName`. The instance variable of the object that is being constructed is never touched, and remains `null`.

Some programmers give all instance variable names a special prefix to distinguish them from other variables. A common convention is to prefix all instance variable names with the prefix `my`, such as `myValue` or `myName`.

Another way of avoiding this problem is to use the `this` parameter when accessing an instance variable:

```
this.name = aName;
```

Quality Tip 8.5

Minimize Variable Scope

You should give each variable the smallest scope that it needs.

When you make the scope of a variable as small as possible, it becomes less likely that the variable is accidentally corrupted. It also becomes easier to modify or eliminate the variable as you reorganize your code.

As already mentioned, don't make an instance variable public. (The Java library has a few classes with public instance variables, but their creators later regretted their decision when they were unable to make optimizations later.)

When you have a constant, ask yourself who needs it. Everybody (`public static final`)? Only the class (`private static final`)? Only a single method (a `final` local variable)? Choose the smallest scope.

Beware of unnecessary instance variables. For example, consider the `Pyramid` class in Worked Example 4.1. You would not want an instance variable for the volume:

```
public class Pyramid
{
   private double height;
   private double baseLength;
   private double volume; // Not a good idea to use class scope for this variable
   . . .
}
```

Instead, compute the volume when it is needed in the `getVolume` method. That way, no other method can accidentally modify the `volume` variable, or forget to modify it when changing the height or base length.

Finally, with local variables, declare them only when you need them.

8.9 Packages

A package is a set of related classes.

A Java program consists of a collection of classes. So far, most of your programs have consisted of a small number of classes. As programs get larger, however, simply distributing the classes over multiple files isn't enough. An additional structuring mechanism is needed.

In Java, packages provide this structuring mechanism. A Java **package** is a set of related classes. For example, the Java library consists of several hundred packages, some of which are listed in Table 1.

Syntax 8.2 Package Specification

Syntax `package` *packageName*;

Example

```
package com.horstmann.bigjava;
```

The classes in this file belong to this package.

A good choice for a package name is a domain name in reverse.

Table 1 Important Packages in the Java Library

Package	Purpose	Sample Class
`java.lang`	Language support	`Math`
`java.util`	Utilities	`Random`
`java.io`	Input and output	`PrintStream`
`java.awt`	Abstract Windowing Toolkit	`Color`
`java.applet`	Applets	`Applet`
`java.net`	Networking	`Socket`
`java.sql`	Database access through Structured Query Language	`ResultSet`
`javax.swing`	Swing user interface	`JButton`
`omg.w3c.dom`	Document Object Model for XML documents	`Document`

8.9.1 Organizing Related Classes into Packages

To put one of your classes in a package, you must place a line

```
package packageName;
```

as the first instruction in the source file containing the class. A package name consists of one or more identifiers separated by periods. (See Section 8.9.3 for tips on constructing package names.)

For example, let's put the `Financial` class introduced in this chapter into a package named `com.horstmann.bigjava`. The `Financial.java` file must start as follows:

```
package com.horstmann.bigjava;
public class Financial
{
   . . .
}
```

In addition to the named packages (such as `java.util` or `com.horstmann.bigjava`), there is a special package, called the *default package*, which has no name. If you did not include any `package` statement at the top of your source file, its classes are placed in the default package.

8.9.2 Importing Packages

If you want to use a class from a package, you can refer to it by its full name (package name plus class name). For example, `java.util.Scanner` refers to the `Scanner` class in the `java.util` package:

```
java.util.Scanner in = new java.util.Scanner(System.in);
```

The `import` directive lets you refer to a class of a package by its class name, without the package prefix.

Naturally, that is somewhat inconvenient. You can instead *import* a name with an `import` statement:

```
import java.util.Scanner;
```

Then you can refer to the class as `Scanner` without the package prefix.

You can import *all classes* of a package with an `import` statement that ends in `.*`. For example, you can use the statement

```
import java.util.*;
```

to import all classes from the `java.util` package. That statement lets you refer to classes like `Scanner` or `Random` without a `java.util` prefix.

However, you never need to import the classes in the `java.lang` package explicitly. That is the package containing the most basic Java classes, such as `Math` and `Object`. These classes are always available to you. In effect, an automatic `import java.lang.*;` statement has been placed into every source file.

Finally, you don't need to import other classes in the same package. For example, when you implement the class `homework1.Tester`, you don't need to import the class `homework1.Bank`. The compiler will find the `Bank` class without an `import` statement because it is located in the same package, `homework1`.

8.9.3 Package Names

Placing related classes into a package is clearly a convenient mechanism to organize classes. However, there is a more important reason for packages: to avoid **name clashes**. In a large project, it is inevitable that two people will come up with the same name for the same concept. This even happens in the standard Java class library (which has now grown to thousands of classes). There is a class `Timer` in the `java.util` package and another class called `Timer` in the `javax.swing` package. You can still tell the Java compiler exactly which `Timer` class you need, simply by referring to them as `java.util.Timer` and `javax.swing.Timer`.

Of course, for the package-naming convention to work, there must be some way to ensure that package names are unique. It wouldn't be good if the car maker BMW placed all its Java code into the package `bmw`, and some other programmer (perhaps Britney M. Walters) had the same bright idea. To avoid this problem, the inventors of Java recommend that you use a package-naming scheme that takes advantage of the uniqueness of Internet domain names.

Use a domain name in reverse to construct an unambiguous package name.

For example, I have a domain name `horstmann.com`, and there is nobody else on the planet with the same domain name. (I was lucky that the domain name `horstmann.com` had not been taken by anyone else when I applied. If your name is Walters, you will sadly find that someone else beat you to `walters.com`.) To get a package name, turn the domain name around to produce a package name prefix, such as `com.horstmann`.

If you don't have your own domain name, you can still create a package name that has a high probability of being unique by writing your e-mail address backwards. For example, if Britney Walters has an e-mail address `walters@cs.sjsu.edu`, then she can use a package name `edu.sjsu.cs.walters` for her own classes.

Some instructors will want you to place each of your assignments into a separate package, such as `homework1`, `homework2`, and so on. The reason is again to avoid name collision. You can have two classes, `homework1.Bank` and `homework2.Bank`, with slightly different properties.

8.9.4 Packages and Source Files

The path of a class file must match its package name.

A source file must be located in a subdirectory that matches the package name. The parts of the name between periods represent successively nested directories. For example, the source files for classes in the package `com.horstmann.bigjava` would be placed in a subdirectory `com/horstmann/bigjava`. You place the subdirectory inside the *base directory* holding your program's files. For example, if you do your homework assignment in a directory `/home/britney/hw8/problem1`, then you can place the class files for the `com.horstmann.bigjava` package into the directory `/home/britney/hw8/problem1/com/horstmann/bigjava`, as shown in Figure 5. (Here, we are using UNIX-style file names. Under Windows, you might use `c:\Users\Britney\hw8\problem1\com\horstmann\bigjava`.)

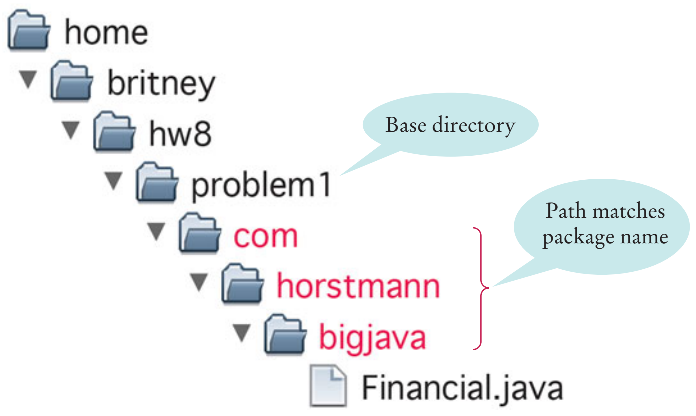


Figure 5
Base Directories and Subdirectories for Packages

SELF CHECK

18. Which of the following are packages?

a. `java`

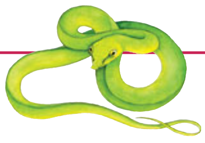
b. `java.lang`

c. `java.util`

d. `java.lang.Math`

19. Is a Java program without `import` statements limited to using the default and `java.lang` packages?

20. Suppose your homework assignments are located in the directory `/home/me/cs101` (`c:\Users\Me\cs101` on Windows). Your instructor tells you to place your homework into packages. In which directory do you place the class `hw1.problem1.TicTacToeTester`?



Common Error 8.3

Confusing Dots

In Java, the dot symbol (`.`) is used as a separator in the following situations:

- Between package names (`java.util`)
- Between package and class names (`homework1.Bank`)
- Between class and inner class names (`Ellipse2D.Double`)
- Between class and instance variable names (`Math.PI`)
- Between objects and methods (`account.getBalance()`)

When you see a long chain of dot-separated names, it can be a challenge to find out which part is the package name, which part is the class name, which part is an instance variable name, and which part is a method name. Consider

```
java.lang.System.out.println(x);
```

Because `println` is followed by an opening parenthesis, it must be a method name. Therefore, `out` must be either an object or a class with a static `println` method. (Of course, we know that `out` is an object reference of type `PrintStream`.) Again, it is not at all clear, without context, whether `System` is another object, with a public variable `out`, or a class with a `static` variable. Judging from the number of pages that the Java language specification devotes to this issue, even the compiler has trouble interpreting these dot-separated sequences of strings.

To avoid problems, it is helpful to adopt a strict coding style. If class names always start with an uppercase letter, and variable, method, and package names always start with a lowercase letter, then confusion can be avoided.

Special Topic 8.5

Package Access

If a class, field, or method has no `public` or `private` modifier, then all methods of classes in the same package can access the feature. For example, if a class is declared as `public`, then all other classes in all packages can use it. But if a class is declared without an access modifier, then only the other classes in the *same* package can use it. Package access is a reasonable default for classes, but it is extremely unfortunate for instance variables.

A field or method that is not declared as `public` or `private` can be accessed by all classes in the same package, which is usually not desirable.

It is a common error to *forget* the reserved word `private`, thereby opening up a potential security hole. For example, at the time of this writing, the `Window` class in the `java.awt` package contained the following declaration:

```
public class Window extends Container
{
   String warningString;
   . . .
}
```

There actually was no good reason to grant package access to the `warningString` instance variable—no other class accesses it.

Package access for instance variables is rarely useful and always a potential security risk. Most instance variables are given package access by accident because the programmer simply forgot the `private` reserved word. It is a good idea to get into the habit of scanning your instance variable declarations for missing `private` modifiers.

How To 8.1 Programming with Packages

This How To explains in detail how to place your programs into packages. For example, your instructor may ask you to place each homework assignment into a separate package. That way, you can have classes with the same name but different implementations in separate packages (such as `homework1.problem1.Bank` and `homework1.problem2.Bank`).

Step 1 Come up with a package name.

Your instructor may give you a package name to use, such as `homework1.problem2`. Or, perhaps you want to use a package name that is unique to you. Start with your e-mail address, written backwards. For example, `walters@cs.sjsu.edu` becomes `edu.sjsu.cs.walters`. Then add a subpackage that describes your project, such as `edu.sjsu.cs.walters.cs1project`.

Step 2 Pick a *base directory.*

The base directory is the directory that contains the directories for your various packages, for example, `/home/britney` or `c:\Users\Britney`.

Step 3 Make a subdirectory from the base directory that matches your package name.

The subdirectory must be contained in your base directory. Each segment must match a segment of the package name. For example,

```
mkdir -p /home/britney/homework1/problem2 (in UNIX)
```

or

```
mkdir /s c:\Users\Britney\homework1\problem2 (in Windows)
```

Step 4 Place your source files into the package subdirectory.

For example, if your homework consists of the files `Tester.java` and `Bank.java`, then you place them into

```
/home/britney/homework1/problem2/Tester.java
/home/britney/homework1/problem2/Bank.java
```

or

```
c:\Users\Britney\homework1\problem2\Tester.java
c:\Users\Britney\homework1\problem2\Bank.java
```

Step 5 Use the `package` statement in each source file.

The first noncomment line of each file must be a package statement that lists the name of the package, such as

```
package homework1.problem2;
```

Step 6 Compile your source files from the *base directory.*

Change to the base directory (from Step 2) to compile your files. For example,

```
cd /home/britney
javac homework1/problem2/Tester.java
```

or

```
c:
cd \Users\Britney
javac homework1\problem2\Tester.java
```

Note that the Java compiler needs the *source file name and not the class name. That is, you need to supply file separators* (/ on UNIX, \ on Windows) and a file extension (`.java`).

Step 7 Run your program from the *base directory.*

Unlike the Java compiler, the Java interpreter needs the *class name (and not a file name) of the class containing the* `main` *method*. That is, use periods as package separators, and don't use a file extension. For example,

```
cd /home/britney
java homework1.problem2.Tester
```

or

```
c:
cd \Users\Britney
java homework1.problem2.Tester
```

Random Fact 8.1

The Explosive Growth of Personal Computers

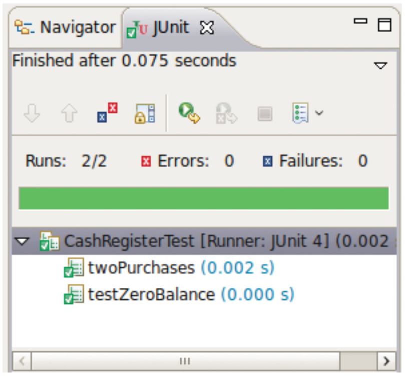
Random Fact 8.1 traces the history of the personal computer, from the advent of the first microprocessor to the first Macintosh.

8.10 Unit Test Frameworks

Up to now, we have used a very simple approach to testing. We provided tester classes whose `main` method computes values and prints actual and expected values. However, that approach has limitations. The `main` method gets messy if it contains many tests. And if an exception occurs during one of the tests, the remaining tests are not executed.

Unit test frameworks simplify the task of writing classes that contain many test cases.

Unit testing frameworks were designed to quickly execute and evaluate test suites, and to make it easy to incrementally add test cases. One of the most popular testing frameworks is JUnit. It is freely available at `http://junit.org`, and it is also built into a number of development environments, including BlueJ and Eclipse. Here we describe JUnit 4, the most current version of the library as this book is written.



Finished after 0.075 seconds

Runs: 2/2 Errors: 0 Failures: 0

CashRegisterTest [Runner: JUnit 4] (0.002
twoPurchases (0.002 s)
testZeroBalance (0.000 s)

Figure 6
Unit Testing with JUnit

When you use JUnit, you design a companion test class for each class that you develop. You provide a method for each test case that you want to have executed. You use “annotations” to mark the test methods. An annotation is an advanced Java feature that places a marker into the code that is interpreted by another tool. In the case of JUnit, the `@Test` annotation is used to mark test methods.

In each test case, you make some computations and then compute some condition that you believe to be true. You then pass the result to a method that communicates a test result to the framework, most commonly the `assertEquals` method. The `assertEquals` method takes as parameters the expected and actual values and, for floating-point numbers, a tolerance value.

It is also customary (but not required) that the name of the test class ends in `Test`, such as `CashRegisterTest`. Here is a typical example:

```
import org.junit.Test;
import org.junit.Assert;

public class CashRegisterTest
{
   @Test public void twoPurchases()
   {
      CashRegister register = new CashRegister();
      register.recordPurchase(0.75);
      register.recordPurchase(1.50);
      register.enterPayment(2, 0, 5, 0, 0);
      double expected = 0.25;
      Assert.assertEquals(expected, register.giveChange(), EPSILON);
   }
   // More test cases
   . . .
}
```

If all test cases pass, the JUnit tool shows a green bar (see Figure 6). If any of the test cases fail, the JUnit tool shows a red bar and an error message.

Your test class can also have other methods (whose names should not be annotated with `@Test`). These methods typically carry out steps that you want to share among test methods.

The JUnit philosophy is to run all tests whenever you change your code.

The JUnit philosophy is simple. Whenever you implement a class, also make a companion test class. You design the tests as you design the program, one test method at a time. The test cases just keep accumulating in the test class. Whenever you have detected an actual failure, add a test case that flushes it out, so that you can be sure that you won’t introduce that particular bug again. Whenever you modify your class, simply run the tests again.

If all tests pass, the user interface shows a green bar and you can relax. Otherwise, there is a red bar, but that’s also good. It is much easier to fix a bug in isolation than inside a complex program.

SELF CHECK

21. Provide a JUnit test class with one test case for the `Earthquake` class in Chapter 5.

22. What is the significance of the `EPSILON` parameter in the `assertEquals` method?

Summary of Learning Objectives

Find classes that are appropriate for solving a programming problem.

- A class should represent a single concept from a problem domain, such as business, science, or mathematics.

Analyze cohesiveness and coupling of classes.

- The public interface of a class is cohesive if all of its features are related to the concept that the class represents.
- A class depends on another class if it uses objects of that class.
- It is a good practice to minimize the coupling (i.e., dependency) between classes.

Recognize immutable classes and their benefits.

- An immutable class has no mutator methods.
- References to objects of an immutable class can be safely shared.

Recognize side effects and the need to minimize them.

- A side effect of a method is any externally observable data modification.
- In Java, a method can never change parameters of primitive type.
- When designing methods, minimize side effects.

Document preconditions and postconditions of methods.

- A precondition is a requirement that the caller of a method must meet.
- If a method is called in violation of a precondition, the method is not responsible for computing the correct result.
- An assertion is a logical condition in a program that you believe to be true.
- If a method has been called in accordance with its preconditions, then it must ensure that its postconditions are valid.

Implement static methods that do not operate on objects.

- A static method is not invoked on an object.
- When you design a static method, you must find a class into which it should be placed.

Use static variables to describe properties of a class.

- A static variable belongs to the class, not to any object of the class.

Determine the scopes of local variables and instance variables.

- The scope of a variable is the region of a program in which the variable can be accessed.
- The scope of a local variable cannot contain the declaration of another local variable with the same name.
- A local variable can shadow an instance variable with the same name. You can access the shadowed variable name through the `this` reference.
- You should give each variable the smallest scope that it needs.

Use packages to organize sets of related classes.

- A package is a set of related classes.
- The `import` directive lets you refer to a class of a package by its class name, without the package prefix.
- Use a domain name in reverse to construct an unambiguous package name.
- The path of a class file must match its package name.
- A field or method that is not declared as `public` or `private` can be accessed by all classes in the same package, which is usually not desirable.

Use JUnit for writing unit tests.

- Unit test frameworks simplify the task of writing classes that contain many test cases.
- The JUnit philosophy is to run all tests whenever you change your code.

Media Resources

WILEY PLUS

www.wiley.com/college/horstmann

- Lab Exercises
- ⊕ ***Animation*** A Method Cannot Modify a Numeric Parameter
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★★ **R8.1** Consider the following problem description:

> Users place coins in a vending machine and select a product by pushing a button. If the inserted coins are sufficient to cover the purchase price of the product, the product is dispensed and change is given. Otherwise, the inserted coins are returned to the user.

What classes should you use to implement it?

★★ **R8.2** Consider the following problem description:

> Employees receive their biweekly paychecks. They are paid their hourly rates for each hour worked; however, if they worked more than 40 hours per week, they are paid at 150 percent of their regular wage for those overtime hours.

What classes should you use to implement it?

★★★ **R8.3** Consider the following problem description:

> Customers order products from a store. Invoices are generated to list the items and quantities ordered, payments received, and amounts still due. Products are shipped to the shipping address of the customer, and invoices are sent to the billing address.

What classes should you use to implement it?

★★★ **R8.4** Look at the public interface of the `java.lang.System` class and discuss whether or not it is cohesive.

★★ **R8.5** Suppose an `Invoice` object contains descriptions of the products ordered, and the billing and shipping addresses of the customer. Draw a UML diagram showing the dependencies between the classes `Invoice`, `Address`, `Customer`, and `Product`.

★★ **R8.6** Suppose a vending machine contains products, and users insert coins into the vending machine to purchase products. Draw a UML diagram showing the dependencies between the classes `VendingMachine`, `Coin`, and `Product`.

★★ **R8.7** On which classes does the class `Integer` in the standard library depend?

★★ **R8.8** On which classes does the class `Rectangle` in the standard library depend?

★ **R8.9** Classify the methods of the class `Scanner` that are used in this book as accessors and mutators.

★ **R8.10** Classify the methods of the class `Rectangle` as accessors and mutators.

★ **R8.11** Which of the following classes are immutable?

a. `Rectangle`
b. `String`
c. `Random`

★ **R8.12** Which of the following classes are immutable?

a. `PrintStream`
b. `Date`
c. `Integer`

★★ **R8.13** What side effect, if any, do the following three methods have:

```
public class Coin
{
   . . .
   public void print()
   {
      System.out.println(name + " " + value);
   }

   public void print(PrintStream stream)
   {
      stream.println(name + " " + value);
   }

   public String toString()
   {
      return name + " " + value;
   }
}
```

★★★ **R8.14** Ideally, a method should have no side effects. Can you write a program in which no method has a side effect? Would such a program be useful?

★★ **R8.15** Write preconditions for the following methods. Do not implement the methods.

a. `public static double sqrt(double x)`
b. `public static String romanNumeral(int n)`
c. `public static double slope(Line2D.Double a)`
d. `public static String weekday(int day)`

★★ **R8.16** What preconditions do the following methods from the standard Java library have?

a. `Math.sqrt`
b. `Math.tan`
c. `Math.log`
d. `Math.pow`
e. `Math.abs`

★★ **R8.17** What preconditions do the following methods from the standard Java library have?

a. `Integer.parseInt(String s)`
b. `StringTokenizer.nextToken()`
c. `Random.nextInt(int n)`
d. `String.substring(int m, int n)`

★★★ **R8.18** When a method is called with parameters that violate its precondition(s), it can terminate (by throwing an exception or an assertion error), or it can return to its caller. Give two examples of library methods (standard or the library methods used in this book) that return some result to their callers when called with invalid parameters, and give two examples of library methods that terminate.

★★ **R8.19** Consider a `CashRegister` class with methods

- `public void enterPayment(int coinCount, Coin coinType)`
- `public double getTotalPayment()`

Give a reasonable postcondition of the `enterPayment` method. What preconditions would you need so that the `CashRegister` class can ensure that postcondition?

★★ **R8.20** Consider the following method that is intended to swap the values of two floating-point numbers:

```
public static void falseSwap(double a, double b)
{
   double temp = a;
   a = b;
   b = temp;
}

public static void main(String[] args)
{
   double x = 3;
   double y = 4;
   falseSwap(x, y);
   System.out.println(x + " " + y);
}
```

Why doesn't the method swap the contents of `x` and `y`?

★★★ **R8.21** How can you write a method that swaps two floating-point numbers?
Hint: `Point2D.Double`.

★★ **R8.22** Draw a memory diagram that shows why the following method can't swap two `BankAccount` objects:

```
public static void falseSwap(BankAccount a, BankAccount b)
{
   BankAccount temp = a;
   a = b;
   b = temp;
}
```

★ **R8.23** Consider an enhancement of the `Die` class of Chapter 6 with a static variable

```
public class Die
{
   private int sides;
   private static Random generator = new Random();
   public Die(int s) { . . . }
   public int cast() { . . . }
}
```

Draw a memory diagram that shows three dice:

```
Die d4 = new Die(4);
Die d6 = new Die(6);
Die d8 = new Die(8);
```

Be sure to indicate the values of the `sides` and `generator` variables.

★ **R8.24** Try compiling the following program. Explain the error message that you get.

```
public class Print13
{
   public void print(int x)
   {
      System.out.println(x);
   }

   public static void main(String[] args)
   {
      int n = 13;
      print(n);
   }
}
```

★ **R8.25** Look at the methods in the `Integer` class. Which are static? Why?

★★ **R8.26** Look at the methods in the `String` class (but ignore the ones that take a parameter of type `char[]`). Which are static? Why?

★★ **R8.27** The `in` and `out` variables of the `System` class are public static variables of the `System` class. Is that good design? If not, how could you improve on it?

★★ **R8.28** In the following class, the variable `n` occurs in multiple scopes. Which declarations of `n` are legal and which are illegal?

```
public class X
{
   private int n;

   public int f()
   {
      int n = 1;
      return n;
   }

   public int g(int k)
   {
      int a;
      for (int n = 1; n <= k; n++)
         a = a + n;
      return a;
   }
```

```
      public int h(int n)
      {
         int b;
         for (int n = 1; n <= 10; n++)
            b = b + n;
         return b + n;
      }

      public int k(int n)
      {
         if (n < 0)
         {
            int k = -n;
            int n = (int) (Math.sqrt(k));
            return n;
         }
         else return n;
      }

      public int m(int k)
      {
         int a;
         for (int n = 1; n <= k; n++)
            a = a + n;
         for (int n = k; n >= 1; n++)
            a = a + n;
         return a;
      }
   }
```

★★ **R8.29** Every Java program can be rewritten to avoid `import` statements. Explain how, and rewrite `RectangleComponent.java` from Chapter 2 to avoid `import` statements.

★ **R8.30** What is the default package? Have you used it before this chapter in your programming?

★★T **R8.31** What does JUnit do when a test method throws an exception? Try it out and report your findings.

Programming Exercises

★★ **P8.1** Implement the `Coin` class described in Section 8.2. Modify the `CashRegister` class so that coins can be added to the cash register, by supplying a method

```
void enterPayment(int coinCount, Coin coinType)
```

The caller needs to invoke this method multiple times, once for each type of coin that is present in the payment.

★★ **P8.2** Modify the `giveChange` method of the `CashRegister` class so that it returns the number of coins of a particular type to return:

```
int giveChange(Coin coinType)
```

The caller needs to invoke this method for each coin type, in decreasing value.

★ **P8.3** Real cash registers can handle both bills and coins. Design a single class that expresses the commonality of these concepts. Redesign the `CashRegister` class and provide a method for entering payments that are described by your class. Your primary challenge is to come up with a good name for this class.

★ **P8.4** Enhance the `BankAccount` class by adding preconditions for the constructor and the `deposit` method that require the `amount` parameter to be at least zero, and a precondition for the `withdraw` method that requires `amount` to be a value between `0` and the current balance. Use assertions to test the preconditions.

★★ **P8.5** Write static methods

- `public static double sphereVolume(double r)`
- `public static double sphereSurface(double r)`
- `public static double cylinderVolume(double r, double h)`
- `public static double cylinderSurface(double r, double h)`
- `public static double coneVolume(double r, double h)`
- `public static double coneSurface(double r, double h)`

that compute the volume and surface area of a sphere with radius `r`, a cylinder with circular base with radius `r` and height `h`, and a cone with circular base with radius `r` and height `h`. Place them into a class `Geometry`. Then write a program that prompts the user for the values of `r` and `h`, calls the six methods, and prints the results.

★★ **P8.6** Solve Exercise P8.5 by implementing classes `Sphere`, `Cylinder`, and `Cone`. Which approach is more object-oriented?

★★ **P8.7** Modify the grade book application of How To 7.1 so that it can deal with multiple students. First, ask the user for all student names. Then read in the scores for all quizzes, prompting for the score of each student. Finally, print the names of all students and their final scores. Use a single class and only static methods.

★★★ **P8.8** Repeat Exercise P8.7, using multiple classes. Modify the `GradeBook` class so that it collects objects of type `Student`. Each such object should have a list of scores.

★★★ **P8.9** Write methods

```
public static double perimeter(Ellipse2D.Double e);
public static double area(Ellipse2D.Double e);
```

that compute the area and the perimeter of the ellipse `e`. Add these methods to a class `Geometry`. The challenging part of this assignment is to find and implement an accurate formula for the perimeter. Why does it make sense to use a static method in this case?

★★ **P8.10** Write methods

```
public static double angle(Point2D.Double p, Point2D.Double q)
public static double slope(Point2D.Double p, Point2D.Double q)
```

that compute the angle between the *x*-axis and the line joining two points, measured in degrees, and the slope of that line. Add the methods to the class `Geometry`. Supply suitable preconditions. Why does it make sense to use a static method in this case?

★★★ **P8.11** Write methods

```
public static boolean isInside(Point2D.Double p, Ellipse2D.Double e)
public static boolean isOnBoundary(Point2D.Double p, Ellipse2D.Double e)
```

that test whether a point is inside or on the boundary of an ellipse. Add the methods to the class `Geometry`.

★ **P8.12** Write a method

```
public static int readInt(
      Scanner in, String prompt, String error, int min, int max)
```

that displays the prompt string, reads an integer, and tests whether it is between the minimum and maximum. If not, print an error message and repeat reading the input. Add the method to a class `Input`.

★★ **P8.13** Consider the following algorithm for computing x^n for an integer n. If $n < 0$, x^n is $1/x^{-n}$. If n is positive and even, then $x^n = (x^{n/2})^2$. If n is positive and odd, then $x^n = x^{n-1} \cdot x$. Implement a static method `double intPower(double x, int n)` that uses this algorithm. Add it to a class called `Numeric`.

★★ **P8.14** Improve the `Needle` class of Chapter 6. Turn the `generator` variable into a static variable so that all needles share a single random number generator.

★★ **P8.15** Implement a `Coin` and `CashRegister` class as described in Exercise P8.1. Place the classes into a package called `money`. Keep the `CashRegisterTester` class in the default package.

★ **P8.16** Place a `BankAccount` class in a package whose name is derived from your e-mail address, as described in Section 8.9. Keep the `BankAccountTester` class in the default package.

★★T **P8.17** Provide a JUnit test class `BankTest` with three test methods, each of which tests a different method of the `Bank` class in Chapter 7.

★★T **P8.18** Provide JUnit test class `TaxReturnTest` with three test methods that test different tax situations for the `TaxReturn` class in Chapter 5.

★G **P8.19** Write methods

- `public static void drawH(Graphics2D g2, Point2D.Double p);`
- `public static void drawE(Graphics2D g2, Point2D.Double p);`
- `public static void drawL(Graphics2D g2, Point2D.Double p);`
- `public static void drawO(Graphics2D g2, Point2D.Double p);`

that show the letters H, E, L, O on the graphics window, where the point `p` is the top-left corner of the letter. Then call the methods to draw the words "HELLO" and "HOLE" on the graphics display. Draw lines and ellipses. Do not use the `drawString` method. Do not use `System.out`.

★★G **P8.20** Repeat Exercise P8.17 by designing classes `LetterH`, `LetterE`, `LetterL`, and `LetterO`, each with a constructor that takes a `Point2D.Double` parameter (the top-left corner) and a method `draw(Graphics2D g2)`.Which solution is more object-oriented?

Programming Projects

Project 8.1 Implement a program that prints paychecks for a group of student assistants. Deduct federal and Social Security taxes. (You may want to use the tax computation used in Chapter 5. Find out about Social Security taxes on the Internet.) Your program should prompt for the names, hourly wages, and hours worked of each student.

Project 8.2 For faster sorting of letters, the United States Postal Service encourages companies that send large volumes of mail to use a bar code denoting the ZIP code (see Figure 7).

The encoding scheme for a five-digit ZIP code is shown in Figure 8. There are full-height frame bars on each side. The five encoded digits are followed by a check digit, which is computed as follows: Add up all digits, and choose the check digit to make the sum a multiple of 10. For example, the sum of the digits in the ZIP code 95014 is 19, so the check digit is 1 to make the sum equal to 20.

Each digit of the ZIP code, and the check digit, is encoded according to the table at right, where 0 denotes a half bar and 1 a full bar. Note that they represent all combinations of two full and three half bars. The digit can be computed easily from the bar code using the column weights 7, 4, 2, 1, 0. For example, 01100 is

$$0 \cdot 7 + 1 \cdot 4 + 1 \cdot 2 + 0 \cdot 1 + 0 \cdot 0 = 6$$

The only exception is 0, which would yield 11 according to the weight formula.

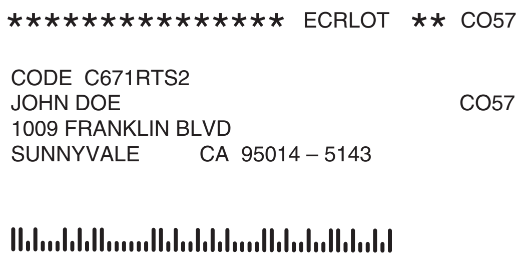
	7	4	2	1	0
1	0	0	0	1	1
2	0	0	1	0	1
3	0	0	1	1	1
4	0	1	0	0	0
5	0	1	0	1	1
6	0	1	1	0	0
7	1	0	0	0	0
8	1	0	0	1	1
9	1	0	1	0	0
0	1	1	0	0	0

Write a program that asks the user for a ZIP code and prints the bar code. Use : for half bars, | for full bars. For example, 95014 becomes

```
||:|:::|:|:||::::::||:|::|:::|||
```

(Alternatively, write a graphical application that draws real bars.)

Your program should also be able to carry out the opposite conversion: Translate bars into their ZIP code, reporting any errors in the input format or a mismatch of the digits.


```
*************** ECRLOT  ** CO57

CODE  C671RTS2
JOHN DOE                        CO57
1009 FRANKLIN BLVD
SUNNYVALE       CA  95014 – 5143
```

Figure 7 A Postal Bar Code

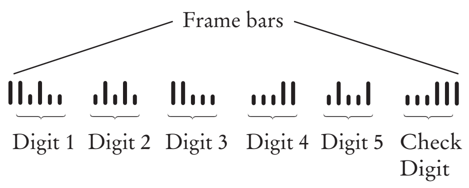


Figure 8 Encoding for Five-Digit Bar Codes

Answers to Self-Check Questions

1. Look for nouns in the problem description.
2. Yes (`ChessBoard`) and no (`MovePiece`).
3. Some of its features deal with payments, others with coin values.
4. None of the coin operations require the `CashRegister` class.
5. If a class doesn't depend on another, it is not affected by interface changes in the other class.
6. It is an accessor—calling `substring` doesn't modify the string on which the method is invoked. In fact, all methods of the `String` class are accessors.
7. No—`translate` is a mutator.
8. It is a side effect; this kind of side effect is common in object-oriented programming.
9. Yes—the method affects the state of the `Scanner` parameter.
10. Then you don't have to worry about checking for invalid values—it becomes the caller's responsibility.
11. No—you can take any action that is convenient for you.
12. `Math m = new Math(); y = m.sqrt(x);`
13. You cannot add a method to the `ArrayList` class—it is a class in the standard Java library that you cannot modify.
14. `System.in` and `System.out`.
15. Yes, it works. Static methods can access static variables of the same class. But it is a terrible idea. As your programming tasks get more complex, you will want to use objects and classes to organize your programs.
16. Yes. The scopes are disjoint.
17. It starts at the beginning of the class and ends at the end of the class.
18. (a) No; (b) Yes; (c) Yes; (d) No
19. No—you simply use fully qualified names for all other classes, such as `java.util.Random` and `java.awt.Rectangle`.
20. `/home/me/cs101/hw1/problem1` or, on Windows, `c:\Users\Me\cs101\hw1\problem1`.
21. Here is one possible answer.

```
public class EarthquakeTest
{
   @Test public void testLevel4()
   {
      Earthquake quake = new Earthquake(4);
      Assert.assertEquals("Felt by many people, no destruction",
            quake.getDescription());
    }
}
```

22. It is a tolerance threshold for comparing floating-point numbers. We want the equality test to pass if there is a small roundoff error.

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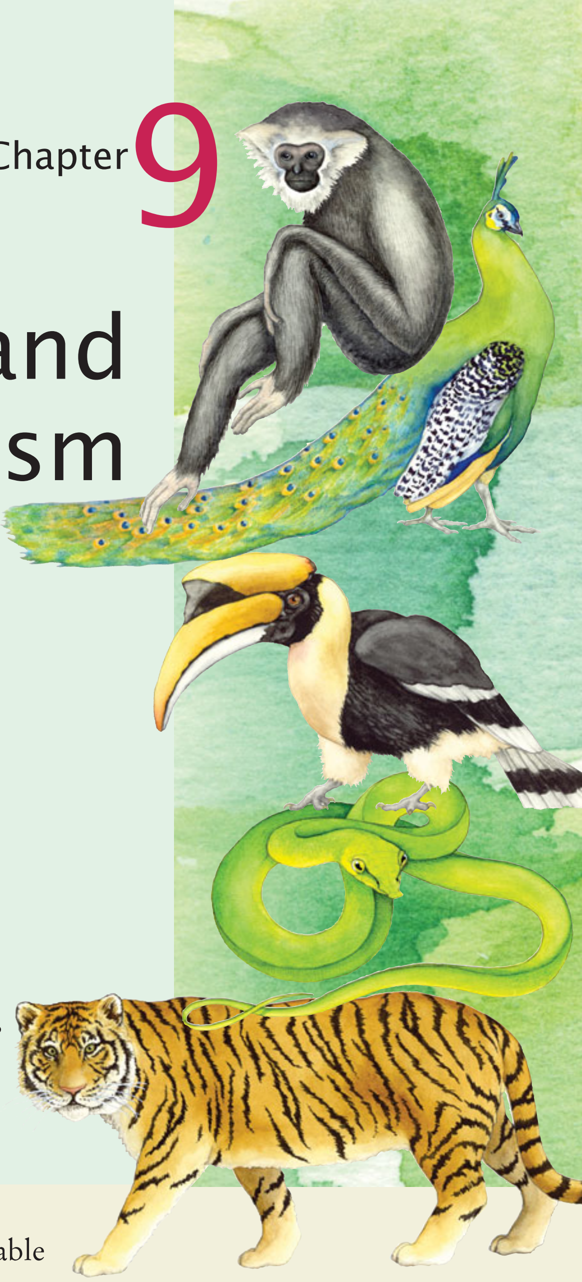
Chapter 9

Interfaces and Polymorphism



CHAPTER GOALS

- To be able to declare and use interface types
- To understand the concept of polymorphism
- To appreciate how interfaces can be used to decouple classes
- To learn how to implement helper classes as inner classes

G To implement event listeners in graphical applications

In order to increase programming productivity, we want to be able to *reuse* software components in multiple projects. However, some adaptations are often required to make reuse possible. In this chapter, you will learn an important strategy for separating the reusable part of a computation from the parts that vary in each reuse scenario. The reusable part invokes methods of an *interface*. It is combined with a class that implements the interface methods. To produce a different application, you simply plug in another class that implements the same interface. The program's behavior varies according to the implementation that is plugged in—this phenomenon is called *polymorphism*.

CHAPTER CONTENTS

9.1 Using Interfaces for Algorithm Reuse 330
Syntax 9.1: Declaring an Interface 332
Syntax 9.2: Implementing an Interface 333
Common Error 9.1: Forgetting to Declare Implementing Methods as Public 335
Special Topic 9.1: Constants in Interfaces 335

9.2 Converting Between Class and Interface Types 336
Common Error 9.2: Trying to Instantiate an Interface 337

9.3 Polymorphism 338
Worked Example 9.1: Investigating Number Sequences ⊕

9.4 Using Interfaces for Callbacks 339

9.5 Inner Classes 343
Special Topic 9.2: Anonymous Classes ⊕
Random Fact 9.1: Operating Systems ⊕

9.6T Mock Objects 345

9.7G Events, Event Sources, and Event Listeners 347
Common Error 9.3: Modifying Parameter Types in the Implementing Method 349

9.8G Using Inner Classes for Listeners 350

9.9G Building Applications with Buttons 352
Common Error 9.4: Forgetting to Attach a Listener 355
Productivity Hint 9.1: Don't Use a Container as a Listener 355
Common Error 9.5: By Default, Components Have Zero Width and Height 356

9.10G Processing Timer Events ⊕
Common Error 9.6: Forgetting to Repaint 356

9.11G Mouse Events ⊕
Special Topic 9.3: Event Adapters ⊕
Random Fact 9.2: Programming Languages ⊕

9.1 Using Interfaces for Algorithm Reuse

It is often possible to make a service available to a wider set of inputs by focusing on the essential operations that the service requires. *Interface types* are used to express these common operations.

Consider the DataSet class of Chapter 6. That class provides a service, namely computing the average and maximum of a set of input values. Unfortunately, the class is suitable only for computing the average of a set of *numbers*. If we wanted to process bank accounts to find the bank account with the highest balance, we could not use the class in its current form. We could modify the class, like this:

```
public class DataSet // Modified for BankAccount objects
{
   private double sum;
   private BankAccount maximum;
   private int count;
   . . .
   public void add(BankAccount x)
   {
      sum = sum + x.getBalance();
      if (count == 0 || maximum.getBalance() < x.getBalance())
         maximum = x;
      count++;
   }
```

```
      public BankAccount getMaximum()
      {
         return maximum;
      }
   }
```

Or suppose we wanted to find the coin with the highest value among a set of coins. We would need to modify the DataSet class again.

```
   public class DataSet // Modified for Coin objects
   {
      private double sum;
      private Coin maximum;
      private int count;
      . . .
      public void add(Coin x)
      {
         sum = sum + x.getValue();
         if (count == 0 || maximum.getValue() < x.getValue())
            maximum = x;
         count++;
      }

      public Coin getMaximum()
      {
         return maximum;
      }
   }
```

Clearly, the algorithm for the data analysis service is the same in all cases, but the details of measurement differ. We would like to provide a *single* class that provides this service to any objects that can be measured.

Suppose that the various classes agree on a method getMeasure that obtains the measure to be used in the data analysis. For bank accounts, getMeasure returns the balance. For coins, getMeasure returns the coin value, and so on. Then we can implement a DataSet class whose add method looks like this:

```
   sum = sum + x.getMeasure();
   if (count == 0 || maximum.getMeasure() < x.getMeasure())
      maximum = x;
   count++;
```

What is the type of the variable x? Ideally, x should refer to any class that has a getMeasure method.

A Java interface type declares methods but does not provide their implementations.

In Java, an **interface type** is used to specify required operations. We will declare an interface type that we call Measurable:

```
   public interface Measurable
   {
      double getMeasure();
   }
```

The interface declaration lists all methods that the interface type requires. The Measurable interface type requires a single method, but in general, an interface type can require multiple methods.

Note that the Measurable type is not a type in the standard library—it is a type that was created specifically for this book, in order to make the DataSet class more reusable.

Syntax 9.1 Declaring an Interface

Syntax

```
public interface InterfaceName
{
   method signatures
}
```

Example

```
public interface Measurable
{
   double getMeasure();
}
```

The methods of an interface are automatically public.

No implementation is provided.

Unlike a class, an interface type provides no implementation.

An interface type is similar to a class, but there are several important differences:

- All methods in an interface type are *abstract*; that is, they have a name, parameters, and a return type, but they don't have an implementation.
- All methods in an interface type are automatically public.
- An interface type does not have instance variables.

Now we can use the interface type `Measurable` to declare the variables `x` and `maximum`.

```
public class DataSet
{
   private double sum;
   private Measurable maximum;
   private int count;
   . . .
   public void add(Measurable x)
   {
      sum = sum + x.getMeasure();
      if (count == 0 || maximum.getMeasure() < x.getMeasure())
         maximum = x;
      count++;
   }

   public Measurable getMaximum()
   {
      return maximum;
   }
}
```

Use the `implements` reserved word to indicate that a class implements an interface type.

This `DataSet` class is usable for analyzing objects of any class that implements the `Measurable` interface. A class **implements an interface** type if it declares the interface in an `implements` clause. It should then implement the method or methods that the interface requires.

```
public class BankAccount implements Measurable
{
   . . .
   public double getMeasure()
   {
      return balance;
   }
}
```

Figure 1
Attachments Conform to the Mixer's Interface

Note that the class must declare the method as `public`, whereas the interface need not—all methods in an interface are public.

Similarly, it is an easy matter to modify the `Coin` class to implement the `Measurable` interface.

```
public class Coin implements Measurable
{
   public double getMeasure()
   {
      return value;
   }
   . . .
}
```

In summary, the `Measurable` interface expresses what all measurable objects have in common. This commonality makes the flexibility of the improved `DataSet` class possible. A data set can analyze objects of *any* class that implements the `Measurable` interface.

Use interface types to make code more reusable.

This is a typical usage for interface types. A service provider—in this case, the `DataSet`—specifies an interface for participating in the service. Any class that conforms to that interface can then be used with the service. This is similar to the way a mixer will provide rotation to any attachment that fits its interface (see Figure 1).

Syntax 9.2 Implementing an Interface

Syntax

```
public class ClassName implements InterfaceName, InterfaceName, . . .
{
   instance variables
   methods
}
```

Example

```
public class BankAccount implements Measurable
{
   . . .
   public double getMeasure()
   {
      return balance;
   }
   . . .
}
```

List all interface types that this class implements.

BankAccount instance variables

This method provides the implementation for the method declared in the interface.

Other BankAccount methods

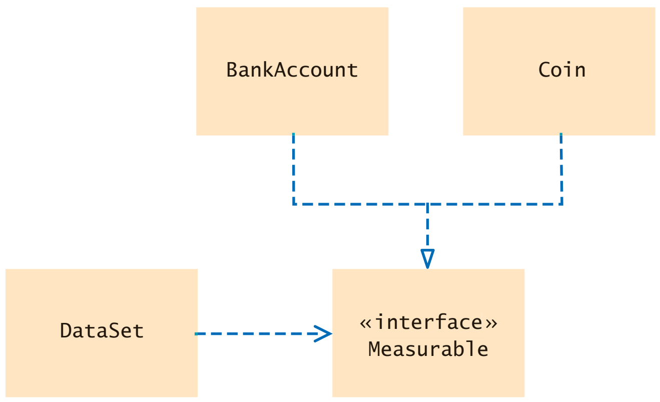


Figure 2 UML Diagram of the `DataSet` Class and the Classes that Implement the `Measurable` Interface

Figure 2 shows the relationships between the `DataSet` class, the `Measurable` interface, and the classes that implement the interface. Note that the `DataSet` class depends only on the `Measurable` interface. It is decoupled from the `BankAccount` and `Coin` classes.

In the UML notation, interfaces are tagged with an indicator «interface». A dotted arrow with a triangular tip denotes the "*is-a*" relationship between a class and an interface. You have to look carefully at the arrow tips—a dotted line with an open arrow tip (⇢) denotes the "*uses*" relationship or dependency.

ch09/measure1/DataSetTester.java

```java
/**
   This program tests the DataSet class.
*/
public class DataSetTester
{
   public static void main(String[] args)
   {
      DataSet bankData = new DataSet();

      bankData.add(new BankAccount(0));
      bankData.add(new BankAccount(10000));
      bankData.add(new BankAccount(2000));

      System.out.println("Average balance: " + bankData.getAverage());
      System.out.println("Expected: 4000");
      Measurable max = bankData.getMaximum();
      System.out.println("Highest balance: " + max.getMeasure());
      System.out.println("Expected: 10000");

      DataSet coinData = new DataSet();

      coinData.add(new Coin(0.25, "quarter"));
      coinData.add(new Coin(0.1, "dime"));
      coinData.add(new Coin(0.05, "nickel"));

      System.out.println("Average coin value: " + coinData.getAverage());
      System.out.println("Expected: 0.133");
      max = coinData.getMaximum();
      System.out.println("Highest coin value: " + max.getMeasure());
      System.out.println("Expected: 0.25");
   }
}
```

Program Run

```
Average balance: 4000.0
Expected: 4000
Highest balance: 10000.0
Expected: 10000
Average coin value: 0.13333333333333333
Expected: 0.133
Highest coin value: 0.25
Expected: 0.25
```

SELF CHECK

1. Suppose you want to use the `DataSet` class to find the `Country` object with the largest population. What condition must the `Country` class fulfill?
2. Why can't the `add` method of the `DataSet` class have a parameter of type `Object`?

Common Error 9.1

Forgetting to Declare Implementing Methods as Public

The methods in an interface are not declared as `public`, because they are public by default. However, the methods in a class are not public by default—their default access level is "package" access, which we discuss in Chapter 8. It is a common error to forget the `public` reserved word when declaring a method from an interface:

```
public class BankAccount implements Measurable
{
   . . .
   double getMeasure() // Oops—should be public
   {
      return balance;
   }
}
```

Then the compiler complains that the method has a weaker access level, namely package access instead of public access. The remedy is to declare the method as public.

Special Topic 9.1

Constants in Interfaces

Interfaces cannot have instance variables, but it is legal to specify *constants*. For example, the `SwingConstants` interface declares various constants, such as `SwingConstants.NORTH`, `SwingConstants.EAST`, and so on.

When declaring a constant in an interface, you can (and should) omit the reserved words `public static final`, because all variables in an interface are automatically `public static final`.

For example,

```
public interface SwingConstants
{
   int NORTH = 1;
   int NORTHEAST = 2;
   int EAST = 3;
   . . .
}
```

9.2 Converting Between Class and Interface Types

Interfaces are used to express the commonality between classes. In this section, we discuss when it is legal to convert between class and interface types.

Have a close look at the call

```
bankData.add(new BankAccount(1000));
```

from the test program of the preceding section. Here we pass an object of type `BankAccount` to the `add` method of the `DataSet` class. However, that method has a parameter of type `Measurable`:

```
public void add(Measurable x)
```

You can convert from a class type to an interface type, provided the class implements the interface.

It it legal to convert from the `BankAccount` type to the `Measurable` type. In general, you can convert from a class type to the type of any interface that the class implements. For example,

```
BankAccount account = new BankAccount(1000);
Measurable meas = account; // OK
```

Alternatively, a `Measurable` variable can refer to an object of the `Coin` class of the preceding section because that class also implements the `Measurable` interface.

```
Coin dime = new Coin(0.1, "dime");
Measurable meas = dime; // Also OK
```

However, the `Rectangle` class from the standard library doesn't implement the `Measurable` interface. Therefore, the following assignment is an error:

```
Measurable meas = new Rectangle(5, 10, 20, 30); // Error
```

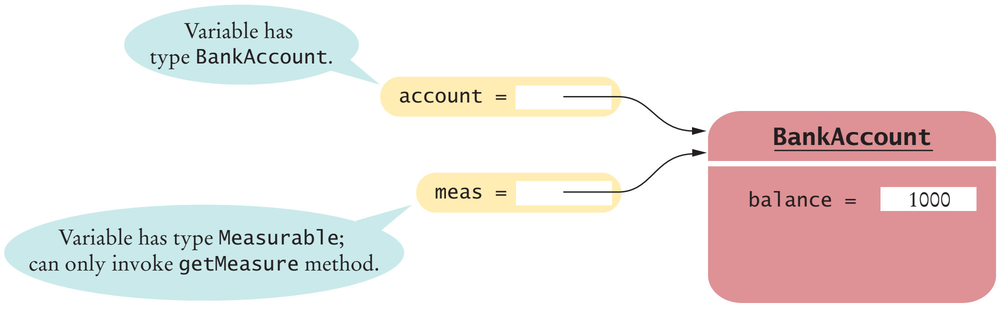

Variable has type BankAccount.
account =
BankAccount
balance = 1000
meas =
Variable has type Measurable; can only invoke getMeasure method.

Figure 3 Variables of Class and Interface Types

Occasionally, it happens that you store an object in an interface reference and you need to convert its type back. This happens in the `getMaximum` method of the `DataSet` class. The `DataSet` stores the object with the largest measure, *as a* `Measurable` *reference*.

```
DataSet coinData = new DataSet();
coinData.add(new Coin(0.25, "quarter"));
coinData.add(new Coin(0.1, "dime"));
coinData.add(new Coin(0.05, "nickel"));
Measurable max = coinData.getMaximum();
```

Now what can you do with the `max` reference? *You* know it refers to a `Coin` object, but the compiler doesn't. For example, you cannot call the `getName` method:

```
String coinName = max.getName(); // Error
```

That call is an error, because the `Measurable` type has no `getName` method.

You need a cast to convert from an interface type to a class type.

However, as long as you are absolutely sure that `max` refers to a `Coin` object, you can use the **cast** notation to convert its type back:

```
Coin maxCoin = (Coin) max;
String name = maxCoin.getName();
```

If you are wrong, and the object doesn't actually refer to a coin, a run-time exception will occur.

This cast notation is the same notation that you saw in Chapter 4 to convert between number types. For example, if `x` is a floating-point number, then `(int) x` is the integer part of the number. The intent is similar—to convert from one type to another. However, there is one big difference between casting of number types and casting of class types. When casting number types, you may *lose information*, and you use the cast to tell the compiler that you agree to the potential information loss. When casting object types, on the other hand, you *take a risk* of causing an exception, and you tell the compiler that you agree to that risk.

SELF CHECK

3. Can you use a cast `(BankAccount) meas` to convert a `Measurable` variable `meas` to a `BankAccount` reference?

4. If both `BankAccount` and `Coin` implement the `Measurable` interface, can a `Coin` reference be converted to a `BankAccount` reference?

Common Error 9.2

Trying to Instantiate an Interface

You can declare variables whose type is an interface, for example:

```
Measurable meas;
```

However, you can *never* construct an object of an interface type:

```
Measurable meas = new Measurable(); // Error
```

Interfaces aren't classes. There are no objects whose types are interfaces. If an interface variable refers to an object, then the object must belong to some class—a class that implements the interface:

```
Measurable meas = new BankAccount(); // OK
```

9.3 Polymorphism

When multiple classes implement the same interface, each class can implement the methods of the interface in different ways. How is the correct method executed when the interface method is invoked? We will answer that question in this section.

It is worth emphasizing once again that it is perfectly legal—and in fact very common—to have variables whose type is an interface, such as

```
Measurable meas;
```

Just remember that the object to which `meas` refers doesn't have type `Measurable`. In fact, *no object* has type `Measurable`. Instead, the type of the object is some class that implements the `Measurable` interface. This might be an object of the `BankAccount` or `Coin` class, or some other class with a `getMeasure` method.

```
meas = new BankAccount(1000); // OK
meas = new Coin(0.1, "dime"); // OK
```

ANIMATION *Polymorphism*

What can you do with an interface variable, given that you don't know the class of the object that it references? You can invoke the methods of the interface:

```
double m = meas.getMeasure();
```

The `DataSet` class took advantage of this capability by computing the measure of the added object, without knowing exactly what kind of object was added.

Now let's think through the call to the `getMeasure` method more carefully. *Which* `getMeasure` method? The `BankAccount` and `Coin` classes provide two *different* implementations of that method. How did the correct method get called if the caller didn't even know the exact class to which `meas` belongs?

When the virtual machine calls an instance method, it locates the method of the implicit parameter's class. This is called dynamic method lookup.

The Java virtual machine locates the correct method by first looking at the class of the actual object, and then calling the method with the given name in that class. That is, if `meas` refers to a `BankAccount` object, then the `BankAccount.getMeasure` method is called. If `meas` refers to a `Coin` object, then the `Coin.getMeasure` method is called. This means that one method call

```
double m = meas.getMeasure();
```

can invoke different methods depending on the momentary contents of `meas`. This mechanism for locating the appropriate method is called *dynamic method lookup.*

Polymorphism denotes the ability to treat objects with differences in behavior in a uniform way.

Dynamic method lookup enables a programming technique called **polymorphism**. The term "polymorphism" comes from the Greek words for "many shapes". The same computation works for objects of many shapes, and adapts itself to the nature of the objects.

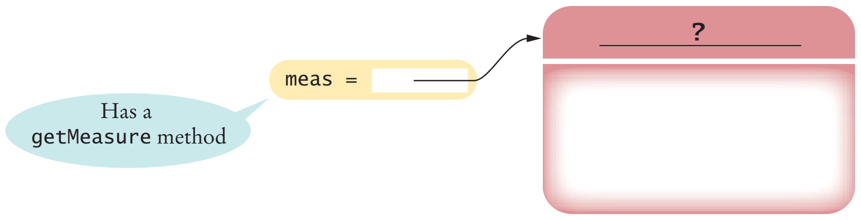


Figure 4 An Interface Reference Can Refer to an Object of Any Class that Implements the Interface

5. Why is it impossible to construct a `Measurable` object?
6. Why can you nevertheless declare a variable whose type is `Measurable`?
7. What does this code fragment print? Why is this an example of polymorphism?

```
DataSet data = new DataSet();
data.add(new BankAccount(1000));
data.add(new Coin(0.1, "dime"));
System.out.println(data.getAverage());
```

Worked Example 9.1

Investigating Number Sequences

Worked Example 9.1 uses a `Sequence` interface to investigate properties of arbitrary number sequences.

9.4 Using Interfaces for Callbacks

In this section, we introduce the notion of a callback, show how it leads to a more flexible `DataSet` class, and study how a callback can be implemented in Java by using interface types.

To understand why a further improvement to the `DataSet` class is desirable, consider these limitations of the `Measurable` interface:

- You can add the `Measurable` interface only to classes under your control. If you want to process a set of `Rectangle` objects, you cannot make the `Rectangle` class implement another interface—it is a system class, which you cannot change.
- You can measure an object in only one way. If you want to analyze a set of savings accounts both by bank balance and by interest rate, you are stuck.

Therefore, let's rethink the `DataSet` class. The data set needs to measure the objects that are added. When the objects are required to be of type `Measurable`, the responsibility of measuring lies with the added objects themselves, which is the cause of the limitations that we noted.

It would be better if we could give a method for measuring objects to a data set. When collecting rectangles, we might give it a method for computing the area of a rectangle. When collecting savings accounts, we might give it a method for getting the account's interest rate.

A callback is a mechanism for specifying code that is executed at a later time.

Such a method is called a **callback**. A callback is a mechanism for bundling up a block of code so that it can be invoked at a later time.

In some programming languages, it is possible to specify callbacks directly, as blocks of code or names of methods. But Java is an object-oriented language. Therefore, you turn callbacks into objects. This process starts by declaring an interface for the callback:

```
public interface Measurer
{
   double measure(Object anObject);
}
```

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

The measure method measures an object and returns its measurement. Here we use the fact that all objects can be converted to the type Object, the “lowest common denominator” of all classes in Java. We will discuss the Object type in greater detail in Chapter 10.

The code that makes the call to the callback receives an object of a class that implements this interface. In our case, the improved DataSet class is constructed with a Measurer object (that is, an object of some class that implements the Measurer interface). That object is saved in a measurer instance variable.

```
public DataSet(Measurer aMeasurer)
{
   sum = 0;
   count = 0;
   maximum = null;
   measurer = aMeasurer;
}
```

The measurer variable is used to carry out the measurements, like this:

```
public void add(Object x)
{
   sum = sum + measurer.measure(x);
   if (count == 0 || measurer.measure(maximum) < measurer.measure(x))
      maximum = x;
   count++;
}
```

The DataSet class simply makes a callback to the measure method whenever it needs to measure any object.

Finally, a specific callback is obtained by implementing the Measurer interface. For example, here is how you can measure rectangles by area. Provide a class

```
public class RectangleMeasurer implements Measurer
{
   public double measure(Object anObject)
   {
      Rectangle aRectangle = (Rectangle) anObject;
      double area = aRectangle.getWidth() * aRectangle.getHeight();
      return area;
   }
}
```

Note that the measure method must accept a parameter of type Object, even though this particular measurer just wants to measure rectangles. The method parameter types must match those of the measure method in the Measurer interface. Therefore, the Object parameter is cast to the Rectangle type:

```
Rectangle aRectangle = (Rectangle) anObject;
```

What can you do with a RectangleMeasurer? You need it for a DataSet that compares rectangles by area. Construct an object of the RectangleMeasurer class and pass it to the DataSet constructor.

```
Measurer m = new RectangleMeasurer();
DataSet data = new DataSet(m);
```

Next, add rectangles to the data set.

```
data.add(new Rectangle(5, 10, 20, 30));
data.add(new Rectangle(10, 20, 30, 40));
. . .
```

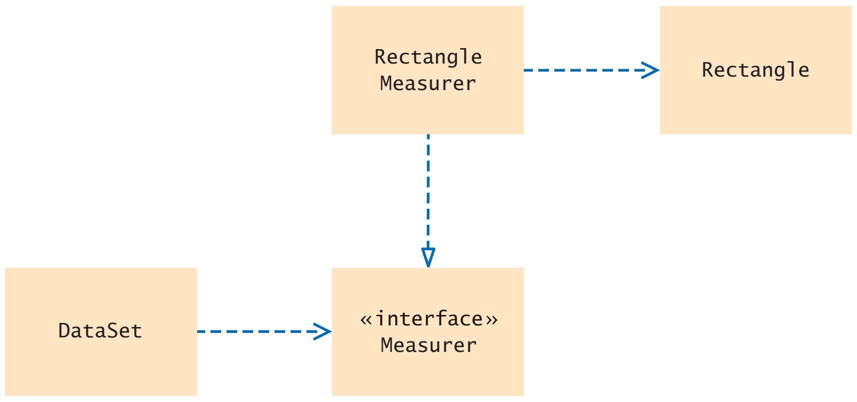


Figure 5 UML Diagram of the `DataSet` Class and the `Measurer` Interface

The data set will ask the `RectangleMeasurer` object to measure the rectangles. In other words, the data set uses the `RectangleMeasurer` object to carry out callbacks.

Figure 5 shows the UML diagram of the classes and interfaces of this solution. As in Figure 2, the `DataSet` class is decoupled from the `Rectangle` class whose objects it processes. However, unlike in Figure 2, the `Rectangle` class is no longer coupled with another class. Instead, to process rectangles, you provide a small "helper" class `RectangleMeasurer`. This helper class has only one purpose: to tell the `DataSet` how to measure its objects.

ch09/measure2/Measurer.java

```java
/**
   Describes any class whose objects can measure other objects.
*/
public interface Measurer
{
   /**
      Computes the measure of an object.
      @param anObject the object to be measured
      @return the measure
   */
   double measure(Object anObject);
}
```

ch09/measure2/RectangleMeasurer.java

```java
import java.awt.Rectangle;

/**
   Objects of this class measure rectangles by area.
*/
public class RectangleMeasurer implements Measurer
{
   public double measure(Object anObject)
   {
      Rectangle aRectangle = (Rectangle) anObject;
      double area = aRectangle.getWidth() * aRectangle.getHeight();
      return area;
   }
}
```

ch09/measure2/DataSet.java

```java
/**
   Computes the average of a set of data values.
*/
public class DataSet
{
   private double sum;
   private Object maximum;
   private int count;
   private Measurer measurer;

   /**
      Constructs an empty data set with a given measurer.
      @param aMeasurer the measurer that is used to measure data values
   */
   public DataSet(Measurer aMeasurer)
   {
      sum = 0;
      count = 0;
      maximum = null;
      measurer = aMeasurer;
   }

   /**
      Adds a data value to the data set.
      @param x a data value
   */
   public void add(Object x)
   {
      sum = sum + measurer.measure(x);
      if (count == 0 || measurer.measure(maximum) < measurer.measure(x))
         maximum = x;
      count++;
   }

   /**
      Gets the average of the added data.
      @return the average or 0 if no data has been added
   */
   public double getAverage()
   {
      if (count == 0) return 0;
      else return sum / count;
   }

   /**
      Gets the largest of the added data.
      @return the maximum or 0 if no data has been added
   */
   public Object getMaximum()
   {
      return maximum;
   }
}
```

ch09/measure2/DataSetTester2.java

```java
import java.awt.Rectangle;

```

```
/**
   This program demonstrates the use of a Measurer.
*/
public class DataSetTester2
{
   public static void main(String[] args)
   {
      Measurer m = new RectangleMeasurer();

      DataSet data = new DataSet(m);

      data.add(new Rectangle(5, 10, 20, 30));
      data.add(new Rectangle(10, 20, 30, 40));
      data.add(new Rectangle(20, 30, 5, 15));

      System.out.println("Average area: " + data.getAverage());
      System.out.println("Expected: 625");

      Rectangle max = (Rectangle) data.getMaximum();
      System.out.println("Maximum area rectangle: " + max);
      System.out.println("Expected: "
            + "java.awt.Rectangle[x=10,y=20,width=30,height=40]");
   }
}
```

Program Run

```
Average area: 625
Expected: 625
Maximum area rectangle: java.awt.Rectangle[x=10,y=20,width=30,height=40]
Expected: java.awt.Rectangle[x=10,y=20,width=30,height=40]
```

SELF CHECK

8. Suppose you want to use the DataSet class of Section 9.1 to find the longest String from a set of inputs. Why can't this work?
9. How can you use the DataSet class of this section to find the longest String from a set of inputs?
10. Why does the measure method of the Measurer interface have one more parameter than the getMeasure method of the Measurable interface?

9.5 Inner Classes

The RectangleMeasurer class is a very trivial class. We need this class only because the DataSet class needs an object of some class that implements the Measurer interface. When you have a class that serves a very limited purpose, such as this one, you can declare the class inside the method that needs it:

```
public class DataSetTester3
{
   public static void main(String[] args)
   {
      class RectangleMeasurer implements Measurer
      {
         . . .
         }

         Measurer m = new RectangleMeasurer();
         DataSet data = new DataSet(m);
         . . .
      }
   }
```

An inner class is declared inside another class.

A class that is declared inside another class, such as the `RectangleMeasurer` class in this example, is called an **inner class**. This arrangement signals to the reader of your program that the `RectangleMeasurer` class is not interesting beyond the scope of this method. Since an inner class inside a method is not a publicly accessible feature, you don't need to document it as thoroughly.

Inner classes are commonly used for utility classes that should not be visible elsewhere in a program.

You can also declare an inner class inside an enclosing class, but outside of its methods. Then the inner class is available to all methods of the enclosing class.

```
   public class DataSetTester3
   {
      class RectangleMeasurer implements Measurer
      {
         . . .
      }

      public static void main(String[] args)
      {

         Measurer m = new RectangleMeasurer();
         DataSet data = new DataSet(m);
         . . .
      }
   }
```

When you compile the source files for a program that uses inner classes, have a look at the class files in your program directory—you will find that the inner classes are stored in files with curious names, such as `DataSetTester3$1RectangleMeasurer.class`. The exact names aren't important. The point is that the compiler turns an inner class into a regular class file.

ch09/measure3/DataSetTester3.java

```
import java.awt.Rectangle;

/**
   This program demonstrates the use of an inner class.
*/
public class DataSetTester3
{
   public static void main(String[] args)
   {
      class RectangleMeasurer implements Measurer
      {
         public double measure(Object anObject)
         {
            Rectangle aRectangle = (Rectangle) anObject;
            double area
                  = aRectangle.getWidth() * aRectangle.getHeight();
            return area;
         }
      }

      Measurer m = new RectangleMeasurer();

      DataSet data = new DataSet(m);

      data.add(new Rectangle(5, 10, 20, 30));
      data.add(new Rectangle(10, 20, 30, 40));
      data.add(new Rectangle(20, 30, 5, 15));

      System.out.println("Average area: " + data.getAverage());
      System.out.println("Expected: 625");

      Rectangle max = (Rectangle) data.getMaximum();
      System.out.println("Maximum area rectangle: " + max);
      System.out.println("Expected: "
            + "java.awt.Rectangle[x=10,y=20,width=30,height=40]");
   }
}
```

SELF CHECK

11. Why would you use an inner class instead of a regular class?

12. How many class files are produced when you compile the `DataSetTester3` program?

Special Topic 9.2

Anonymous Classes

Special Topic 9.2 shows how you can simplify the declaration of inner classes with the "anonymous class" syntax.

Random Fact 9.1

Operating Systems

Random Fact 9.1 discusses operating systems, the software that provides common services to all programs that execute on a computer.

9.6 Mock Objects

When you work on a program that consists of multiple classes, you often want to test some of the classes before the entire program has been completed. A very effective technique for this purpose is the use of **mock objects**. A mock object provides the same services as another object, but in a simplified manner.

A mock object provides the same services as another object, but in a simplified manner.

Consider a grade book application that manages quiz scores for students. This calls for a class `GradeBook` with methods such as

```
public void addScore(int studentId, double score)
public double getAverageScore(int studentId)
public void save(String filename)
```

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Now consider the class GradingProgram that manipulates a GradeBook object. That class calls the methods of the GradeBook class. We would like to test the GradingProgram class without having a fully functional GradeBook class.

To make this work, declare an interface type with the same methods that the GradeBook class provides. A common convention is to use the letter I as the prefix for such an interface:

```
public interface IGradeBook
{
   void addScore(int studentId, double score);
   double getAverageScore(int studentId);
   void save(String filename);
   . . .
}
```

The GradingProgram class should *only* use this interface, never the GradeBook class. Of course, the GradeBook class implements this interface, but as already mentioned, it may not be ready for some time.

Both the mock class and the actual class implement the same interface.

In the meantime, provide a mock implementation that makes some simplifying assumptions. Saving is not actually necessary for testing the user interface. We can temporarily restrict to the case of a single student.

```
public class MockGradeBook implements IGradeBook
{
   private ArrayList<Double> scores;

   public void addScore(int studentId, double score)
   {
      // Ignore studentId
      scores.add(score);
   }
   double getAverageScore(int studentId)
   {
      double total = 0;
      for (double x : scores) { total = total + x; }
      return total / scores.size();
   }
   void save(String filename)
   {
      // Do nothing
   }
   . . .
}
```

Now construct an instance of MockGradeBook and use it in the GradingProgram class. You can immediately test the GradingProgram class. When you are ready to test the actual class, simply use a GradeBook instance instead. Don't erase the mock class—it will still come in handy for regression testing.

SELF CHECK

13. Why is it necessary that the real class and the mock class implement the same interface type?
14. Why is the technique of mock objects particularly effective when the GradeBook and GradingProgram class are developed by two programmers?

9.7 Events, Event Sources, and Event Listeners

This and the following sections continue the book's graphics track. You will learn how interfaces are used when programming graphical user interfaces.

In the applications that you have written so far, user input was under control of the *program*. The program asked the user for input in a specific order. For example, a program might ask the user to supply first a name, then a dollar amount. But the programs that you use every day on your computer don't work like that. In a program with a graphical user interface, the *user* is in control. The user can use both the mouse and the keyboard and can manipulate many parts of the user interface in any desired order. For example, the user can enter information into text fields, pull down menus, click buttons, and drag scroll bars in any order. The program must react to the user commands, in whatever order they arrive. Having to deal with many possible inputs in random order is quite a bit harder than simply forcing the user to supply input in a fixed order.

User-interface events include key presses, mouse moves, button clicks, menu selections, and so on.

In the following sections, you will learn how to write Java programs that can react to user-interface events, such as menu selections and mouse clicks. The Java windowing toolkit has a very sophisticated mechanism that allows a program to specify the events in which it is interested and which objects to notify when one of these events occurs.

Whenever the user of a graphical program types characters or uses the mouse anywhere inside one of the windows of the program, the Java windowing toolkit sends a notification to the program that an **event** has occurred. The windowing toolkit generates huge numbers of events. For example, whenever the mouse moves a tiny interval over a window, a "mouse move" event is generated. Whenever the mouse button is clicked, a "mouse pressed" and a "mouse released" event are generated. In addition, higher level events are generated when a user selects a menu item or button.

An event listener belongs to a class that is provided by the application programmer. Its methods describe the actions to be taken when an event occurs.

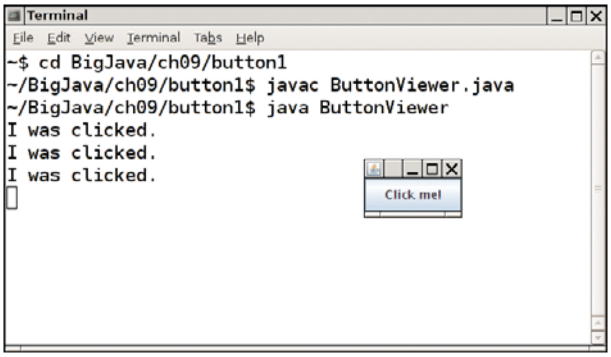
Most programs don't want to be flooded by boring events. For example, consider what happens when selecting a menu item with the mouse. The mouse moves over the menu item, then the mouse button is pressed, and finally the mouse button is released. Rather than receiving lots of irrelevant mouse events, a program can indicate that it only cares about menu selections, not about the underlying mouse events. However, if the mouse input is used for drawing shapes on a virtual canvas, it is necessary to closely track mouse events.

Every program must indicate which events it needs to receive. It does that by installing **event listener** objects. An event listener object belongs to a class that you provide. The methods of your event listener classes contain the instructions that you want to have executed when the events occur.

Event sources report on events. When an event occurs, the event source notifies all event listeners.

To install a listener, you need to know the **event source**. The event source is the user-interface component that generates a particular event. You add an event listener object to the appropriate event sources. Whenever the event occurs, the event source calls the appropriate methods of all attached event listeners.

This sounds somewhat abstract, so let's run through an extremely simple program that prints a message whenever a button is clicked (see Figure 6).



```
~$ cd BigJava/ch09/button1
~/BigJava/ch09/button1$ javac ButtonViewer.java
~/BigJava/ch09/button1$ java ButtonViewer
I was clicked.
I was clicked.
I was clicked.
```

Figure 6 Implementing an Action Listener

Use JButton components for buttons. Attach an ActionListener to each button.

Button listeners must belong to a class that implements the ActionListener interface:

```
public interface ActionListener
{
   void actionPerformed(ActionEvent event);
}
```

This particular interface has a single method, actionPerformed. It is your job to supply a class whose actionPerformed method contains the instructions that you want executed whenever the button is clicked. Here is a very simple example of such a listener class:

ch09/button1/ClickListener.java

```
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;

/**
   An action listener that prints a message.
*/
public class ClickListener implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      System.out.println("I was clicked.");
   }
}
```

We ignore the event parameter of the actionPerformed method—it contains additional details about the event, such as the time at which it occurred.

Once the listener class has been declared, we need to construct an object of the class and add it to the button:

```
ActionListener listener = new ClickListener();
button.addActionListener(listener);
```

Whenever the button is clicked, it calls

```
listener.actionPerformed(event);
```

As a result, the message is printed.

You can think of the actionPerformed method as another example of a callback, similar to the measure method of the Measurer class. The windowing toolkit calls the actionPerformed method whenever the button is pressed, whereas the DataSet calls the measure method whenever it needs to measure an object.

The ButtonViewer class, whose source code is provided at the end of this section, constructs a frame with a button and adds a ClickListener to the button. You can test this program out by opening a console window, starting the ButtonViewer program from that console window, clicking the button, and watching the messages in the console window.

ch09/button1/ButtonViewer.java

```java
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JFrame;

/**
   This program demonstrates how to install an action listener.
*/
public class ButtonViewer
{
   private static final int FRAME_WIDTH = 100;
   private static final int FRAME_HEIGHT = 60;

   public static void main(String[] args)
   {
      JFrame frame = new JFrame();
      JButton button = new JButton("Click me!");
      frame.add(button);

      ActionListener listener = new ClickListener();
      button.addActionListener(listener);

      frame.setSize(FRAME_WIDTH, FRAME_HEIGHT);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

SELF CHECK

15. Which objects are the event source and the event listener in the ButtonViewer program?

16. Why is it legal to assign a ClickListener object to a variable of type ActionListener?

Common Error 9.3

Modifying Parameter Types in the Implementing Method

When you implement an interface, you must declare each method *exactly* as it is specified in the interface. Accidentally making small changes to the parameter types is a common error. Here is the classic example,

```
class MyListener implements ActionListener
{
   public void actionPerformed()
   // Oops . . . forgot ActionEvent parameter
   {
      . . .
      }
   }
```

As far as the compiler is concerned, this class fails to provide the method

```
public void actionPerformed(ActionEvent event)
```

You have to read the error message carefully and pay attention to the parameter and return types to find your error.

9.8 Using Inner Classes for Listeners

In the preceding section, you saw how the code that is executed when a button is clicked is placed into a listener class. It is common to implement listener classes as inner classes like this:

```
JButton button = new JButton(". . .");

// This inner class is declared in the same method as the button variable
class MyListener implements ActionListener
{
   . . .
};

ActionListener listener = new MyListener();
button.addActionListener(listener);
```

There are two reasons for this arrangement. The trivial listener class is located exactly where it is needed, without cluttering up the remainder of the project. Moreover, inner classes have a very attractive feature: Their methods can access variables that are declared in surrounding blocks. In this regard, method declarations of inner classes behave similarly to nested blocks.

Recall that a block is a statement group enclosed by braces. If a block is nested inside another, the inner block has access to all variables from the surrounding block:

```
{  // Surrounding block
   BankAccount account = new BankAccount();
   if (. . .)
   {  // Inner block
      . . .
      // OK to access variable from surrounding block
      account.deposit(interest);
     . . .
   }  // End of inner block
   . . .
}  // End of surrounding block
```

Methods of an inner class can access local and instance variables from the surrounding scope.

The same nesting works for inner classes. Except for some technical restrictions, which we will examine later in this section, the methods of an inner class can access the variables from the enclosing scope. This feature is very useful when implementing event handlers. It allows the inner class to access variables without having to pass them as constructor or method parameters.

Let's look at an example. Suppose we want to add interest to a bank account whenever a button is clicked.

```
JButton button = new JButton("Add Interest");
final BankAccount account = new BankAccount(INITIAL_BALANCE);

// This inner class is declared in the same method as the account and button variables.
class AddInterestListener implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      // The listener method accesses the account variable
      // from the surrounding block
      double interest = account.getBalance() * INTEREST_RATE / 100;
      account.deposit(interest);
   }
};

ActionListener listener = new AddInterestListener();
button.addActionListener(listener);
```

Local variables that are accessed by an inner class method must be declared as `final`.

There is a technical wrinkle. An inner class can access surrounding *local* variables only if they are declared as `final`. That sounds like a restriction, but it is usually not an issue in practice. Keep in mind that an object variable is `final` when the variable always refers to the same object. The state of the object can change, but the variable can't refer to a different object. For example, in our program, we never intended to have the `account` variable refer to multiple bank accounts, so there was no harm in declaring it as `final`.

An inner class can also access *instance* variables of the surrounding class, again with a restriction. The instance variable must belong to the object that constructed the inner class object. If the inner class object was created inside a static method, it can only access static variables.

Here is the source code for the program.

ch09/button2/InvestmentViewer1.java

```
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JFrame;

/**
   This program demonstrates how an action listener can access
   a variable from a surrounding block.
*/
public class InvestmentViewer1
{
   private static final int FRAME_WIDTH = 120;
   private static final int FRAME_HEIGHT = 60;

   private static final double INTEREST_RATE = 10;
   private static final double INITIAL_BALANCE = 1000;

   public static void main(String[] args)
   {
      JFrame frame = new JFrame();

      // The button to trigger the calculation
      JButton button = new JButton("Add Interest");
      frame.add(button);

      // The application adds interest to this bank account
      final BankAccount account = new BankAccount(INITIAL_BALANCE);

      class AddInterestListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            // The listener method accesses the account variable
            // from the surrounding block
            double interest = account.getBalance() * INTEREST_RATE / 100;
            account.deposit(interest);
            System.out.println("balance: " + account.getBalance());
         }
      }

      ActionListener listener = new AddInterestListener();
      button.addActionListener(listener);

      frame.setSize(FRAME_WIDTH, FRAME_HEIGHT);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

Program Run

```
balance: 1100.0
balance: 1210.0
balance: 1331.0
balance: 1464.1
```

SELF CHECK

17. Why would an inner class method want to access a variable from a surrounding scope?

18. If an inner class accesses a local variable from a surrounding scope, what special rule applies?

9.9 Building Applications with Buttons

In this section, you will learn how to structure a graphical application that contains buttons. We will put a button to work in our simple investment viewer program. Whenever the button is clicked, interest is added to a bank account, and the new balance is displayed (see Figure 7).

First, we construct an object of the `JButton` class. Pass the button label to the constructor:

```
JButton button = new JButton("Add Interest");
```

We also need a user-interface component that displays a message, namely the current bank balance. Such a component is called a *label*. You pass the initial message string to the `JLabel` constructor, like this:

Use a `JPanel` container to group multiple user-interface components together.

```
JLabel label = new JLabel("balance: " + account.getBalance());
```

The frame of our application contains both the button and the label. However, we cannot simply add both components directly to the frame—they would be placed

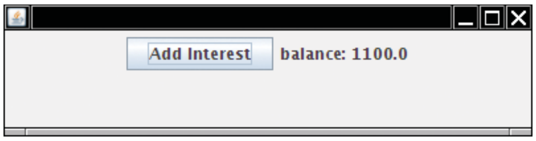


Figure 7 An Application with a Button

on top of each other. The solution is to put them into a **panel**, a container for other user-interface components, and then add the panel to the frame:

```
JPanel panel = new JPanel();
panel.add(button);
panel.add(label);
frame.add(panel);
```

You specify button click actions through classes that implement the `ActionListener` interface.

Now we are ready for the hard part—the event listener that handles button clicks. As in the preceding section, it is necessary to provide a class that implements the `ActionListener` interface, and to place the button action into the `actionPerformed` method. Our listener class adds interest and displays the new balance:

```
class AddInterestListener implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      double interest = account.getBalance() * INTEREST_RATE / 100;
      account.deposit(interest);
      label.setText("balance: " + account.getBalance());
   }
}
```

There is just a minor technicality. The `actionPerformed` method manipulates the `account` and `label` variables. These are local variables of the `main` method of the investment viewer program, not instance variables of the `AddInterestListener` class. We therefore need to declare the `account` and `label` variables as `final` so that the `actionPerformed` method can access them.

Let's put the pieces together.

```
public static void main(String[] args)
{
   . . .
   JButton button = new JButton("Add Interest");
   final BankAccount account = new BankAccount(INITIAL_BALANCE);
   final JLabel label = new JLabel("balance: " + account.getBalance());

   class AddInterestListener implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         double interest = account.getBalance() * INTEREST_RATE / 100;
         account.deposit(interest);
         label.setText("balance: " + account.getBalance());
      }
   }

   ActionListener listener = new AddInterestListener();
   button.addActionListener(listener);
   . . .
}
```

With a bit of practice, you will learn to glance at this code and translate it into plain English: “When the button is clicked, add interest and set the label text.”

Here is the complete program. It demonstrates how to add multiple components to a frame, by using a panel, and how to implement listeners as inner classes.

ch09/button3/InvestmentViewer2.java

```java
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JTextField;

/**
   This program displays the growth of an investment.
*/
public class InvestmentViewer2
{
   private static final int FRAME_WIDTH = 400;
   private static final int FRAME_HEIGHT = 100;

   private static final double INTEREST_RATE = 10;
   private static final double INITIAL_BALANCE = 1000;

   public static void main(String[] args)
   {
      JFrame frame = new JFrame();

      // The button to trigger the calculation
      JButton button = new JButton("Add Interest");

      // The application adds interest to this bank account
      final BankAccount account = new BankAccount(INITIAL_BALANCE);

      // The label for displaying the results
      final JLabel label = new JLabel("balance: " + account.getBalance());

      // The panel that holds the user-interface components
      JPanel panel = new JPanel();
      panel.add(button);
      panel.add(label);
      frame.add(panel);

      class AddInterestListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            double interest = account.getBalance() * INTEREST_RATE / 100;
            account.deposit(interest);
            label.setText("balance: " + account.getBalance());
         }
      }

      ActionListener listener = new AddInterestListener();
      button.addActionListener(listener);

```

```
         frame.setSize(FRAME_WIDTH, FRAME_HEIGHT);
         frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
         frame.setVisible(true);
      }
   }
```

SELF CHECK

19. How do you place the `"balance: . . ."` message to the left of the `"Add Interest"` button?

20. Why was it not necessary to declare the `button` variable as `final`?

Common Error 9.4

Forgetting to Attach a Listener

If you run your program and find that your buttons seem to be dead, double-check that you attached the button listener. The same holds for other user-interface components. It is a surprisingly common error to program the listener class and the event handler action without actually attaching the listener to the event source.

Productivity Hint 9.1

Don't Use a Container as a Listener

In this book, we use inner classes for event listeners. That approach works for many different event types. Once you master the technique, you don't have to think about it anymore. Many development environments automatically generate code with inner classes, so it is a good idea to be familiar with them.

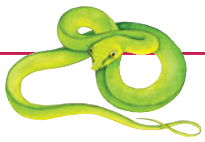
However, some programmers bypass the event listener classes and instead turn a container (such as a panel or frame) into a listener. Here is a typical example. The `actionPerformed` method is added to the viewer class. That is, the viewer implements the `ActionListener` interface.

```
public class InvestmentViewer
      implements ActionListener // This approach is not recommended
{
   public InvestmentViewer()
   {
      JButton button = new JButton("Add Interest");
      button.addActionListener(this);
      . . .
   }

   public void actionPerformed(ActionEvent event)
   {
      . . .
   }
   . . .
}
```

Now the `actionPerformed` method is a part of the `InvestmentViewer` class rather than part of a separate listener class. The listener is installed as `this`.

This technique has two major flaws. First, it separates the button declaration from the button action. Also, it doesn't *scale* well. If the viewer class contains two buttons that each generate action events, then the `actionPerformed` method must investigate the event source, which leads to code that is tedious and error-prone.



Common Error 9.5

By Default, Components Have Zero Width and Height

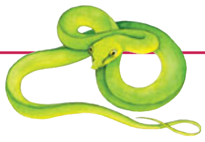
You must be careful when you add a painted component to a panel, such as a component displaying a car. You add the component in the same way as a button or label:

```
panel.add(button);
panel.add(label);
panel.add(carComponent);
```

However, the default size for a component is `0` by `0` pixels, and the car component will not be visible. The remedy is to call the `setPreferredSize` method, like this:

```
carComponent.setPreferredSize(new Dimension(CAR_COMPONENT_WIDTH, CAR_COMPONENT_HEIGHT));
```

Sections 9.10 and 9.11, available in WileyPLUS or on the companion web site, show how you can process timer and mouse events.

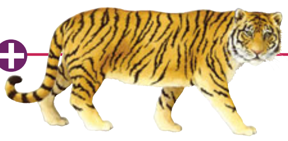


Common Error 9.6

Forgetting to Repaint

You have to be careful when your event handlers change the data in a painted component. When you make a change to the data, the component is not automatically painted with the new data. You must call the `repaint` method of the component, either in the event handler or in the component's mutator methods. Your component's `paintComponent` method will then be invoked with an appropriate `Graphics` object. Note that you should not call the `paintComponent` method directly.

This is a concern only for your own painted components. When you make a change to a standard Swing component such as a `JLabel`, the component is automatically repainted.



Special Topic 9.3

Event Adapters

Special Topic 9.3 shows how to use event adapter classes to simplify listener classes.

Random Fact 9.2

Programming Languages

Random Fact 9.2 traces the history of several common programming languages.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Summary of Learning Objectives

Use interfaces for making a service available to multiple classes.

- A Java interface type declares methods but does not provide their implementations.
- Unlike a class, an interface type provides no implementation.
- Use the `implements` reserved word to indicate that a class implements an interface type.
- Use interface types to make code more reusable.

Describe how to convert between class and interface types.

- You can convert from a class type to an interface type, provided the class implements the interface.
- You need a cast to convert from an interface type to a class type.

Describe dynamic method lookup and polymorphism.

- When the virtual machine calls an instance method, it locates the method of the implicit parameter's class. This is called dynamic method lookup.
- Polymorphism denotes the ability to treat objects with differences in behavior in a uniform way.

Describe how to use interface types for providing callbacks.

- A callback is a mechanism for specifying code that is executed at a later time.

Use inner classes to limit the scope of a utility class.

- An inner class is declared inside another class.
- Inner classes are commonly used for utility classes that should not be visible elsewhere in a program.

Use mock objects for supplying test versions of classes.

- A mock object provides the same services as another object, but in a simplified manner.
- Both the mock class and the actual class implement the same interface.

Recognize the use of events and event listeners in user-interface programming.

- User-interface events include key presses, mouse moves, button clicks, menu selections, and so on.
- An event listener belongs to a class that is provided by the application programmer. Its methods describe the actions to be taken when an event occurs.
- Event sources report on events. When an event occurs, the event source notifies all event listeners.
- Use `JButton` components for buttons. Attach an `ActionListener` to each button.

Implement event listeners as inner classes.

- Methods of an inner class can access local and instance variables from the surrounding scope.
- Local variables that are accessed by an inner class method must be declared as `final`.

Build graphical applications that use buttons.

- Use a `JPanel` container to group multiple user-interface components together.
- You specify button click actions through classes that implement the `ActionListener` interface.

Classes, Objects, and Methods Introduced in this Chapter

```
java.awt.Component
   addMouseListener
   repaint
   setPreferredSize
java.awt.Container
   add
java.awt.Dimension
java.awt.Rectangle
   setLocation
java.awt.event.ActionListener
   actionPerformed
java.awt.event.MouseEvent
   getX
   getY
java.awt.event.MouseListener
   mouseClicked
   mouseEntered
   mouseExited
   mousePressed
   mouseReleased
javax.swing.AbstractButton
   addActionListener
javax.swing.JButton
javax.swing.JLabel
javax.swing.JPanel
javax.swing.Timer
   start
   stop
```

Media Resources

www.wiley.com/ college/ horstmann

- ***Worked Example*** Investigating Number Sequences
- Lab Exercises
- ***Animation*** Polymorphism
- Practice Quiz
- Code Completion Exercises

Review Exercises

★ **R9.1** Suppose `C` is a class that implements the interfaces `I` and `J`. Which of the following assignments require a cast?

```
C c = . . .;
I i = . . .;
J j = . . .;
```

a. `c = i;`
b. `j = c;`
c. `i = j;`

★ **R9.2** Suppose `C` is a class that implements the interfaces `I` and `J`, and suppose `i` is declared as

```
I i = new C();
```

Which of the following statements will throw an exception?

a. `C c = (C) i;`
b. `J j = (J) i;`
c. `i = (I) null;`

★ **R9.3** Suppose the class `Sandwich` implements the `Edible` interface, and you are given the variable declarations

```
Sandwich sub = new Sandwich();
Rectangle cerealBox = new Rectangle(5, 10, 20, 30);
Edible e = null;
```

Which of the following assignment statements are legal?

a. `e = sub;`
b. `sub = e;`
c. `sub = (Sandwich) e;`
d. `sub = (Sandwich) cerealBox;`
e. `e = cerealBox;`
f. `e = (Edible) cerealBox;`
g. `e = (Rectangle) cerealBox;`
h. `e = (Rectangle) null;`

★★ **R9.4** How does a cast such as `(BankAccount) x` differ from a cast of number values such as `(int) x`?

★★ **R9.5** The classes `Rectangle2D.Double`, `Ellipse2D.Double`, and `Line2D.Double` implement the `Shape` interface. The `Graphics2D` class depends on the `Shape` interface but not on the rectangle, ellipse, and line classes. Draw a UML diagram denoting these facts.

★★ **R9.6** Suppose `r` contains a reference to a `new Rectangle(5, 10, 20, 30)`. Which of the following assignments is legal? (Look inside the API documentation to check which interfaces the `Rectangle` class implements.)

a. `Rectangle a = r;`
b. `Shape b = r;`
c. `String c = r;`
d. `ActionListener d = r;`
e. `Measurable e = r;`
f. `Serializable f = r;`
g. `Object g = r;`

★★ **R9.7** Classes such as `Rectangle2D.Double`, `Ellipse2D.Double` and `Line2D.Double` implement the `Shape` interface. The `Shape` interface has a method

```
Rectangle getBounds()
```

that returns a rectangle completely enclosing the shape. Consider the method call:

```
Shape s = . . .;
Rectangle r = s.getBounds();
```

Explain why this is an example of polymorphism.

★★★ **R9.8** In Java, a method call such as `x.f()` uses dynamic method lookup—the exact method to be called depends on the type of the object to which `x` refers. Give two kinds of method calls that do not look dynamic method lookup in Java.

★★ **R9.9** Suppose you need to process an array of employees to find the average and the highest salaries. Discuss what you need to do to use the implementation of the `DataSet` class in Section 9.1 (which processes `Measurable` objects). What do you need to do to use the second implementation (in Section 9.4)? Which is easier?

★★★ **R9.10** What happens if you add a `String` object to the implementation of the `DataSet` class in Section 9.1? What happens if you add a `String` object to a `DataSet` object of the implementation in Section 9.4 that uses a `RectangleMeasurer` class?

★ **R9.11** How would you reorganize the `DataSetTester3` program if you needed to make `RectangleMeasurer` into a top-level class (that is, not an inner class)?

★★ **R9.12** What is a callback? Can you think of another use for a callback for the `DataSet` class? (*Hint:* Exercise P9.12.)

★★ **R9.13** Consider this top-level and inner class. Which variables can the `f` method access?

```
public class T
{
   private int t;

   public void m(final int x, int y)
   {
      int a;
      final int b;

      class C implements I
      {
         public void f()
         {
            . . .
         }
      }

      final int c;
      . . .
   }
}
```

★★ **R9.14** What happens when an inner class tries to access a non-`final` local variable? Try it out and explain your findings.

★★★G **R9.15** How would you reorganize the `InvestmentViewer1` program if you needed to make `AddInterestListener` into a top-level class (that is, not an inner class)?

★G **R9.16** What is an event object? An event source? An event listener?

★G **R9.17** From a programmer's perspective, what is the most important difference between the user interfaces of a console application and a graphical application?

★G **R9.18** What is the difference between an `ActionEvent` and a `MouseEvent`?

★★G **R9.19** Why does the `ActionListener` interface have only one method, whereas the `MouseListener` has five methods?

★★G **R9.20** Can a class be an event source for multiple event types? If so, give an example.

★★G **R9.21** What information does an action event object carry? What additional information does a mouse event object carry?

★★★G **R9.22** Why are we using inner classes for event listeners? If Java did not have inner classes, could we still implement event listeners? How?

★★G **R9.23** What is the difference between the `paintComponent` and `repaint` methods?

★G **R9.24** What is the difference between a frame and a panel?

Programming Exercises

★ **P9.1** Have the `Die` class of Chapter 6 implement the `Measurable` interface. Generate dice, cast them, and add them to the implementation of the `DataSet` class in Section 9.1. Display the average.

★ **P9.2** Implement a class `Quiz` that implements the `Measurable` interface. A quiz has a score and a letter grade (such as `B+`). Use the implementation of the `DataSet` class in Section 9.1 to process a collection of quizzes. Display the average score and the quiz with the highest score (both letter grade and score).

★ **P9.3** A person has a name and a height in centimeters. Use the implementation of the `DataSet` class in Section 9.4 to process a collection of `Person` objects. Display the average height and the name of the tallest person.

★ **P9.4** Modify the implementation of the `DataSet` class in Section 9.1 (the one processing `Measurable` objects) to also compute the minimum data element.

★ **P9.5** Modify the implementation of the `DataSet` class in Section 9.4 (the one using a `Measurer` object) to also compute the minimum data element.

★ **P9.6** Using a different `Measurer` object, process a set of `Rectangle` objects to find the rectangle with the largest perimeter.

★★★ **P9.7** Enhance the `DataSet` class so that it can either be used with a `Measurer` object or for processing `Measurable` objects. *Hint:* Supply a constructor with no parameters that implements a `Measurer` that processes `Measurable` objects.

★ **P9.8** Modify the `display` method of the `LastDigitDistribution` class of Worked Example 9.1 so that it produces a histogram, like this:

```
0: *************
1: ******************
2: *************
```

Scale the bars so that widest one has length `40`.

★★ **P9.9** Write a class `PrimeSequence` that implements the `Sequence` interface of Worked Example 9.1, producing the sequence of prime numbers.

★ **P9.10** Add a method `hasNext` to the `Sequence` interface of Worked Example 9.1 that returns `false` if the sequence has no more values. Implement a class `MySequence` producing a sequence of real data of your choice, such as populations of cities or countries, temperatures, or stock prices. Obtain the data from the Internet and reformat the values so that they are placed into an array. Return one value at a time in the `next` method, until you reach the end of the data. Your `SequenceTester` class should display all data in the sequence and check whether the last digits are randomly distributed.

★ **P9.11** Provide a class `FirstDigitDistribution` that works just like the `LastDigitDistribution` class of Worked Example 9.1, except that it counts the distribution of the first digit of each value. (It is a well-known fact that the first digits of random values are *not* uniformly distributed. This fact has been used to detect accounting fraud, when sequences of transaction amounts had an unnatural distribution of their first digits.)

★★ **P9.12** Declare an interface `Filter` as follows:

```
public interface Filter
{
   boolean accept(Object x);
}
```

Modify the implementation of the `DataSet` class in Section 9.4 to use both a `Measurer` and a `Filter` object. Only objects that the filter accepts should be processed. Demonstrate your modification by having a data set process a collection of bank accounts, filtering out all accounts with balances less than $1,000.

★★ **P9.13** The standard Java library provides a `Comparable` interface:

```
public interface Comparable
{
   /**
      Compares this object with another.
      @param other  the object to be compared
      @return  a negative integer, zero, or a positive integer if this object
      is less than, equal to, or greater than, other
   */
   public int compareTo(Object other);
}
```

Modify the `DataSet` class of Section 9.1 to accept `Comparable` objects. With this interface, it is no longer meaningful to compute the average. The `DataSet` class should record the minimum and maximum data values. Test your modified `DataSet` class by adding a number of `String` objects. (The `String` class implements the `Comparable` interface.)

★ **P9.14** Modify the `Coin` class to have it implement the `Comparable` interface described in Exercise P9.13.

★★ **P9.15** The `System.out.printf` method has predefined formats for printing integers, floating-point numbers, and other data types. But it is also extensible. If you use the `S` format, you can print any class that implements the `Formattable` interface. That interface has a single method:

```
void formatTo(Formatter formatter, int flags, int width, int precision)
```

In this exercise, you should make the `BankAccount` class implement the `Formattable` interface. Ignore the flags and precision and simply format the bank balance, using the given width. In order to achieve this task, you need to get an `Appendable` reference like this:

```
Appendable a = formatter.out();
```

`Appendable` is another interface with a method

```
void append(CharSequence sequence)
```

`CharSequence` is yet another interface that is implemented by (among others) the `String` class. Construct a string by first converting the bank balance into a string and then padding it with spaces so that it has the desired width. Pass that string to the `append` method.

★★★ **P9.16** Enhance the `formatTo` method of Exercise P9.15 by taking into account the precision.

★T **P9.17** Consider the task of writing a program that plays TicTacToe against a human opponent. A user interface `TicTacToeUI` reads the user's moves and displays the computer's moves and the board. A class TicTacToeStrategy determines the next move that the computer makes. A class TicTacToeBoard represents the current state of the board. Complete all classes except for the strategy class. Instead, use a mock class that simply picks the first available empty square.

★★T **P9.18** Consider the task of translating a plain text book from Project Gutenberg (http://gutenberg.org) to HTML. For example, here is the start of the first chapter of Tolstoy's Anna Karenina:

```
Chapter 1

Happy families are all alike; every unhappy family is unhappy in
its own way.

Everything was in confusion in the Oblonskys' house. The wife
had discovered that the husband was carrying on an intrigue with
a French girl, who had been a governess in their family, and she
had announced to her husband that she could not go on living in
the same house with him ...
```

The equivalent HTML is:

```
<h1>Chapter 1</h1>
<p>Happy families are all alike; every unhappy family is unhappy in
its own way.</p>
<p>Everything was in confusion in the Oblonskys&rsquo; house. The wife
had discovered that the husband was carrying on an intrigue with
a French girl, who had been a governess in their family, and she
had announced to her husband that she could not go on living in
the same house with him ...</p>
```

The HTML conversion can be carried out in two steps. First, the plain text is assembled into *segments*, blocks of text of the same kind (heading, paragraph, and so on). Then each segment is converted, by surrounding it with the HTML tags and converting special characters.

Plain Text	HTML
“ ”	&ldquo; (left) *or* &rdquo; (right)
‘ ’	&lsquo; (left) *or* &rsquo; (right)
—	&emdash;
<	&lt;
>	&gt;
&	&amp;

Fetching the text from the Internet and breaking it into segments is a challenging task. Provide an interface and a mock implementation. Combine it with a class that uses the mock implementation to finish the formatting task.

★★★G **P9.19** Write a method randomShape that randomly generates objects implementing the Shape interface: some mixture of rectangles, ellipses, and lines, with random positions. Call it 10 times and draw all of them.

★G **P9.20** Enhance the `ButtonViewer` program so that it prints a message “I was clicked *n* times!” whenever the button is clicked. The value *n* should be incremented with each click.

★★G **P9.21** Enhance the `ButtonViewer` program so that it has two buttons, each of which prints a message “I was clicked *n* times!” whenever the button is clicked. Each button should have a separate click count.

★★G **P9.22** Enhance the `ButtonViewer` program so that it has two buttons labeled A and B, each of which prints a message “Button *x* was clicked!”, where *x* is A or B.

★★G **P9.23** Implement a `ButtonViewer` program as in Exercise P9.22, using only a single listener class.

★G **P9.24** Enhance the `ButtonViewer` program so that it prints the time at which the button was clicked.

★★★G **P9.25** Implement the `AddInterestListener` in the `InvestmentViewer1` program as a regular class (that is, not an inner class). *Hint:* Store a reference to the bank account. Add a constructor to the listener class that sets the reference.

★★★G **P9.26** Implement the `AddInterestListener` in the `InvestmentViewer2` program as a regular class (that is, not an inner class). *Hint:* Store references to the bank account and the label in the listener. Add a constructor to the listener class that sets the references.

★★G **P9.27** Write a program that demonstrates the growth of a roach population. Start with two roaches and double the number of roaches with each button click.

★★G **P9.28** Write a program that uses a timer to print the current time once a second. *Hint:* The following code prints the current time:

```
Date now = new Date();
System.out.println(now);
```

The `Date` class is in the `java.util` package.

★★★G **P9.29** Change the `RectangleComponent` for the animation program in Section 9.10 so that the rectangle bounces off the edges of the component rather than simply moving outside. (See `ch09/timer/` in your source code.)

★★G **P9.30** Write a program that animates a car so that it moves across a frame.

★★★G **P9.31** Write a program that animates two cars moving across a frame in opposite directions (but at different heights so that they don’t collide.)

★G **P9.32** Change the `RectangleComponent` for the mouse listener program in Section 9.11 so that a new rectangle is added to the component whenever the mouse is clicked. *Hint:* Keep an `ArrayList<Rectangle>` and draw all rectangles in the `paintComponent` method. (See `ch09/mouse/` in your source code.)

★G **P9.33** Write a program that prompts the user to enter the *x*- and *y*-positions of the center and a radius, using `JOptionPane` dialogs.When the user clicks a “Draw” button, draw a circle with that center and radius in a component.

★★G **P9.34** Write a program that allows the user to specify a circle by typing the radius in a `JOptionPane` and then clicking on the center. Note that you don’t need a “Draw” button.

★★★G **P9.35** Write a program that allows the user to specify a circle with two mouse presses, the first one on the center and the second on a point on the periphery. *Hint:* In the mouse press handler, you must keep track of whether you already received the center point in a previous mouse press.

Programming Projects

Project 9.1 Design an interface `MoveableShape` that can be used as a generic mechanism for animating a shape. A moveable shape must have two methods: `move` and `draw`. Write a generic `AnimationPanel` that paints and moves any `MoveableShape` (or array list of `MoveableShape` objects if you covered Chapter 7). Supply moveable rectangle and car shapes.

Project 9.2 Your task is to design a general program for managing board games with two players. Your program should be flexible enough to handle games such as tic-tac-toe, chess, or the Game of Nim of Project 6.2.

Design an interface `Game` that describes a board game. Think about what your program needs to do. It asks the first player to input a move—a string in a game-specific format, such as `Be3` in chess. Your program knows nothing about specific games, so the `Game` interface must have a method such as

```
boolean isValidMove(String move)
```

Once the move is found to be valid, it needs to be executed—the interface needs another method `executeMove`. Next, your program needs to check whether the game is over. If not, the other player's move is processed. You should also provide some mechanism for displaying the current state of the board.

Design the `Game` interface and provide two implementations of your choice—such as `Nim` and `Chess` (or `TicTacToe` if you are less ambitious). Your `GamePlayer` class should manage a `Game` reference without knowing which game is played, and process the moves from both players. Supply two programs that differ only in the initialization of the `Game` reference.

Answers to Self-Check Questions

1. It must implement the `Measurable` interface, and its `getMeasure` method must return the population.
2. The `Object` class doesn't have a `getMeasure` method, and the `add` method invokes the `getMeasure` method.
3. Only if `x` actually refers to a `BankAccount` object.
4. No—a `Coin` reference can be converted to a `Measurable` reference, but if you attempt to cast that reference to a `BankAccount`, an exception occurs.
5. `Measurable` is an interface. Interfaces have no instance variables and no method implementations.
6. That variable never refers to a `Measurable` object. It refers to an object of some class—a class that implements the `Measurable` interface.
7. The code fragment prints 500.05. Each call to `add` results in a call `x.getMeasure()`. In the first call, `x` is a `BankAccount`. In the second call, `x` is a `Coin`. A different `getMeasure`

method is called in each case. The first call returns the account balance, the second one the coin value.

8. The `String` class doesn't implement the `Measurable` interface.
9. Implement a class `StringMeasurer` that implements the `Measurer` interface.
10. A measurer measures an object, whereas `getMeasure` measures "itself", that is, the implicit parameter.
11. Inner classes are convenient for insignificant classes. Also, their methods can access local and instance variables from the surrounding scope.
12. Four: one for the outer class, one for the inner class, and two for the `DataSet` and `Measurer` classes.
13. You want to implement the `GradingProgram` class in terms of that interface so that it doesn't have to change when you switch between the mock class and the actual class.
14. Because the developer of `GradingProgram` doesn't have to wait for the `GradeBook` class to be complete.
15. The `button` object is the event source. The `listener` object is the event listener.
16. The `ClickListener` class implements the `ActionListener` interface.
17. Direct access is simpler than the alternative—passing the variable as a parameter to a constructor or method.
18. The local variable must be declared as `final`.
19. First add `label` to the `panel`, then add `button`.
20. The `actionPerformed` method does not access that variable.
21. The timer needs to call some method whenever the time interval expires. It calls the `actionPerformed` method of the listener object.

Chapter 10

Inheritance

CHAPTER GOALS

- To learn about inheritance
- To understand how to inherit and override superclass methods
- To be able to invoke superclass constructors
- To learn about protected and package access control
- To understand the common superclass `Object` and how to override its `toString` and `equals` methods

G To use inheritance for customizing user interfaces

In this chapter, we discuss the important concept of inheritance. Specialized classes can be created that inherit behavior from more general classes. You will learn how to implement inheritance in Java, and how to make use of the `Object` class—the most general class in the inheritance hierarchy.

CHAPTER CONTENTS

10.1 Inheritance Hierarchies 368

10.2 Implementing Subclasses 371
SYNTAX 10.1: Inheritance 372
COMMON ERROR 10.1: Confusing Super- and Subclasses 373
COMMON ERROR 10.2: Shadowing Instance Variables 374

10.3 Overriding Methods 375
SYNTAX 10.2: Calling a Superclass Method 376
COMMON ERROR 10.3: Accidental Overloading 377
COMMON ERROR 10.4: Failing to Invoke the Superclass Method 378

10.4 Subclass Construction 378
SYNTAX 10.3: Calling a Superclass Constructor 379

10.5 Converting Between Subclass and Superclass Types 381
SYNTAX 10.4: The `instanceof` Operator 382

10.6 Polymorphism and Inheritance 383
SPECIAL TOPIC 10.1: Abstract Classes ⊕
SPECIAL TOPIC 10.2: Final Methods and Classes ⊕
COMMON ERROR 10.5: Overriding Methods to Be Less Accessible 385
SPECIAL TOPIC 10.3: Protected Access ⊕
HOW TO 10.1: Developing an Inheritance Hierarchy 386
WORKED EXAMPLE 10.1: Implementing an Employee Hierarchy for Payroll Processing ⊕

10.7 `Object`: The Cosmic Superclass 391
QUALITY TIP 10.1: Supply `toString` in All Classes 395
SPECIAL TOPIC 10.4: Inheritance and the `toString` Method ⊕
COMMON ERROR 10.6: Declaring the `equals` Method with the Wrong Parameter Type 395
SPECIAL TOPIC 10.5: Inheritance and the `equals` Method ⊕
QUALITY TIP 10.2: Clone Mutable Instance Variables in Accessor Methods ⊕
SPECIAL TOPIC 10.6: Implementing the `clone` Method ⊕
SPECIAL TOPIC 10.7: Enumeration Types Revisited ⊕
RANDOM FACT 10.1: Scripting Languages ⊕

10.8G Using Inheritance to Customize Frames 397
SPECIAL TOPIC 10.8: Adding the `main` Method to the Frame Class 398

10.1 Inheritance Hierarchies

In the real world, you often categorize concepts into *hierarchies.* Hierarchies are frequently represented as trees, with the most general concepts at the root of the hierarchy and more specialized ones towards the branches. Figure 1 shows a typical example.

Sets of classes can form complex inheritance hierarchies.

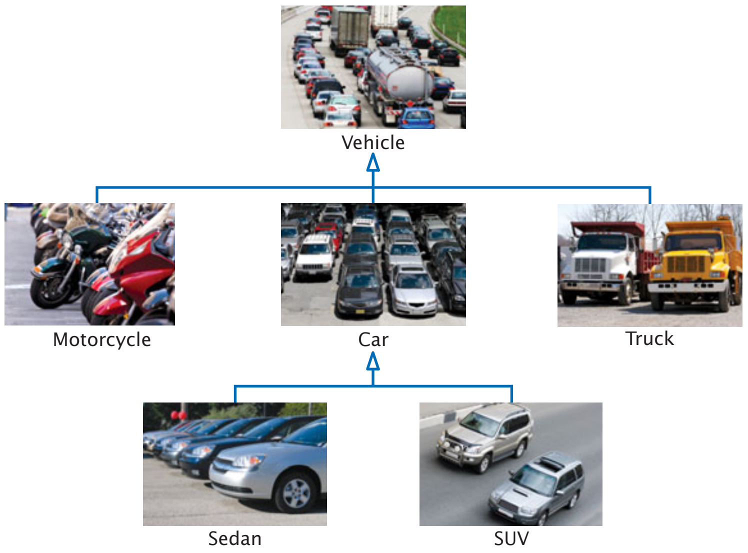
In Java it is equally common to group classes in *inheritance hierarchies*. The classes representing the most general concepts are near the root, more specialized classes towards the branches. For example, Figure 2 shows part of the hierarchy of Swing user-interface components in Java.

We must introduce some more terminology for expressing the relationship between the classes in an inheritance hierarchy. The more general class is called the **superclass**. The more specialized class that inherits from the superclass is called the **subclass**. In our example, `JPanel` is a subclass of `JComponent`.

Figure 2 uses the UML notation for inheritance. In a class diagram, you denote inheritance by a solid arrow with a “hollow triangle” tip that points to the superclass.

When designing a hierarchy of classes, you ask yourself which features and behaviors are common to all the classes that you are designing. Those common properties are placed in a superclass. For example, all user-interface components have a width and height, and the `getWidth` and `getHeight` methods of the `JComponent`

Figure 1
A Hierarchy of Vehicle Types



class return the component's dimensions. More specialized properties can be found in subclasses. For example, buttons can have text and icon labels. The class `AbstractButton`, but not the superclass `JComponent`, has methods to set and get the button text and icon, and instance variables to store them. The individual button classes (such

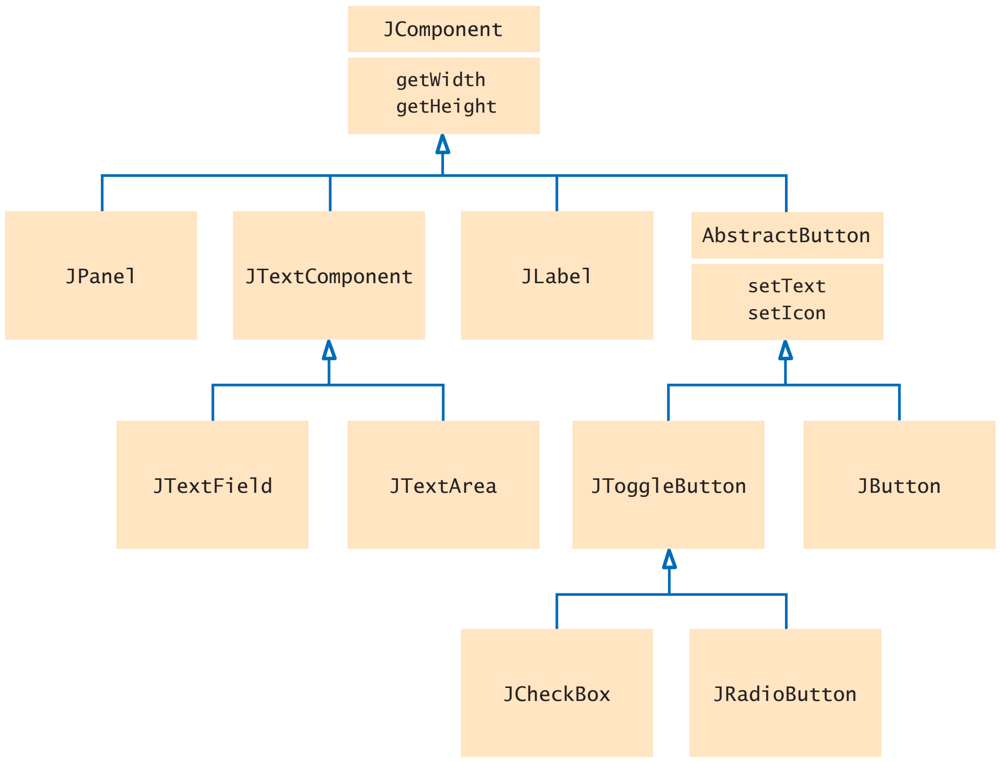


Figure 2 A Part of the Hierarchy of Swing User-interface Components

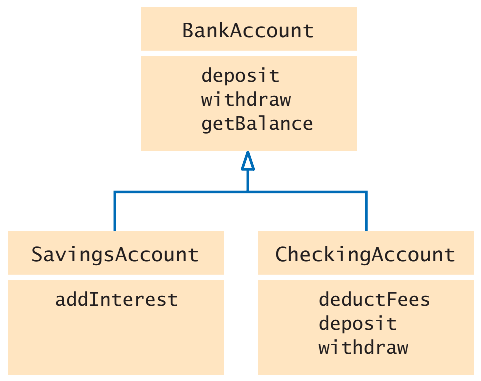


Figure 3 Inheritance Hierarchy for Bank Account Classes

as JButton, JRadioButton, and JCheckBox) inherit these properties. In fact, the AbstractButton class was created to express the commonality among these buttons.

We will use a simpler example of a hierarchy in our study of inheritance concepts. Consider a bank that offers its customers the following account types:

1. The checking account has no interest, gives you a small number of free transactions per month, and charges a transaction fee for each additional transaction.
2. The savings account earns interest that compounds monthly. (In our implementation, the interest is compounded using the balance of the last day of the month, which is somewhat unrealistic. Typically, banks use either the average or the minimum daily balance. Exercise P10.1 asks you to implement this enhancement.)

Figure 3 shows the inheritance hierarchy. Exercise P10.2 asks you to add another class to this hierarchy.

Next, let us determine the behavior of these classes. All bank accounts support the getBalance method, which simply reports the current balance. They also support the deposit and withdraw methods, although the details of the implementation differ. For example, a checking account must keep track of the number of transactions to account for the transaction fees.

The checking account needs a method deductFees to deduct the monthly fees and to reset the transaction counter. The deposit and withdraw methods must be overridden to count the transactions.

The savings account needs a method addInterest to add interest.

To summarize: The subclasses support all methods from the superclass, but their implementations may be modified to match the specialized purposes of the subclasses. In addition, subclasses are free to introduce additional methods.

SELF CHECK

1. What is the purpose of the JTextComponent class in Figure 2?
2. Why don't we place the addInterest method in the BankAccount class?

10.2 Implementing Subclasses

Inheritance is a mechanism for extending existing classes by adding instance variables and methods.

In this section, we begin building the inheritance hierarchy of bank account classes. You will learn how to form a subclass from a given superclass. Let's start with the `SavingsAccount` class. Here is the syntax for the class declaration:

```
public class SavingsAccount extends BankAccount
{
   added instance variables
   new methods
}
```

A subclass inherits the methods of its superclass.

In the `SavingsAccount` class declaration you specify only new methods and instance variables. The `SavingsAccount` class *automatically inherits* the methods of the `BankAccount` class. For example, the `deposit` method automatically applies to savings accounts:

```
SavingsAccount collegeFund = new SavingsAccount(10);
   // Savings account with 10% interest
collegeFund.deposit(500);
   // OK to use BankAccount method with SavingsAccount object
```

Let's see how savings account objects are different from `BankAccount` objects. We will set an interest rate in the constructor, and we need a method to apply that interest periodically. That is, in addition to the three methods that can be applied to every account, there is an additional method `addInterest`. The new method and instance variable must be declared in the subclass.

```
public class SavingsAccount extends BankAccount
{
   private double interestRate;

   public SavingsAccount(double rate)
   {
      Constructor implementation
   }

   public void addInterest()
   {
      Method implementation
   }
}
```

The instance variables declared in the superclass are present in subclass objects.

A subclass object automatically has the instance variables declared in the superclass. For example, a `SavingsAccount` object has an instance variable `balance` that was declared in the `BankAccount` class.

Any new instance variables that you declare in the subclass are present only in subclass objects. For example, every `SavingsAccount` object has an instance variable `interestRate`. Figure 4 shows the layout of a `SavingsAccount` object.

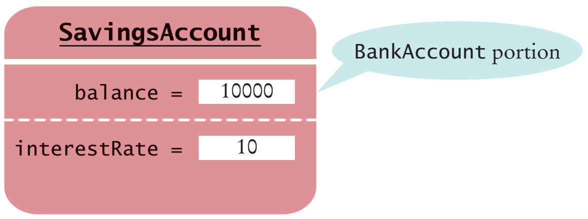


Figure 4 Layout of a Subclass Object

Syntax 10.1 Inheritance

Syntax

```
class SubclassName extends SuperclassName
{
   instance variables
   methods
}
```

Example

```
public class SavingsAccount extends BankAccount
{
   private double interestRate;
   . . .

   public void addInterest()
   {
      double interest = getBalance() * interestRate / 100;
      deposit(interest);
   }
}
```

Subclass

Superclass

Declare instance variables that are added to the subclass.

The reserved word extends denotes inheritance.

Declare methods that are specific to the subclass.

Next, you need to implement the new addInterest method. The method computes the interest due on the current balance and deposits that interest to the account.

```
public class SavingsAccount extends BankAccount
{
   private double interestRate;

   public SavingsAccount(double rate)
   {
      interestRate = rate;
   }

   public void addInterest()
   {
      double interest = getBalance() * interestRate / 100;
      deposit(interest);
   }
}
```

A subclass has no access to private instance variables of its superclass.

The addInterest method calls the getBalance and deposit methods rather than directly updating the balance variable of the superclass. This is a consequence of **encapsulation**. The balance variable was declared as private in the BankAccount class. The addInterest method is declared in the SavingsAccount class. It does not have the right to access a private instance variable of another class.

Note how the addInterest method calls the inherited getBalance and deposit methods without specifying an implicit parameter. This means that the calls apply to the implicit parameter of the addInterest method.

In other words, the statements in the addInterest method are a shorthand for the following statements:

```
double interest = this.getBalance() * this.interestRate / 100;
this.deposit(interest);
```

This completes the implementation of the SavingsAccount class. You will find the complete source code below.

Inheriting from a class differs from implementing an interface: The subclass inherits behavior from the superclass.

You may wonder at this point in what way inheritance differs from implementing an interface. An interface is not a class. It has *no behavior*. It merely tells you which methods you should implement. A superclass has specific behavior that the subclasses inherit.

ch10/accounts/SavingsAccount.java

```java
/**
   An account that earns interest at a fixed rate.
*/
public class SavingsAccount extends BankAccount
{
   private double interestRate;

   /**
      Constructs a bank account with a given interest rate.
      @param rate the interest rate
   */
   public SavingsAccount(double rate)
   {
      interestRate = rate;
   }

   /**
      Adds the earned interest to the account balance.
   */
   public void addInterest()
   {
      double interest = getBalance() * interestRate / 100;
      deposit(interest);
   }
}
```

SELF CHECK

3. Which instance variables does an object of class SavingsAccount have?
4. Name four methods that you can apply to SavingsAccount objects.
5. If the class Manager extends the class Employee, which class is the superclass and which is the subclass?

Common Error 10.1

Confusing Super- and Subclasses

If you compare an object of type SavingsAccount with an object of type BankAccount, then you find that

- The reserved word extends suggests that the SavingsAccount object is an extended version of a BankAccount.
- The SavingsAccount object is larger; it has an added instance variable interestRate.
- The SavingsAccount object is more capable; it has an addInterest method.

It seems a superior object in every way. So why is SavingsAccount called the *subclass* and BankAccount the *superclass*?

The *super/sub* terminology comes from set theory. Look at the set of all bank accounts. Not all of them are `SavingsAccount` objects; some of them are other kinds of bank accounts. Therefore, the set of `SavingsAccount` objects is a *subset* of the set of all `BankAccount` objects, and the set of `BankAccount` objects is a *superset* of the set of `SavingsAccount` objects. The more specialized objects in the subset have a richer state and more capabilities.

Common Error 10.2

Shadowing Instance Variables

A subclass has no access to the private instance variables of the superclass. For example, the methods of the `SavingsAccount` class cannot access the `balance` instance variable:

```
public class SavingsAccount extends BankAccount
{
   public void addInterest()
   {
      double interest = getBalance() * interestRate / 100;
      balance = balance + interest; // Error
   }
   . . .
}
```

It is a common beginner's error to "solve" this problem by adding *another* instance variable with the same name.

```
public class SavingsAccount extends BankAccount
{
   private double balance; // Don't
   . . .
   public void addInterest()
   {
      double interest = getBalance() * interestRate / 100;
      balance = balance + interest; // Compiles but doesn't update the correct balance
   }
}
```

Sure, now the `addInterest` method compiles, but it doesn't update the correct balance! Such a `SavingsAccount` object has two instance variables, both named `balance` (see Figure 5). The `getBalance` method of the superclass retrieves one of them, and the `addInterest` method of the subclass updates the other.

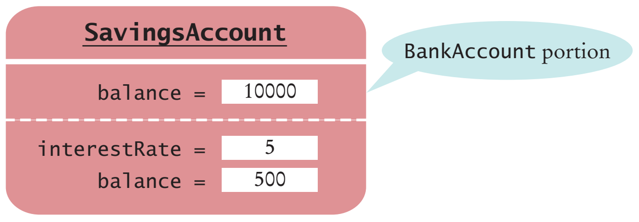


Figure 5 Shadowing Instance Variables

10.3 Overriding Methods

A subclass can inherit a superclass method or override it by providing another implementation.

A subclass method **overrides** a superclass method if it has the same name and parameter types as a superclass method. When such a method is applied to a subclass object, the overriding method, and not the original method, is executed.

We turn to the CheckingAccount class for an example of overriding methods. Recall that the BankAccount class has three methods:

```
public class BankAccount
{
   . . .
   public void deposit(double amount) { . . . }
   public void withdraw(double amount) { . . . }
   public double getBalance() { . . . }
}
```

The CheckingAccount class declares these methods:

```
public class CheckingAccount extends BankAccount
{
   . . .
   public void deposit(double amount) { . . . }
   public void withdraw(double amount) { . . . }
   public void deductFees() { . . . }
}
```

These methods override BankAccount methods.

The deposit and withdraw methods of the CheckingAccount class override the deposit and withdraw methods of the BankAccount class to handle transaction fees. However, the deductFees method does not override another method, and the getBalance method is not overridden.

Let's implement the deposit method of the CheckingAccount class. It increments the transaction count and deposits the money:

```
public class CheckingAccount extends BankAccount
{
   . . .
   public void deposit(double amount)
   {
      transactionCount++;
      // Now add amount to balance
      . . .
   }
}
```

Now we have a problem. We can't simply add amount to balance:

```
public class CheckingAccount extends BankAccount
{
   . . .
   public void deposit(double amount)
   {
      transactionCount++;
      // Now add amount to balance
      balance = balance + amount; // Error
   }
}
```

Although every CheckingAccount object has a balance instance variable, that instance variable is *private* to the superclass BankAccount. Subclass methods have no more

Syntax 10.2 Calling a Superclass Method

Syntax `super.methodName(parameters);`

Example

```
public void deposit(double amount)
{
   transactionCount++;
   super.deposit(amount);
}
```

Calls the method of the superclass instead of the method of the current class.

If you omit super, this method calls itself. See page 378.

access rights to the private data of the superclass than any other methods. If you want to modify a private superclass instance variable, you must use a public method of the superclass.

How can we add the deposit amount to the balance, using the public interface of the `BankAccount` class? There is a perfectly good method for that purpose—namely, the `deposit` method of the `BankAccount` class. So we must invoke the `deposit` method on some object. On which object? The checking account into which the money is deposited—that is, the implicit parameter of the `deposit` method of the `CheckingAccount` class. To invoke another method on the implicit parameter, you don't specify the parameter but simply write the method name, like this:

```
public class CheckingAccount extends BankAccount
{
   public void deposit(double amount)
   {
      transactionCount++;
      // Now add amount to balance
      deposit(amount); // Not complete
   }
   . . .
}
```

But this won't quite work. The compiler interprets

```
deposit(amount);
```

as

```
this.deposit(amount);
```

The `this` parameter is of type `CheckingAccount`. There is a method called `deposit` in the `CheckingAccount` class. Therefore, that method will be called—but that is just the method we are currently writing! The method will call itself over and over, and the program will die in an infinite recursion (discussed in Chapter 13).

Use the super reserved word to call a method of the superclass.

Instead, we must be specific that we want to invoke only the *superclass's* `deposit` method. There is a special reserved word `super` for this purpose:

```
public class CheckingAccount extends BankAccount
{
   public void deposit(double amount)
   {
      transactionCount++;
      // Now add amount to balance
      super.deposit(amount);
   }
   . . .
}
```

ANIMATION
Inheritance

This version of the deposit method is correct. To deposit money into a checking account, update the transaction count and call the deposit method of the superclass.

The remaining methods of the CheckingAccount class also invoke a superclass method.

```
public class CheckingAccount extends BankAccount
{
   private static final int FREE_TRANSACTIONS = 3;
   private static final double TRANSACTION_FEE = 2.0;

   private int transactionCount;
   . . .
   public void withdraw(double amount)
   {
      transactionCount++;
      // Now subtract amount from balance
      super.withdraw(amount);
   }

   public void deductFees()
   {
      if (transactionCount > FREE_TRANSACTIONS)
      {
         double fees = TRANSACTION_FEE * (transactionCount - FREE_TRANSACTIONS);
         super.withdraw(fees);
      }
      transactionCount = 0;
   }
   . . .
}
```

SELF CHECK

6. Categorize the methods of the SavingsAccount class as inherited, new, and overridden.
7. Why does the withdraw method of the CheckingAccount class call super.withdraw?
8. Why does the deductFees method set the transaction count to zero?

Common Error 10.3

Accidental Overloading

Recall from Section 2.4 that two methods can have the same name, provided they have *different* method parameters. For example, the PrintStream class has methods called println with headers

```
void println(int x)
```

and

```
void println(String x)
```

These are different methods, each with its own implementation. The Java compiler considers them to be completely unrelated. We say that the `println` name is **overloaded**. This is different from overriding, where a subclass method provides an implementation of a method with the *same* method parameters.

If you mean to override a method but supply a different parameter type, then you accidentally introduce an overloaded method. For example,

```
public class CheckingAccount extends BankAccount
{
   . . .
   public void deposit(int amount) // Error: should be double
   {
      . . .
   }
}
```

The compiler will not complain. It thinks that you want to provide a `deposit` method just for `int` parameters, while inheriting another `deposit` method for `double` parameters.

When overriding a method, be sure to check that the parameter types match exactly.

Common Error 10.4

Failing to Invoke the Superclass Method

A common error in extending the functionality of a superclass method is to forget the `super` qualifier. For example, to withdraw money from a checking account, update the transaction count and then withdraw the amount:

```
public void withdraw(double amount)
{
   transactionCount++;
   withdraw(amount);
   // Error—should be super.withdraw(amount)
}
```

Here `withdraw(amount)` refers to the `withdraw` method applied to the implicit parameter of the method. The implicit parameter is of type `CheckingAccount`, and the `CheckingAccount` class has a `withdraw` method, so that method is called. Of course, that calls the current method all over again, which will call itself yet again, over and over, until the program runs out of memory. Instead, you must precisely identify which `withdraw` method you want to call.

Another common error is to forget to call the superclass method altogether. Then the functionality of the superclass mysteriously vanishes.

10.4 Subclass Construction

In this section, we discuss the implementation of constructors in subclasses. As an example, let's declare a constructor to set the initial balance of a checking account.

We want to invoke the `BankAccount` constructor to set the balance to the initial balance. There is a special instruction to call the superclass constructor from a subclass constructor. You use the reserved word super, followed by the construction parameters in parentheses:

```
public class CheckingAccount extends BankAccount
{
   public CheckingAccount(double initialBalance)
   {
      // Construct superclass
      super(initialBalance);
      // Initialize transaction count
      transactionCount = 0;
   }
   . . .
}
```

To call the superclass constructor, you use the super reserved word in the first statement of the subclass constructor.

When the reserved word super is immediately followed by a parenthesis, it indicates a call to the superclass constructor. When used in this way, the constructor call must be *the first statement of the subclass constructor*. If super is followed by a period and a method name, on the other hand, it indicates a call to a superclass method, as you saw in the preceding section. Such a call can be made anywhere in any subclass method.

The dual use of the super reserved word is analogous to the dual use of the this reserved word (see Special Topic 3.1).

If a subclass constructor does not call the superclass constructor, the superclass must have a constructor without parameters. That constructor is used to initialize the superclass data. However, if all constructors of the superclass require parameters, then the compiler reports an error.

For example, you can implement the CheckingAccount constructor without calling the superclass constructor. Then the BankAccount class is constructed with its BankAccount() constructor, which sets the balance to zero. Of course, then the CheckingAccount constructor must explicitly deposit the initial balance.

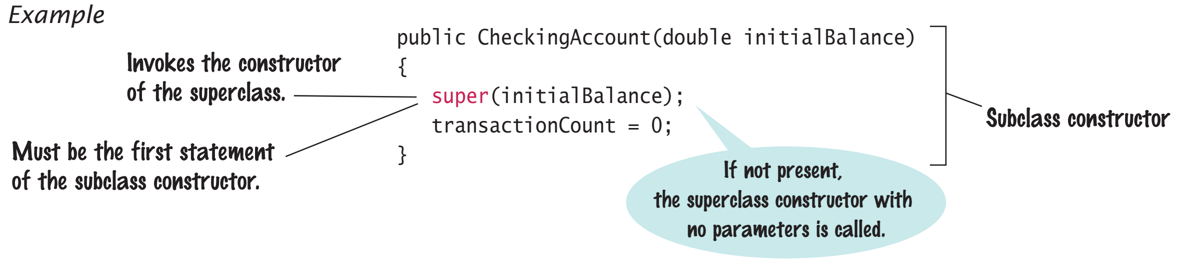
Most commonly, however, subclass constructors have some parameters that they pass on to the superclass and others that they use to initialize subclass instance variables.

Syntax 10.3 Calling a Superclass Constructor

Syntax

```
accessSpecifier ClassName(parameterType parameterName, . . .)
{
   super(parameters);
   . . .
}
```

Example



```
public CheckingAccount(double initialBalance)
{
   super(initialBalance);
   transactionCount = 0;
}
```

Invokes the constructor of the superclass.
Must be the first statement of the subclass constructor.
Subclass constructor
If not present, the superclass constructor with no parameters is called.

ch10/accounts/CheckingAccount.java

```java
/**
   A checking account that charges transaction fees.
*/
public class CheckingAccount extends BankAccount
{
   private static final int FREE_TRANSACTIONS = 3;
   private static final double TRANSACTION_FEE = 2.0;

   private int transactionCount;

   /**
      Constructs a checking account with a given balance.
      @param initialBalance the initial balance
   */
   public CheckingAccount(double initialBalance)
   {
      // Construct superclass
      super(initialBalance);

      // Initialize transaction count
      transactionCount = 0;
   }

   public void deposit(double amount)
   {
      transactionCount++;
      // Now add amount to balance
      super.deposit(amount);
   }

   public void withdraw(double amount)
   {
      transactionCount++;
      // Now subtract amount from balance
      super.withdraw(amount);
   }

   /**
      Deducts the accumulated fees and resets the
      transaction count.
   */
   public void deductFees()
   {
      if (transactionCount > FREE_TRANSACTIONS)
      {
         double fees = TRANSACTION_FEE *
               (transactionCount - FREE_TRANSACTIONS);
         super.withdraw(fees);
      }
      transactionCount = 0;
   }
}
```

SELF CHECK

9. Why didn't the `SavingsAccount` constructor in Section 10.2 call its superclass constructor?

10. When you invoke a superclass method with the `super` reserved word, does the call have to be the first statement of the subclass method?

10.5 Converting Between Subclass and Superclass Types

It is often necessary to convert a subclass type to a superclass type. Occasionally, you need to carry out the conversion in the opposite direction. This section discusses the conversion rules.

Subclass references can be converted to superclass references.

The class `SavingsAccount` extends the class `BankAccount`. In other words, a `SavingsAccount` object is a special case of a `BankAccount` object. Therefore, a reference to a `SavingsAccount` object can be converted to a `BankAccount` reference.

```
SavingsAccount collegeFund = new SavingsAccount(10);
BankAccount anAccount = collegeFund; // OK
```

Furthermore, all references can be converted to the type `Object`.

```
Object anObject = collegeFund; // OK
```

Now the three object references stored in `collegeFund`, `anAccount`, and `anObject` all refer to the same object of type `SavingsAccount` (see Figure 6).

However, the variables `anAccount` and `anObject` know less than the full story about the object references that they store. Because `anAccount` is a variable of type `BankAccount`, you can invoke the `deposit` and `withdraw` methods. You cannot use the `addInterest` method, though—it is not a method of the `BankAccount` class:

```
anAccount.deposit(1000); // OK
anAccount.addInterest(); // No—not a method of the type of the anAccount variable
```

And, of course, the variable `anObject` knows even less. You can't even invoke the `deposit` method on it—`deposit` is not a method of the `Object` class.

Why would anyone *want* to know less about an object reference and use a variable whose type is a superclass? This can happen if you want to *reuse code* that knows about the superclass but not the subclass. Here is a typical example. Consider a `transfer` method that transfers money from one account to another:

```
public void transfer(double amount, BankAccount other)
{
   withdraw(amount);
   other.deposit(amount);
}
```

You can use this method to transfer money from one bank account to another:

```
BankAccount momsAccount = . . . ;
BankAccount harrysAccount = . . . ;
momsAccount.transfer(1000, harrysAccount);
```

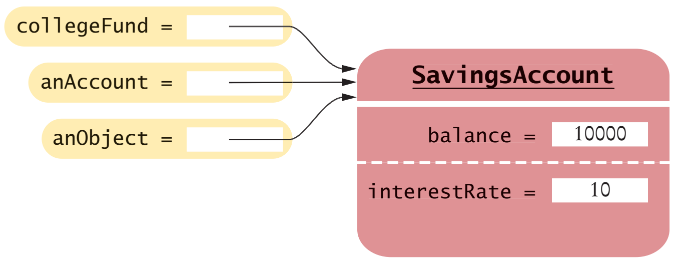


Figure 6 Variables of Different Types Can Refer to the Same Object

You can *also* use the method to transfer money into a CheckingAccount:

```
CheckingAccount harrysChecking = . . . ;
momsAccount.transfer(1000, harrysChecking);
   // OK to pass a CheckingAccount reference to a method expecting a BankAccount
```

The transfer method expects a reference to a BankAccount, and it gets a reference to a CheckingAccount object. That is perfectly legal. The transfer method doesn't actually know that, in this case, the parameter variable other contains a reference to a CheckingAccount object. All it cares about is that the object can carry out the deposit method. This is assured because the other variable has the type BankAccount.

Very occasionally, you need to carry out the opposite conversion, from a superclass type to a subclass type. For example, you may have a variable of type Object, and you know that it actually holds a BankAccount reference. In that case, you can use a cast to convert the type:

```
BankAccount anAccount = (BankAccount) anObject;
```

However, this cast is somewhat dangerous. If you are wrong, and anObject actually refers to an object of an unrelated type, then an exception is thrown.

The instanceof operator tests whether an object belongs to a particular type.

To protect against bad casts, you can use the instanceof operator. It tests whether an object belongs to a particular type. For example,

```
anObject instanceof BankAccount
```

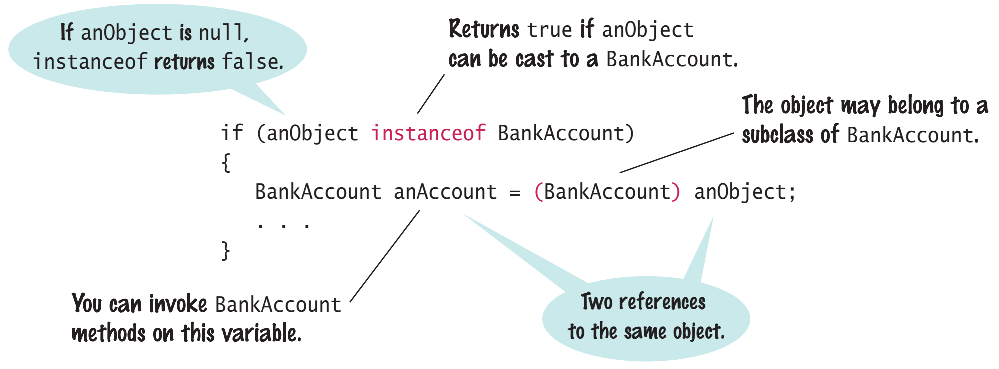
returns true if the type of anObject is convertible to BankAccount. This happens if anObject refers to an actual BankAccount or a subclass such as SavingsAccount. Using the instanceof operator, a safe cast can be programmed as follows:

```
if (anObject instanceof BankAccount)
{
   BankAccount anAccount = (BankAccount) anObject;
   . . .
}
```

Syntax 10.4 The instanceof Operator

Syntax *object* instanceof *TypeName*

Example



```
if (anObject instanceof BankAccount)
{
   BankAccount anAccount = (BankAccount) anObject;
   . . .
}
```

If anObject is null, instanceof returns false.
Returns true if anObject can be cast to a BankAccount.
The object may belong to a subclass of BankAccount.
You can invoke BankAccount methods on this variable.
Two references to the same object.

SELF CHECK

11. Why did the second parameter of the `transfer` method have to be of type `BankAccount` and not, for example, `SavingsAccount`?

12. Why can't we change the second parameter of the `transfer` method to the type `Object`?

10.6 Polymorphism and Inheritance

In Java, the type of a variable does not determine the type of the object to which it refers. For example, a variable of type `BankAccount` can hold a reference to a `BankAccount` object or to a subclass object such as `SavingsAccount`. You already encountered this phenomenon in Chapter 9 with variables whose type was an interface. A variable whose type is `Measurable` holds a reference to an object of a class that implements the `Measurable` interface, perhaps a `Coin` object or an object of an entirely different class.

What happens when you invoke a method on a variable of type `BankAccount`? For example,

```
BankAccount anAccount = new CheckingAccount();
anAccount.deposit(1000);
```

Which deposit method is called? The `anAccount` variable has type `BankAccount`, so it would appear as if `BankAccount.deposit` is called. On the other hand, the `CheckingAccount` class provides its own `deposit` method that updates the transaction count. The reference stored in the `anAccount` variable actually refers to an object of the subclass `CheckingAccount`, so it would be appropriate if the `CheckingAccount.deposit` method were called instead.

When the virtual machine calls an instance method, it locates the method of the implicit parameter's class. This is called dynamic method lookup.

Java uses *dynamic method lookup* to determine which method to invoke. The method to be called is always determined by the type of the actual object, not the type of the variable. That is, if the actual object has the type `CheckingAccount`, then the `CheckingAccount.deposit` method is called. It does not matter that the object reference is stored in a variable of type `BankAccount`.

Have another look at the `transfer` method:

```
public void transfer(double amount, BankAccount other)
{
   withdraw(amount);
   other.deposit(amount);
}
```

Suppose you call

```
anAccount.transfer(1000, anotherAccount);
```

Two method calls are the result:

```
anAccount.withdraw(1000);
anotherAccount.deposit(1000);
```

Depending on the actual types of the objects whose references are stored in anAccount and `anotherAccount`, different versions of the `withdraw` and `deposit` methods are called. This is an example of *polymorphism*. As we discussed in Chapter 9, polymorphism is the ability to treat objects with differences in behavior in a uniform way.

If you look into the implementation of the `transfer` method, it may not be immediately obvious that the first method call

```
withdraw(amount);
```

depends on the type of an object. However, that call is a shortcut for

```
this.withdraw(amount);
```

The `this` parameter holds a reference to the implicit parameter, which can refer to a `BankAccount` or a subclass object.

The following program calls the polymorphic `withdraw` and `deposit` methods. You should manually calculate what the program should print for each account balance, and confirm that the correct methods have in fact been called.

ch10/accounts/AccountTester.java

```java
/**
   This program tests the BankAccount class and
   its subclasses.
*/
public class AccountTester
{
   public static void main(String[] args)
   {
      SavingsAccount momsSavings = new SavingsAccount(0.5);

      CheckingAccount harrysChecking = new CheckingAccount(100);

      momsSavings.deposit(10000);

      momsSavings.transfer(2000, harrysChecking);
      harrysChecking.withdraw(1500);
      harrysChecking.withdraw(80);

      momsSavings.transfer(1000, harrysChecking);
      harrysChecking.withdraw(400);

      // Simulate end of month
      momsSavings.addInterest();
      harrysChecking.deductFees();

      System.out.println("Mom's savings balance: "
            + momsSavings.getBalance());
      System.out.println("Expected: 7035");

      System.out.println("Harry's checking balance: "
            + harrysChecking.getBalance());
      System.out.println("Expected: 1116");
   }
}
```

Program Run

```
Mom's savings balance: 7035.0
Expected: 7035
Harry's checking balance: 1116.0
Expected: 1116
```

SELF CHECK

13. If `a` is a variable of type `BankAccount` that holds a non-`null` reference, what do you know about the object to which `a` refers?

14. If `a` refers to a checking account, what is the effect of calling `a.transfer(1000, a)`?

Special Topic 10.1

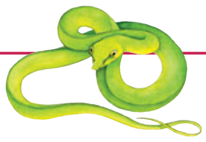
Abstract Classes

Special Topic 10.1 introduces the concept of abstract classes and methods. An abstract method has no implementation. (All methods of an interface are automatically abstract.) You cannot construct objects of abstract classes, typically because the class has one or more abstract methods. However, abstract classes differ from interfaces in an important way—they can have instance variables, and they can have concrete methods and constructors.

Special Topic 10.2

Final Methods and Classes

Special Topic 10.2 discusses final methods and classes. A final method cannot be overridden in a subclass. A final class cannot be subclassed.



Common Error 10.5

Overriding Methods to Be Less Accessible

If a superclass declares a method to be publicly accessible, you cannot override it to be more private. For example,

```
public class BankAccount
{
   public void withdraw(double amount) { . . . }
   . . .
}

public class CheckingAccount extends BankAccount
{
   private void withdraw(double amount) { . . . }
      // Error—subclass method cannot be more private
   . . .
}
```

The compiler does not allow this, because the increased privacy would conflict with polymorphism. Suppose the `AccountTester` class has this method call:

```
BankAccount account = new CheckingAccount();
account.withdraw(100000); // Should CheckingAccount.withdraw be called?
```

Polymorphism dictates that `CheckingAccount.withdraw` should be called, but that is a private method that should not be accessible in `AccountTester`.

Therefore, the compiler reports an error if you override a public method and make it private or give it package access. The latter is a common oversight. If you forget the `public` modifier, your subclass method has package access, which is more restrictive. Simply restore the `public` modifier, and the error will go away.

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Special Topic 10.3

Protected Access

Special Topic 10.3 covers the `protected` access specifier. A protected instance variable or method can be accessed by all subclasses and by all classes in the same package.

How To 10.1 Developing an Inheritance Hierarchy

When you work with a set of classes, some of which are more general and others more specialized, you want to organize them into an inheritance hierarchy. This enables you to process objects of different classes in a uniform way.

To illustrate the design process, consider an application that presents a quiz and grades the user's responses. A quiz consists of questions, and there are different kinds of questions:

- Fill-in-the-blank
- Choice (single or multiple)
- Numeric (where an approximate answer is ok; e.g., 1.33 when the actual answer is 4/3)
- Free response

Step 1 List the classes that are part of the hierarchy.

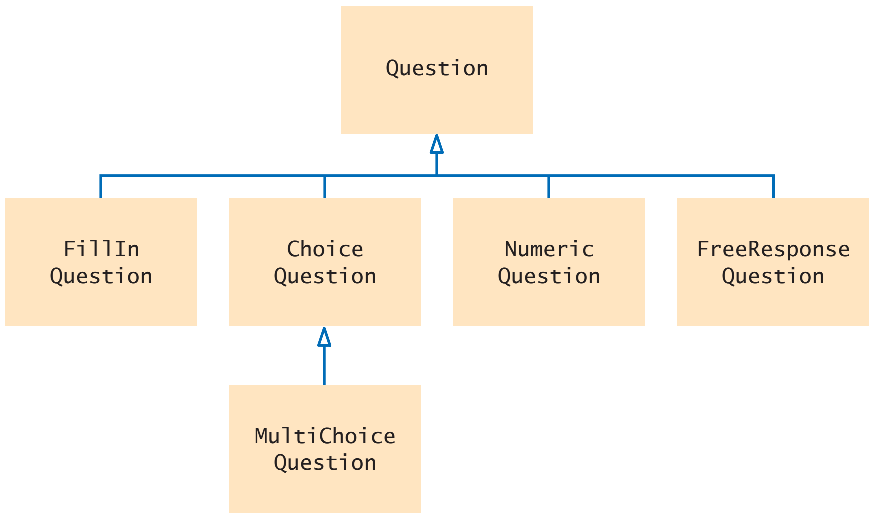
From the problem description, we can find these classes:

`FillInQuestion` (fill in the blank)
`ChoiceQuestion` (offers answer choices to the user)
`MultiChoiceQuestion` (offers answer choices to the user; user can pick more than one)
`NumericQuestion`
`FreeResponseQuestion`

In addition, we introduce a common superclass `Question` to model the commonality among these classes.

Step 2 Organize the classes into an inheritance hierarchy.

Draw a UML diagram that shows super- and subclasses. Here is the diagram for our example.



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Step 3 Determine the common responsibilities.

In Step 2, you will have identified a class at the root of the hierarchy. That class needs to have sufficient responsibilities to carry out the tasks at hand.

To find out what those tasks are, write pseudocode for processing the objects.

```
For each question
   Display the question to the user.
   Get the user response.
   Check whether the response is correct.
```

From the pseudocode, we obtain the following list of common responsibilities that every question must carry out:

```
Display the question.
Check the response.
```

Step 4 Decide which methods are overridden in subclasses.

For each subclass and each of the common responsibilities, decide whether the inherited behavior is appropriate or whether it needs to be overridden. Be sure to declare any methods that are inherited or overridden in the root of the hierarchy.

We place the responsibilities common to all questions into the `Question` superclass.

```
public class Question
{
   . . .
   /**
      Displays this question.
   */
   public void display() { . . . }

   /**
      Checks a given response for correctness.
      @param response the response to check
      @return true if the response was correct, false otherwise
   */
   public boolean checkAnswer(String response) { . . . }
}
```

The `ChoiceQuestion` class will need to override the `display` method to display all the choices. The `NumericQuestion` class will need to override the `checkAnswer` method, converting the response to a number and checking that it is approximately the same as the expected answer.

From now on, we will only consider the `ChoiceQuestion` in detail. For the other question types, see the programming exercises at the end of this chapter.

Step 5 Define the public interface of each subclass.

Typically, subclasses have responsibilities other than those of the superclass. List those, as well as the methods that need to be overridden. You also need to specify how the objects of the subclasses should be constructed.

With the `ChoiceQuestion`, we need a way of adding choices, like this:

```
ChoiceQuestion question = new ChoiceQuestion(
   "In which country was the inventor of Java born?");
question.addChoice("Australia", false);
question.addChoice("Canada", true);
question.addChoice("Denmark", false);
question.addChoice("United States", false);
```

We then override the `display` method to display those choices in the form

```
1: Australia
2: Canada
3: Denmark
4: United States
```

Here are the methods that we just discovered for the `ChoiceQuestion` class:

```
public class ChoiceQuestion extends Question
{
   . . .
   /**
      Adds an answer choice to this question.
      @param choice the choice to add
      @param correct true if this is the correct choice, false otherwise
   */
   public void addChoice(String choice, boolean correct)

   public void display() { . . . } // Overrides superclass method
}
```

Step 6 Identify instance variables.

List the instance variables for each class. If you find a instance variable that is common to all classes, be sure to place it in the base of the hierarchy.

All questions have a question text and an answer. We store those values in the `Question` superclass.

```
public class Question
{
   private String text;
   private String answer;
   . . .
}
```

The `ChoiceQuestion` class needs to store the list of choices.

```
public class ChoiceQuestion extends Question
{
   private ArrayList<String> choices;
   . . .
}
```

We need to spend some thought on how question objects are constructed. We can supply the question text in the constructor. However, the answer for a choice question is only known when the correct choice is added, so we need a setter method for it:

```
public class Question
{
   . . .
   /**
      Constructs a question with a given text and an empty answer.
      @param questionText the text of this question
   */
   public Question(String questionText) { . . . }

   /**
      Sets the answer for this question.
      @param correctResponse the answer
   */
   public void setAnswer(String correctResponse) { . . . }
}
```

Step 7 Implement constructors and methods.

The methods of the `Question` class are very straightforward:

```
public class Question
{
   . . .
   public Question(String questionText)
   {
      text = questionText;
      answer = "";
   }

   public void setAnswer(String correctResponse)
   {
      answer = correctResponse;
   }

   public boolean checkAnswer(String response)
   {
      return response.equals(answer);
   }

   public void display()
   {
      System.out.println(text);
   }
}
```

The `ChoiceQuestion` constructor must call the superclass constructor to set the question text:

```
public ChoiceQuestion(String questionText)
{
   super(questionText);
   choices = new ArrayList<String>();
}
```

The `addChoice` method sets the answer when the correct choice is added.

```
public void addChoice(String choice, boolean correct)
{
   choices.add(choice);
   if (correct)
   {
      // Convert choices.size() to string
      String choiceString = "" + choices.size();
      setAnswer(choiceString);
   }
}
```

Finally, the `display` method of the `ChoiceQuestion` class displays the question text, then the choices. Note the call to the superclass method.

```
public void display()
{
   super.display();
   for (int i = 0; i < choices.size(); i++)
   {
      int choiceNumber = i + 1;
      System.out.println(choiceNumber + ": " + choices.get(i));
   }
}
```

Step 8 Construct objects of different subclasses and process them.

In our sample program, we construct two questions and present them to the user.

```
public class QuestionDemo
{
   public static void main(String[] args)
   {
      Question[] quiz = new Question[2];

      quiz[0] = new Question("Who was the inventor of Java?");
      quiz[0].setAnswer("James Gosling");

      ChoiceQuestion question = new ChoiceQuestion(
         "In which country was the inventor of Java born?");
      question.addChoice("Australia", false);
      question.addChoice("Canada", true);
      question.addChoice("Denmark", false);
      question.addChoice("United States", false);
      quiz[1] = question;

      Scanner in = new Scanner(System.in);
      for (Question q : quiz)
      {
         q.display();
         System.out.print("Your answer: ");
         String response = in.nextLine();
         System.out.println(q.checkAnswer(response));
      }
   }
}
```

Program Run

```
Who was the inventor of Java?
Your answer: James Gosling
true
In which country was the inventor of Java born?
1: Australia
2: Canada
3: Denmark
4: United States
Your answer: 4
false
```

The complete program is contained in the `ch10/questions` directory of your source code.

Worked Example 10.1

Implementing an Employee Hierarchy for Payroll Processing

This Worked Example shows how to implement payroll processing that works for different kinds of employees.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

10.7 Object: The Cosmic Superclass

Every class extends the Object class either directly or indirectly.

In Java, every class that is declared without an explicit extends clause automatically extends the class Object. That is, the class Object is the direct or indirect superclass of *every* class in Java (see Figure 7).

Of course, the methods of the Object class are very general. Here are the most useful ones:

Method	Purpose
`String toString()`	Returns a string representation of the object
`boolean equals(Object otherObject)`	Tests whether the object equals another object
`Object clone()`	Makes a full copy of an object

It is a good idea for you to override these methods in your classes.

10.7.1 Overriding the toString Method

In your classes, provide toString methods that describe each object's state.

The toString method returns a string representation for each object. It is useful for debugging. For example,

```
Rectangle box = new Rectangle(5, 10, 20, 30);
String s = box.toString();
   // Sets s to "java.awt.Rectangle[x=5,y=10,width=20,height=30]"
```

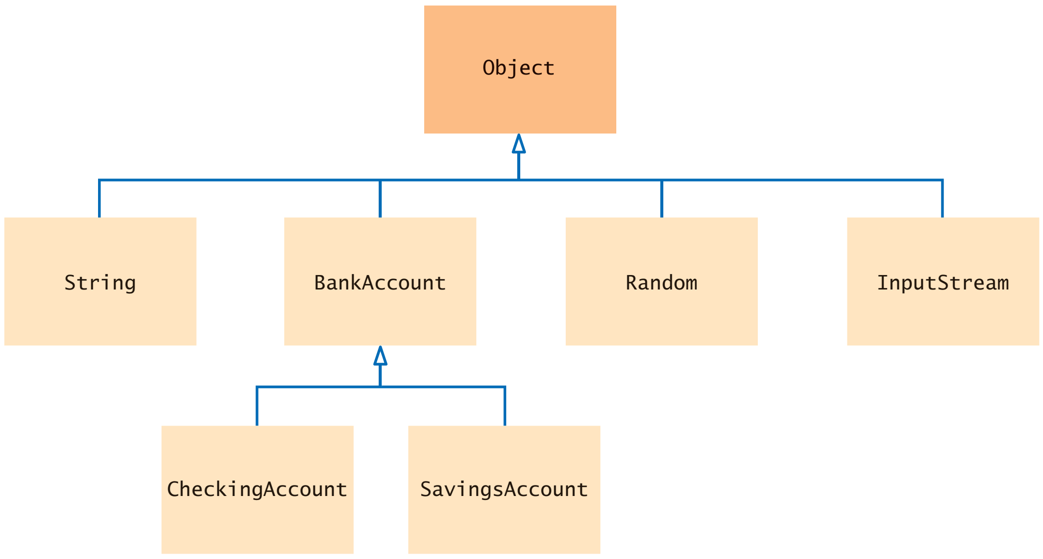


Figure 7 The Object Class Is the Superclass of Every Java Class

In fact, this `toString` method is called whenever you concatenate a string with an object. Consider the concatenation

```
"box=" + box;
```

On one side of the `+` concatenation operator is a string, but on the other side is an object reference. The Java compiler automatically invokes the `toString` method to turn the object into a string. Then both strings are concatenated. In this case, the result is the string

```
"box=java.awt.Rectangle[x=5,y=10,width=20,height=30]"
```

The compiler can invoke the `toString` method, because it knows that *every* object has a `toString` method: Every class extends the `Object` class, and that class provides a `toString` method.

As you know, numbers are also converted to strings when they are concatenated with other strings. For example,

```
int age = 18;
String s = "Harry's age is " + age;
   // Sets s to "Harry's age is 18"
```

In this case, the `toString` method is not involved. Numbers are not objects, and there is no `toString` method for them. There is only a small set of primitive types, however, and the compiler knows how to convert them to strings.

Let's try the `toString` method for the `BankAccount` class:

```
BankAccount momsSavings = new BankAccount(5000);
String s = momsSavings.toString();
   // Sets s to something like "BankAccount@d24606bf"
```

That's disappointing—all that's printed is the name of the class, followed by the **hash code**, a seemingly random code. The hash code can be used to tell objects apart—different objects are likely to have different hash codes. (See Chapter 16 for the details.)

We don't care about the hash code. We want to know what is inside the object. But, of course, the `toString` method of the `Object` class does not know what is inside the `BankAccount` class. Therefore, we have to override the method and supply our own version in the `BankAccount` class. We'll follow the same format that the `toString` method of the `Rectangle` class uses: first print the name of the class, and then the values of the instance variables inside brackets.

```
public class BankAccount
{
   . . .
   public String toString()
   {
      return "BankAccount[balance=" + balance + "]";
   }
}
```

This works better:

```
BankAccount momsSavings = new BankAccount(5000);
String s = momsSavings.toString();
   // Sets s to "BankAccount[balance=5000]"
```

10.7.2 Overriding the equals Method

When implementing the `equals` method, test whether two objects have equal state.

The `equals` method is called whenever you want to compare whether two objects have the same contents:

```
if (coin1.equals(coin2)) . . .
   // Contents are the same—see Figure 8
```

This is different from the test with the `==` operator, which tests whether the two references are to the *same object:*

```
if (coin1 == coin2) . . .
   // Objects are the same—see Figure 9
```

Let us implement the `equals` method for the `Coin` class. You need to override the `equals` method of the `Object` class:

```
public class Coin
{
   . . .
   public boolean equals(Object otherObject)
   {
      . . .
   }
   . . .
}
```

Now you have a slight problem. The `Object` class knows nothing about coins, so it declares the `otherObject` parameter of the `equals` method to have the type `Object`. When overriding the method, you are not allowed to change the parameter type. To overcome this problem, cast the parameter to the class `Coin`:

```
Coin other = (Coin) otherObject;
```

Then you can compare the two coins.

```
public boolean equals(Object otherObject)
{
   Coin other = (Coin) otherObject;
   return name.equals(other.name) && value == other.value;
}
```

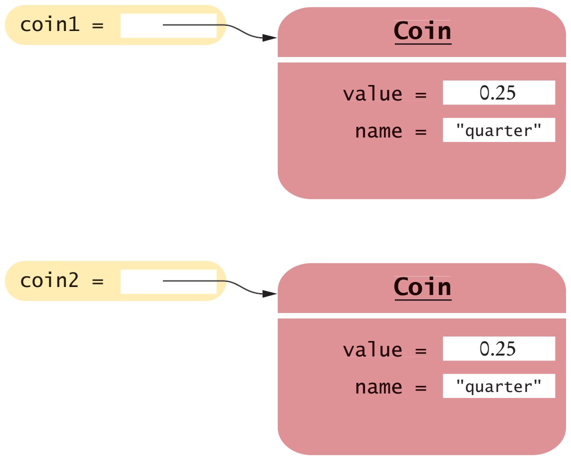


Figure 8 Two References to Equal Objects

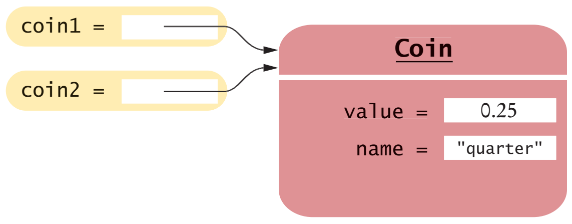


Figure 9 Two References to the Same Object

Note that you must use `equals` to compare object references, but use `==` to compare numbers.

When you override the `equals` method, you should also override the `hashCode` method so that equal objects have the same hash code—see Chapter 16 for details.

10.7.3 The `clone` Method

You know that copying an object reference simply gives you two references to the same object:

```
BankAccount account = new BankAccount(1000);
BankAccount account2 = account;
account2.deposit(500);
   // Now both account and account2 refer to a bank account with a balance of 1500
```

The `clone` method makes a new object with the same state as an existing object.

What can you do if you actually want to make a copy of an object? That is the purpose of the `clone` method. The `clone` method must return a *new* object that has an identical state to the existing object (see Figure 10).

Implementing the `clone` method is quite a bit more difficult than implementing the `toString` or `equals` methods—see Special Topic 10.6 for details.

Let us suppose that someone has implemented the `clone` method for the `BankAccount` class. Here is how to call it:

```
BankAccount clonedAccount = (BankAccount) account.clone();
```

The return type of the `clone` method is the class `Object`. When you call the method, you must use a cast to convince the compiler that `account.clone()` really has the same type as `clonedAccount`.

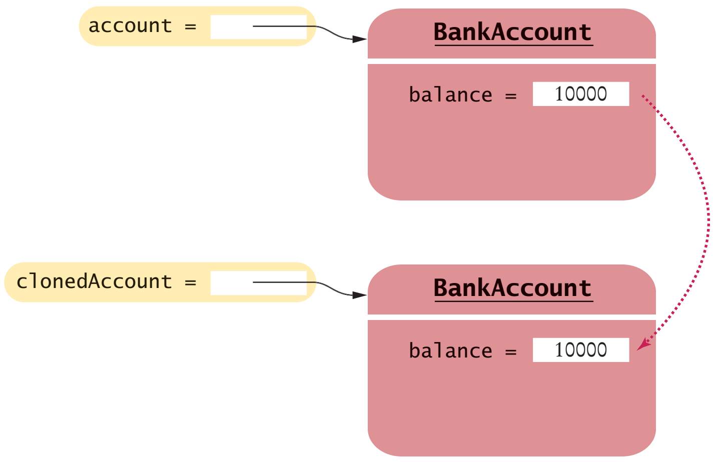


Figure 10
Cloning Objects

SELF CHECK

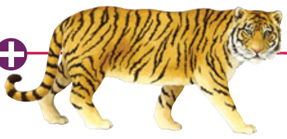
15. Should the call `x.equals(x)` always return `true`?
16. Can you implement `equals` in terms of `toString`? Should you?

Quality Tip 10.1

Supply `toString` in All Classes

If you have a class whose `toString()` method returns a string that describes the object state, then you can simply call `System.out.println(x)` whenever you need to inspect the current state of an object `x`. This works because the `println` method of the `PrintStream` class invokes `x.toString()` when it needs to print an object, which is extremely helpful if there is an error in your program and the objects don't behave the way you think they should. You can simply insert a few print statements and peek inside the object state during the program run. Some debuggers can even invoke the `toString` method on objects that you inspect.

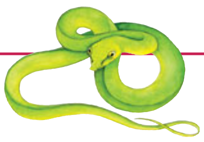
Sure, it is a bit more trouble to write a `toString` method when you aren't sure your program ever needs one—after all, it might work correctly on the first try. Then again, many programs don't work on the first try. As soon as you find out that yours doesn't, consider adding those `toString` methods to help you debug the program.



Special Topic 10.4

Inheritance and the `toString` Method

Special Topic 10.4 gives a recipe for implementing the `toString` method so that it can be easily extended in subclasses.



Common Error 10.6

Declaring the `equals` Method with the Wrong Parameter Type

Consider the following, seemingly simpler, version of the `equals` method for the `Coin` class:

```
public boolean equals(Coin other) // Don't do this!
{
   return name.equals(other.name) && value == other.value;
}
```

Here, the parameter of the `equals` method has the type `Coin`, not `Object`.

Unfortunately, this method *does not override* the `equals` method in the `Object` class. Instead, the `Coin` class now has two different `equals` methods:

```
boolean equals(Coin other) // Declared in the Coin class
boolean equals(Object otherObject) // Inherited from the Object class
```

This is error-prone because the wrong `equals` method can be called. For example, consider these variable declarations:

```
Coin aCoin = new Coin(0.25, "quarter");
Object anObject = new Coin(0.25, "quarter");
```

The call `aCoin.equals(anObject)` calls the second `equals` method, which returns `false`.

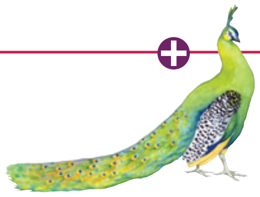
The remedy is to ensure that you use the `Object` type for the explicit parameter of the `equals` method.

⊕ Available online in WileyPLUS and at www.wiley.com/college/horstmann.

Special Topic 10.5

Inheritance and the `equals` Method

Special Topic 10.5 analyzes the subtle problems that arise when the `equals` method is overridden in a subclass, and it gives you a recipe for minimizing these problems.



Quality Tip 10.2

Clone Mutable Instance Variables in Accessor Methods

Quality Tip 10.2 suggests that your accessor methods should not give out references to mutable instance variables, but that the instance variable values should first be cloned.

Special Topic 10.6

Implementing the `clone` Method

Special Topic 10.6 explains how to implement the `clone` method for your own classes.

Special Topic 10.7

Enumeration Types Revisited

Special Topic 10.7 revisits enumeration types and explains that they are all subclasses of the class `Enum`. The `Enum` class has suitable implementations of the `toString`, `equals`, and `clone` methods that are inherited by all enumeration types.

Random Fact 10.1

Scripting Languages

Random Fact 10.1 discusses scripting languages that are designed for rapid development, having a simple structure and fewer syntax rules, and often supporting a particular application (such as office software or a web browser).

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

10.8 Using Inheritance to Customize Frames

Provide a JFrame subclass for a complex frame.

As you add more user-interface components to a frame, the frame can get quite complex. Your programs will become easier to understand when you use inheritance for complex frames.

To do so, design a subclass of JFrame. Store the components as instance variables. Initialize them in the constructor of your subclass. If the initialization code gets complex, simply add some helper methods.

Here, we carry out this process for the investment viewer program in Chapter 9.

```
public class InvestmentFrame extends JFrame
{
   private JButton button;
   private JLabel label;
   private JPanel panel;
   private BankAccount account;

   public InvestmentFrame()
   {
      account = new BankAccount(INITIAL_BALANCE);

      // Use instance variables for components
      label = new JLabel("balance: " + account.getBalance());

      // Use helper methods
      createButton();
      createPanel();

      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }

   private void createButton()
   {
      button = new JButton("Add Interest");
      ActionListener listener = new AddInterestListener();
      button.addActionListener(listener);
   }

   private void createPanel()
   {
      panel = new JPanel();
      panel.add(button);
      panel.add(label);
      add(panel);
   }
   . . .
}
```

This approach differs from the programs in Chapter 9. In those programs, we simply configured the frame in the main method of a viewer class.

It is a bit more work to provide a separate class for the frame. However, the frame class makes it easier to organize the code that constructs the user-interface elements.

Of course, we still need a class with a main method:

```
public class InvestmentViewer2
{
      public static void main(String[] args)
      {
         JFrame frame = new InvestmentFrame();
         frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
         frame.setVisible(true);
      }
   }
```

SELF CHECK

17. How many Java source files are required by the investment viewer application when we use inheritance to declare the frame class?

18. Why does the `InvestmentFrame` constructor call `setSize(FRAME_WIDTH, FRAME_HEIGHT)`, whereas the `main` method of the investment viewer class in Chapter 9 called `frame.setSize(FRAME_WIDTH, FRAME_HEIGHT)`?

Special Topic 10.8

Adding the `main` Method to the Frame Class

Have another look at the `InvestmentFrame` and `InvestmentViewer2` classes. Some programmers prefer to combine these two classes, by adding the `main` method to the frame class:

```
public class InvestmentFrame extends JFrame
{
   public static void main(String[] args)
   {
      JFrame frame = new InvestmentFrame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }

   public InvestmentFrame()
   {
      account = new BankAccount(INITIAL_BALANCE);

      // Use instance variables for components
      label = new JLabel("balance: " + account.getBalance());

      // Use helper methods
      createButton();
      createPanel();

      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }
   . . .
}
```

This is a convenient shortcut that you will find in many programs, but it does muddle the responsibilities between the frame class and the program. Therefore, we do not use this approach in this book.

Summary of Learning Objectives

Explain the notions of inheritance, superclasses, and subclasses.

- Sets of classes can form complex inheritance hierarchies.

Implement subclasses in Java.

- Inheritance is a mechanism for extending existing classes by adding instance variables and methods.
- A subclass inherits the methods of its superclass.
- The instance variables declared in the superclass are present in subclass objects.
- A subclass has no access to private instance variables of its superclass.
- The more general class is called a superclass. The more specialized class that inherits from the superclass is called the subclass.
- Inheriting from a class differs from implementing an interface: The subclass inherits behavior from the superclass.

Describe how a subclass can override methods from its superclass.

- A subclass can inherit a superclass method or override it by providing another implementation.
- Use the `super` reserved word to call a method of the superclass.

Describe how a subclass can construct its superclass.

- To call the superclass constructor, you use the `super` reserved word in the first statement of the subclass constructor.

Describe how to convert between class and superclass types.

- Subclass references can be converted to superclass references.
- The `instanceof` operator tests whether an object belongs to a particular type.

Describe dynamic method lookup and polymorphism.

- When the virtual machine calls an instance method, it locates the method of the implicit parameter's class. This is called dynamic method lookup.

Provide appropriate overrides of the methods of the `Object` superclass.

- Every class extends the `Object` class either directly or indirectly.
- In your classes, provide `toString` methods that describe each object's state.
- When implementing the `equals` method, test whether two objects have equal state.
- The `clone` method makes a new object with the same state as an existing object.

Use inheritance to customize frames.

- Provide a `JFrame` subclass for a complex frame.

Classes, Objects, and Methods Introduced in this Chapter

```
java.lang.Cloneable                      java.lang.Object
java.lang.CloneNotSupportedException        clone
                                            toString
```

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** Implementing an Employee Hierarchy for Payroll Processing
- Lab Exercises
- ***Animation*** Inheritance
- Practice Quiz
- Code Completion Exercises

Review Exercises

★ **R10.1** What is the balance of `b` after the following operations?

```
SavingsAccount b = new SavingsAccount(10);
b.deposit(5000);
b.withdraw(b.getBalance() / 2);
b.addInterest();
```

★ **R10.2** Describe all constructors of the `SavingsAccount` class. List all methods that are inherited from the `BankAccount` class. List all methods that are added to the `SavingsAccount` class.

★★ **R10.3** Can you convert a superclass reference into a subclass reference? A subclass reference into a superclass reference? If so, give examples. If not, explain why not.

★★ **R10.4** Identify the superclass and the subclass in each of the following pairs of classes.

a. `Employee, Manager`
b. `Polygon, Triangle`
c. `GraduateStudent, Student`
d. `Person, Student`
e. `Employee, GraduateStudent`
f. `BankAccount, CheckingAccount`
g. `Vehicle, Car`
h. `Vehicle, Minivan`
i. `Car, Minivan`
j. `Truck, Vehicle`

★ **R10.5** Suppose the class `Sub` extends the class `Sandwich`. Which of the following assignments are legal?

```
Sandwich x = new Sandwich();
Sub y = new Sub();
```

a. `x = y;`
b. `y = x;`
c. `y = new Sandwich();`
d. `x = new Sub();`

★ **R10.6** Draw an inheritance diagram that shows the inheritance relationships between the classes:

- `Person`
- `Employee`
- `Student`
- `Instructor`
- `Classroom`
- `Object`

★★ **R10.7** In an object-oriented traffic simulation system, we have the following classes:

- `Vehicle`
- `Car`
- `Truck`
- `Sedan`
- `Coupe`
- `PickupTruck`
- `SportUtilityVehicle`
- `Minivan`
- `Bicycle`
- `Motorcycle`

Draw an inheritance diagram that shows the relationships between these classes.

★★ **R10.8** What inheritance relationships would you establish among the following classes?

- `Student`
- `Professor`
- `TeachingAssistant`
- `Employee`
- `Secretary`
- `DepartmentChair`
- `Janitor`
- `SeminarSpeaker`
- `Person`
- `Course`
- `Seminar`
- `Lecture`
- `ComputerLab`

★★★ **R10.9** Which of these conditions returns `true`? Check the Java documentation for the inheritance patterns.

a. `Rectangle r = new Rectangle(5, 10, 20, 30);`
b. `if (r instanceof Rectangle) . . .`
c. `if (r instanceof Point) . . .`
d. `if (r instanceof Rectangle2D.Double) . . .`
e. `if (r instanceof RectangularShape) . . .`
f. `if (r instanceof Object) . . .`
g. `if (r instanceof Shape) . . .`

★★ **R10.10** Explain the two meanings of the `super` reserved word. Explain the two meanings of the `this` reserved word. How are they related?

★★★ **R10.11** (Tricky.) Consider the two calls

```
public class D extends B
{
   public void f()
   {
      this.g(); // 1
   }
   public void g()
   {
      super.g(); // 2
   }
   . . .
}
```

Which of them is an example of polymorphism?

★★★ **R10.12** Consider this program:

```
public class AccountPrinter
{
      public static void main(String[] args)
      {
         SavingsAccount momsSavings
               = new SavingsAccount(0.5);

         CheckingAccount harrysChecking
               = new CheckingAccount(0);

         . . .
         endOfMonth(momsSavings);
         endOfMonth(harrysChecking);
         printBalance(momsSavings);
         printBalance(harrysChecking);
      }

      public static void endOfMonth(SavingsAccount savings)
      {
         savings.addInterest();
      }

      public static void endOfMonth(CheckingAccount checking)
      {
         checking.deductFees();
      }

      public static void printBalance(BankAccount account)
      {
         System.out.println("The balance is $"
               + account.getBalance());
      }
   }
```

Do the calls to the `endOfMonth` methods use dynamic method invocation? Inside the `printBalance` method, does the call to `getBalance` use dynamic method invocation?

★ **R10.13** Explain the terms *shallow copy* and *deep copy*.

★ **R10.14** What access attribute should instance variables have? What access attribute should static variables have? How about static final variables?

★ **R10.15** What access attribute should instance methods have? Does the same hold for static methods?

★★ **R10.16** The static variables `System.in` and `System.out` are public. Is it possible to overwrite them? If so, how?

★★ **R10.17** Why are public instance variables dangerous? Are public static variables more dangerous than public instance variables?

Programming Exercises

★ **P10.1** Enhance the `addInterest` method of the `SavingsAccount` class to compute the interest on the *minimum* balance since the last call to `addInterest`. *Hint:* You need to modify the `withdraw` method as well, and you need to add an instance variable to remember the minimum balance.

★★ **P10.2** Add a `TimeDepositAccount` class to the bank account hierarchy. The time deposit account is just like a savings account, but you promise to leave the money in the account for a particular number of months, and there is a $20 penalty for early withdrawal. Construct the account with the interest rate and the number of months to maturity. In the `addInterest` method, decrement the count of months. If the count is positive during a withdrawal, charge the withdrawal penalty.

★ **P10.3** Add a class `NumericQuestion` to the question hierarchy of How To 10.1. If the response and the expected answer differ by no more than 0.01, then accept it as correct.

★★ **P10.4** Add a class `FillInQuestion` to the question hierarchy of How To 10.1. An object of this class is constructed with a string that contains the answer, surrounded by _ _, for example, `"The inventor of Java was _James Gosling_"`. The question should be displayed as

```
The inventor of Java was _____
```

★ **P10.5** Modify the `checkAnswer` method of the `Question` class of How To 10.1 so that it does not take into account different spaces or upper/lowercase characters. For example, the response `" JAMES gosling"` should match an answer of `"James Gosling"`.

★ **P10.6** Add a class `MultiChoiceQuestion` to the question hierarchy of How To 10.1 that allows multiple correct choices. The respondent should provide all correct choices, separated by spaces. Provide instructions in the question text.

★ **P10.7** Add a class `AnyCorrectChoiceQuestion` to the question hierarchy of How To 10.1 that allows multiple correct choices. The respondent should provide any one of the correct choices. The answer string should contain all of the correct choices, separated by spaces.

★ **P10.8** Add a method `addText` to the `Question` class of How To 10.1 and provide a different implementation of `ChoiceQuestion` that calls `addText` rather than storing an array list of choices.

★★ **P10.9** Provide `toString` and `equals` methods for the `Question` and `ChoiceQuestion` classes of How To 10.1.

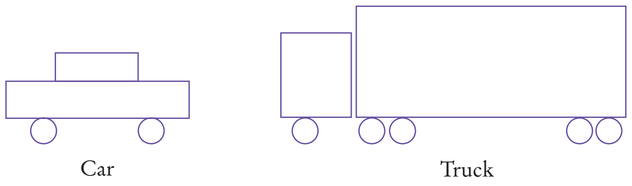
★ **P10.10** Implement a subclass `Square` that extends the `Rectangle` class. In the constructor, accept the *x*- and *y*-positions of the *center* and the side length of the square. Call the `setLocation` and `setSize` methods of the `Rectangle` class. Look up these methods in the documentation for the `Rectangle` class. Also supply a method `getArea` that computes and returns the area of the square. Write a sample program that asks for the center and side length, then prints out the square (using the `toString` method that you inherit from `Rectangle`) and the area of the square.

★ **P10.11** Implement a superclass `Person`. Make two classes, `Student` and `Instructor`, that inherit from `Person`. A person has a name and a year of birth. A student has a major, and an instructor has a salary. Write the class declarations, the constructors, and the methods `toString` for all classes. Supply a test program that tests these classes and methods.

★★ **P10.12** Make a class `Employee` with a name and salary. Make a class `Manager` inherit from `Employee`. Add an instance variable, named `department`, of type `String`. Supply a method `toString` that prints the manager's name, department, and salary. Make a class `Executive` inherit from `Manager`. Supply appropriate `toString` methods for all classes. Supply a test program that tests these classes and methods.

★★★ **P10.13** Reorganize the bank account classes as follows. In the `BankAccount` class, introduce an abstract method `endOfMonth` with no implementation. Rename the `addInterest` and `deductFees` methods into `endOfMonth` in the subclasses. Which classes are now abstract and which are concrete? Write a static method `void test(BankAccount account)` that makes five transactions and then calls `endOfMonth`. Test it with instances of all concrete account classes.

★★★G **P10.14** Implement an abstract class `Vehicle` and concrete subclasses `Car` and `Truck`. A vehicle has a position on the screen. Write methods `draw` that draw cars and trucks as follows:



Then write a method `randomVehicle` that randomly generates `Vehicle` references, with an equal probability for constructing cars and trucks, with random positions. Call it 10 times and draw all of them.

★★G **P10.15** Write a program that prompts the user for an integer, using a `JOptionPane`, and then draws as many rectangles at random positions in a component as the user requested. Use inheritance for your frame class.

★★G **P10.16** Write a program that asks the user to enter an integer n into a `JOptionPane`, and then draws an *n*-by-*n* grid. Use inheritance for the frame class.

Programming Projects

Project 10.1 Your task is to program robots with varying behaviors. The robots try to escape a maze, such as the following:

```
* *******
*     * *
* ***** *
* * *   *
* * *** *
*   *   *
*** * * *
*     * *
******* *
```

A robot has a position and a method `void move(Maze m)` that modifies the position. Provide a common superclass `Robot` whose `move` method does nothing. Provide subclasses `RandomRobot`, `RightHandRuleRobot`, and `MemoryRobot`. Each of these robots has a different strategy for escaping. The `RandomRobot` simply makes random moves. The `RightHandRuleRobot` moves around the maze so that it's right hand always touches a wall. The `MemoryRobot` remembers all positions that it has previously occupied and never goes back to a position that it knows to be a dead end.

Project 10.2 Implement the `toString`, `equals`, and `clone` methods for all subclasses of the `BankAccount` class, as well as the `Bank` class of Chapter 7. Write unit tests that verify that your methods work correctly. Be sure to test a `Bank` that holds objects from a mixture of account classes.

Answers to Self-Check Questions

1. To express the common behavior of text fields and text components.
2. Not all bank accounts earn interest.
3. Two instance variables: `balance` and `interestRate`.
4. `deposit`, `withdraw`, `getBalance`, and `addInterest`.
5. `Manager` is the subclass; `Employee` is the superclass.
6. The `SavingsAccount` class inherits the `deposit`, `withdraw`, and `getBalance` methods. The `addInterest` method is new. No methods override superclass methods.
7. It needs to reduce the balance, and it cannot access the `balance` instance variable directly.
8. So that the count can reflect the number of transactions for the following month.
9. It was content to use the superclass constructor without parameters, which sets the balance to zero.
10. No—this is a requirement only for constructors. For example, the `CheckingAccount.deposit` method first increments the transaction count, then calls the superclass method.
11. We want to use the method for all kinds of bank accounts. Had we used a parameter of type `SavingsAccount`, we couldn't have called the method with a `CheckingAccount` object.
12. We cannot invoke the `deposit` method on a variable of type `Object`.
13. The object is an instance of `BankAccount` or one of its subclasses.
14. The balance of `a` is unchanged (you withdraw from and deposit to the same account), and the transaction count is incremented twice.
15. It certainly should—unless, of course, `x` is `null`.
16. If `toString` returns a string that describes all instance variables, you can simply call `toString` on the implicit and explicit parameters, and compare the results. However, comparing the instance variables is more efficient than converting them into strings.
17. Three: `InvestmentFrameViewer`, `InvestmentFrame`, and `BankAccount`.
18. The `InvestmentFrame` constructor adds the panel to *itself*.

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Chapter 11

Input/Output and Exception Handling

CHAPTER GOALS

- To be able to read and write text files
- To learn how to throw and catch exceptions
- To be able to design your own exception classes
- To understand the difference between checked and unchecked exceptions
- To know when and where to catch an exception

This chapter starts with a discussion of file input and output. Whenever you read or write data, potential errors are to be expected. A file may have been corrupted or deleted, or it may be stored on another computer that was just disconnected from the network. In order to deal with these issues, you need to know about exception handling. This chapter tells you how your programs can report exceptional conditions, and how they can recover when an exceptional condition has occurred.

CHAPTER CONTENTS

11.1 Reading and Writing Text Files 408
Common Error 11.1: Backslashes in File Names 410
Common Error 11.2: Constructing a Scanner with a String 410
Special Topic 11.1: File Dialog Boxes ⊕
Special Topic 11.2: Reading Web Pages 411
Special Topic 11.3: Command Line Arguments ⊕

11.2 Reading Text Input 411
Productivity Hint 11.1: Regular Expressions 415
How To 11.1: Processing Text Files 416
Worked Example 11.1: Analyzing Baby Names ⊕

11.3 Throwing Exceptions 419
Syntax 11.1: Throwing an Exception 419

11.4 Checked and Unchecked Exceptions 421
Syntax 11.2: The throws Clause 423

11.5 Catching Exceptions 423
Syntax 11.3: Catching Exceptions 424
Quality Tip 11.1: Throw Early, Catch Late 425
Quality Tip 11.2: Do Not Squelch Exceptions 425

11.6 The finally Clause 426
Syntax 11.4: The finally Clause 427
Quality Tip 11.3: Do Not Use catch and finally in the Same try Statement 427
Special Topic 11.4: Automatic Resource Management in Java 7 428

11.7 Designing Your Own Exception Types 428
Quality Tip 11.4: Do Throw Specific Exceptions 429

11.8 Case Study: A Complete Example 429
Random Fact 11.1: The Ariane Rocket Incident ⊕

11.1 Reading and Writing Text Files

We begin this chapter by discussing the common task of reading and writing files that contain text. Examples are files that are created with a simple text editor, such as Windows Notepad, as well as Java source code and HTML files.

The simplest mechanism for reading text is to use the `Scanner` class. You already know how to use a `Scanner` for reading console input. To read input from a disk file, the `Scanner` class relies on another class, `File`, which describes disk files and directories. (The `File` class has many methods that we do not discuss in this book; for example, methods that delete or rename a file.) First construct a `File` object with the name of the input file, then use the `File` to construct a `Scanner` object:

```
File inFile = new File("input.txt");
Scanner in = new Scanner(inFile);
```

When reading text files, use the Scanner class.

This `Scanner` object reads text from the file `input.txt`. You can use the `Scanner` methods (such as `next`, `nextLine`, `nextInt`, and `nextDouble`) to read data from the input file.

When writing text files, use the PrintWriter class.

To write output to a file, you construct a `PrintWriter` object with the given file name, for example

```
PrintWriter out = new PrintWriter("output.txt");
```

If the output file already exists, it is emptied before the new data are written into it. If the file doesn't exist, an empty file is created. You can also construct a `PrintWriter` object from a `File` object. This is useful if you use a file chooser (see Special Topic 11.1).

The `PrintWriter` class is an enhancement of the `PrintStream` class that you already know—`System.out` is a `PrintStream` object. You can use the familiar `print`, `println`, and `printf` methods with any `PrintWriter` object:

```
out.print(29.95);
out.println(new Rectangle(5, 10, 15, 25));
out.printf("%10.2f", price);
```

You must close a print stream when you are done writing output.

When you are done writing to a file, be sure to *close* the PrintWriter:

```
out.close();
```

If your program exits without closing the PrintWriter, the disk file may not contain all of the output.

The following program puts these concepts to work. It reads all lines of an input file and sends them to the output file, preceded by *line numbers*. If the input file is

```
Mary had a little lamb
Whose fleece was white as snow.
And everywhere that Mary went,
The lamb was sure to go!
```

then the program produces the output file

```
/* 1 */ Mary had a little lamb
/* 2 */ Whose fleece was white as snow.
/* 3 */ And everywhere that Mary went,
/* 4 */ The lamb was sure to go!
```

The line numbers are enclosed in /* */ delimiters so that the program can be used for numbering Java source files.

There is one additional issue that we need to tackle. When the input or output file doesn't exist, a FileNotFoundException can occur. The compiler insists that we tell it what the program should do when that happens. (In this regard, the FileNotFoundException is different from the exceptions that you have already encountered. We will discuss this difference in detail in Section 11.4.) In our sample program, we take the easy way out and acknowledge that the main method should simply be terminated if the exception occurs. We label the main method like this:

```
public static void main(String[] args) throws FileNotFoundException
```

You will see in the following sections how to deal with exceptions in a more professional way.

ch11/lines/LineNumberer.java

```
import java.io.File;
import java.io.FileNotFoundException;
import java.io.PrintWriter;
import java.util.Scanner;

/**
   This program applies line numbers to a file.
*/
public class LineNumberer
{
   public static void main(String[] args) throws FileNotFoundException
   {
      // Prompt for the input and output file names

      Scanner console = new Scanner(System.in);
      System.out.print("Input file: ");
      String inputFileName = console.next();
      System.out.print("Output file: ");
      String outputFileName = console.next();

      // Construct the Scanner and PrintWriter objects for reading and writing

      File inputFile = new File(inputFileName);
      Scanner in = new Scanner(inputFile);
      PrintWriter out = new PrintWriter(outputFileName);
      int lineNumber = 1;

      // Read the input and write the output

      while (in.hasNextLine())
      {
         String line = in.nextLine();
         out.println("/* " + lineNumber + " */ " + line);
         lineNumber++;
      }

      in.close();
      out.close();
   }
}
```

SELF CHECK

1. What happens when you supply the same name for the input and output files to the `LineNumberer` program?
2. What happens when you supply the name of a nonexistent input file to the `LineNumberer` program?

Common Error 11.1

Backslashes in File Names

When you specify a file name as a string literal, and the name contains backslash characters (as in a Windows file name), you must supply each backslash twice:

```
inFile = new File("c:\\homework\\input.dat");
```

Recall that a single backslash inside quoted strings is an **escape character** that is combined with another character to form a special meaning, such as `\n` for a newline character. The `\\` combination denotes a single backslash.

When a user supplies a file name to a program, however, the user should not type the backslash twice.

Common Error 11.2

Constructing a Scanner with a `String`

When you construct a `PrintWriter` with a string, it writes to a file:

```
PrintWriter out = new PrintWriter("output.txt");
```

However, this does *not* work for a `Scanner`. The statement

```
Scanner in = new Scanner("input.txt"); // ERROR?
```

does *not* open a file. Instead, it simply reads through the string: `in.nextLine()` returns the string `"input.txt"`. This feature can be useful—see Section 11.2.3 for an example.

You must simply remember to use `File` objects in the `Scanner` constructor:

```
Scanner in = new Scanner(new File("input.txt")); // OK
```

Special Topic 11.1

File Dialog Boxes

Special Topic 11.1 shows you how you can present a file chooser dialog box to users of your programs.

Special Topic 11.2

Reading Web Pages

You can read the contents of a web page with this sequence of commands:

```
String address = "http://java.sun.com/index.html";
URL locator = new URL(address);
Scanner in = new Scanner(locator.openStream());
```

Now simply read the contents of the web page with the `Scanner` in the usual way. The `URL` constructor and the `openStream` method can throw an `IOException`. You need to tag the `main` method with `throws IOException`. (See Section 11.3 for more information on the `throws` clause.)

Special Topic 11.3

Command Line Arguments

Special Topic 11.3 shows you how you can process *command line arguments*, strings that are supplied after the name of a program that is launched from a command shell. The command line arguments are passed to the `args` parameter of the `main` method.

11.2 Reading Text Input

In the following sections, you will learn how to process complex text input that you often encounter in real life situations.

11.2.1 Reading Words

In the preceding example program, we read input a line at a time. Sometimes, it is useful to read words rather than lines. For example, consider the loop

```
while (in.hasNext())
{
   String input = in.next();
   System.out.println(input);
```

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

```
}
```

With our sample input, this loop would print a word on every line:

The next method reads a word at a time. Call Scanner.useDelimiter to specify a pattern for word boundaries.

```
Mary
had
a
little
lamb
```

In Java, a *word* is not the same as in English. It is any sequence of characters that is not white space. White space includes spaces, tab characters, and the newline characters that separate lines. For example, the following are considered words:

```
snow.
1729
C++
```

(Note the period after snow—it is considered a part of the word because it is not white space.)

Here is precisely what happens when the next method is executed. Input characters that are *white space* are *consumed*—that is, removed from the input. However, they do not become part of the word. The first character that is not white space becomes the first character of the word. More characters are added until either another white space character occurs, or the end of the input has been reached.

Sometimes, you want to read just the words and discard anything that isn't a letter. You achieve this task by calling the useDelimiter method on your Scanner object:

```
Scanner in = new Scanner(. . .);
in.useDelimiter("[^A-Za-z]+");
```

Here, we set the character pattern that separates words to "any sequence of characters other than letters". (The notation used for describing the character pattern is called a *regular expression*. See Productivity Hint 11.1 on page 415 if you are interested in more details.) With this setting, punctuation and numbers are stripped off from the words returned by the next method.

11.2.2 Processing Lines

The nextLine method reads a line of input and consumes the newline character at the end of the line.

When each line of a file is a data record, it is often best to read entire lines with the nextLine method:

```
String line = in.nextLine();
```

The nextLine method consumes the next input line (including the newline character) and returns the line without the newline character. You can then take the line apart for further processing.

Here is a typical example of processing lines in a file. A file with population data from the CIA Fact Book site (http://www.cia.gov/library/publications/the-world-factbook/) contains lines such as the following:

```
China  1330044605
India  1147995898
United States 303824646
. . .
```

Because some country names have more than one word, it would be tedious to read this file using the next method. For example, after reading United, how would your program know that it still needs to read another word before reading the population count?

Instead, read each input line into a string. Then use the `isDigit` and `isWhitespace` methods to find out where the name ends and the number starts.

Locate the first digit:

```
int i = 0;
while (!Character.isDigit(line.charAt(i))) { i++; }
```

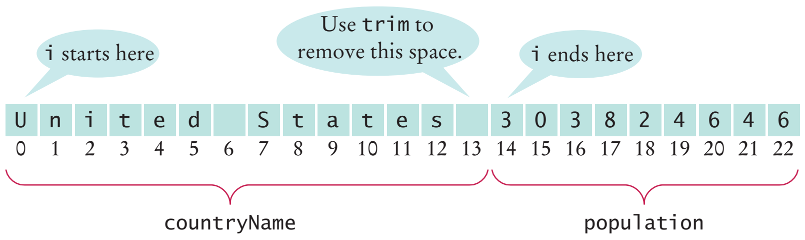
Then extract the country name and population:

```
String countryName = line.substring(0, i);
String population = line.substring(i);
```

However, the country name contains one or more spaces at the end. Use the `trim` method to remove them:

```
countryName = countryName.trim();
```

The `trim` method returns the string with all white space at the beginning and end removed.



There is another problem. The population is stored in a string, not a number. Use the `Integer.parseInt` method to convert it:

```
int populationValue = Integer.parseInt(population);
```

You need to be careful when calling the `Integer.parseInt` method. Its parameter value must be a string containing the digits of an integer or a `NumberFormatException` occurs. The parameter value may not contain any additional characters. Not even spaces are allowed! In our situation, we happen to know that there won't be any spaces at the beginning of the string, but there might be some at the end. Therefore, we use the `trim` method:

```
int populationValue = Integer.parseInt(population.trim());
```

Here you saw how to break a string into parts by looking at individual characters. Another approach is occasionally easier. Construct a new `Scanner` object to read the characters from a string:

```
Scanner lineScanner = new Scanner(line);
```

Then you can use `lineScanner` like any other `Scanner` object, reading words and numbers:

```
String countryName = lineScanner.next();
while (!lineScanner.hasNextInt())
{
   countryName = countryName + " " + lineScanner.next();
}
int populationValue = lineScanner.nextInt();
```

11.2.3 Reading Numbers

The `nextInt` and `nextDouble` methods consume white space and the next number.

You have used the `nextInt` and `nextDouble` methods of the `Scanner` class many times, but here we will have a look at their behavior in detail. Suppose you call

```
double value = in.nextDouble();
```

The `nextDouble` method recognizes floating-point numbers such as `3.14159`, `-21`, or `1E12` (a billion in scientific notation). However, if there is *no number* in the input, then a `NoSuchElementException` occurs.

Consider an input containing the characters

```
   2 1 s t   c e n t u r y
```

White space is consumed and the word `21st` is read. However, this word is not a properly formatted number. In this situation, an "input mismatch exception" occurs.

To avoid exceptions, use the `hasNextDouble` method to screen the input. For example,

```
if (in.hasNextDouble())
{
   double value = in.nextDouble();
   . . .
}
```

Similarly, you should call the `hasNextInt` method before calling `nextInt`.

Note that the `nextInt` and `nextDouble` methods *do not* consume the white space that follows a number. This can be a problem if you alternate between calling `nextInt`/`nextDouble` and `nextLine`. Suppose a file contains student IDs and names in this format:

```
1729
Harry Morgan
1730
Diana Lin
. . .
```

Now suppose you read the file with these instructions:

```
while (in.hasNextInt())
{
   int studentID = in.nextInt();
   String name = in.nextLine();
   Process the student ID and name
}
```

Initially, the input contains

```
1 7 2 9 \n H a r r y
```

After the first call to `nextInt`, the input contains

```
\n H a r r y
```

The call to `nextLine` reads an empty string! The remedy is to add a call to `nextLine` after reading the ID:

```
int studentID = in.nextInt();
in.nextLine(); // Consume the newline
String name = in.nextLine();
```

11.2.4 Reading Characters

To read one character at a time, set the delimiter pattern to the empty string.

Sometimes, you want to read a file one character at a time. You achieve this task by calling the useDelimiter method on your Scanner object with an empty string:

```
Scanner in = new Scanner(. . .);
in.useDelimiter("");
```

Now each call to next returns a string consisting of a single character. Here is how you can process the characters:

```
while (in.hasNext())
{
   char ch = in.next().charAt(0);
   Process ch
}
```

SELF CHECK

3. Suppose the input contains the characters 6,995.0. What is the value of number and input after these statements?

```
int number = in.nextInt();
String input = in.next();
```

4. Suppose the input contains the characters 6,995.00 12. What is the value of price and quantity after these statements?

```
double price = in.nextDouble();
int quantity = in.nextInt();
```

5. Your input file contains a sequence of numbers, but sometimes a value is not available and marked as N/A. How can you read the numbers and skip over the markers?

Productivity Hint 11.1

Regular Expressions

Regular expressions describe character patterns. For example, numbers have a simple form. They contain one or more digits. The regular expression describing numbers is [0-9]+. The set [0-9] denotes any digit between 0 and 9, and the + means "one or more".

The search commands of professional programming editors understand regular expressions. Moreover, several utility programs use regular expressions to locate matching text. A commonly used program that uses regular expressions is *grep* (which stands for "global regular expression print"). You can run grep from a command line or from inside some compilation environments. Grep is part of the UNIX operating system, and versions are available for Windows. It needs a regular expression and one or more files to search. When grep runs, it displays a set of lines that match the regular expression.

Suppose you want to look for all magic numbers (see Quality Tip 4.1) in a file. The command

```
grep [0-9]+ Homework.java
```

lists all lines in the file Homework.java that contain sequences of digits. That isn't terribly useful; lines with variable names x1 will be listed. OK, you want sequences of digits that do *not* immediately follow letters:

```
grep [^A-Za-z][0-9]+ Homework.java
```

The set `[^A-Za-z]` denotes any characters that are *not* in the ranges `A` to `Z` and `a` to `z`. This works much better, and it shows only lines that contain actual numbers.

The `useDelimiter` method of the `Scanner` class accepts a regular expression to describe delimiters—the blocks of text that separate words. As already mentioned, if you set the delimiter pattern to `[^A-Za-z]+`, a delimiter is a sequence of one or more characters that are not letters.

For more information on regular expressions, consult one of the many tutorials on the Internet by pointing your search engine to “regular expression tutorial”.

How To 11.1 Processing Text Files

Processing text files that contain real data can be surprisingly challenging. This How To gives you step-by-step guidance.

As an example, we will consider this task: Read two country data files, `worldpop.txt` and `worldarea.txt` (supplied with your book code). Both files contain data for the same countries in the same order. Write a file `world_pop_density.txt` that contains country names and population densities (people per square km), with the country names aligned left and the numbers aligned right:

```
Afghanistan                                50.56
Akrotiri                                  127.64
Albania                                   125.91
Algeria                                    14.18
American Samoa                            288.92
. . .
```

Step 1 Understand the processing task.

As always, you need to have a clear understanding of the task before designing a solution. Can you carry out the task by hand (perhaps with smaller input files)? If not, get more information about the problem.

One important aspect that you need to consider is whether you can process the data as it becomes available, or whether you need to store it first. For example, if you are asked to write out sorted data, you need to first collect all input, perhaps by placing it in an array list. However, it is often possible to process the data “on the go”, without storing it.

In our example, we can read each file a line at a time and compute the density for each line because our input files store the population and area data in the same order.

The following pseudocode describes our processing task.

```
While there are more lines to be read
   Read a line from each file.
   Extract the country name.
   population = number following the country name in the line from the first file
   area = number following the country name in the line from the second file
   If area != 0
      density = population / area
   Print country name and density.
```

Step 2 Determine which files you need to read and write.

This should be clear from the problem. In our example, there are two input files, the population data and the area data, and one output file.

Step 3 Choose a mechanism for obtaining the file names.

There are four options:

- Hard-coding the file names (such as "worldpop.txt")
- Asking the user:

```
Scanner in = new Scanner(System.in);
System.out.print("Enter filename: ");
String inFile = in.nextLine();
```

- Using command line arguments for the file names (see Special Topic 11.3)
- Using a file dialog box (see Special Topic 11.1)

In our example, we use hard-coded file names for simplicity.

Step 4 Choose between line, word, and character-based input.

As a rule of thumb, read lines if the input data is grouped by lines. That is the case with tabular data, such as in our example, or when you need to report line numbers.

When gathering data that can be distributed over several lines, then it makes more sense to read words. Keep in mind that you lose all white space when you read words.

Reading characters is mostly useful for tasks that require access to individual characters. Examples include analyzing character frequencies, changing tabs to spaces, or encryption.

Step 5 With line-oriented input, extract the required data.

It is simple to read a line of input with the `nextLine` method. Then you need to get the data out of that line. You can extract substrings, as described in Section 11.2.2.

Typically, you will use methods such as `Character.isWhitespace` and `Character.isDigit` to find the boundaries of substrings.

If you need any of the substrings as numbers, you must convert them, using `Integer.parseInt` or `Double.parseDouble`.

Step 6 Use classes and methods to factor out common tasks.

Processing input files usually has repetitive tasks, such as skipping over white space or extracting numbers from strings. It really pays off to isolate these tedious operations from the remainder of the code.

In our example, we have a task that occurs twice: splitting an input line into the country name and the value that follows. We implement a simple `CountryValue` class for this purpose, using the technique described in Section 11.2.2.

Here is the complete source code.

ch11/population/CountryValue.java

```
/**
   Describes a value that is associated with a country.
*/
public class CountryValue
{
   private String country;
   private double value;

   /**
      Constructs a CountryValue from an input line.
      @param line a line containing a country name, followed by a value
   */
   public CountryValue(String line)
   {
      int i = 0; // Locate the start of the first digit
      while (!Character.isDigit(line.charAt(i))) { i++; }
      int j = i - 1; // Locate the end of the preceding word
      while (Character.isWhitespace(line.charAt(j))) { j--; }
      country = line.substring(0, j + 1); // Extract the country name
      value = Double.parseDouble(line.substring(i).trim()); // Extract the value
   }

   /**
      Gets the country name.
      @return the country name
   */
   public String getCountry() { return country; }

   /**
      Gets the associated value.
      @return the value associated with the country
   */
   public double getValue() { return value; }
}
```

ch11/population/PopulationDensity.java

```
import java.io.File;
import java.io.FileNotFoundException;
import java.io.PrintWriter;
import java.util.Scanner;

public class PopulationDensity
{
   public static void main(String[] args) throws FileNotFoundException
   {
      // Open input files
      Scanner in1 = new Scanner(new File("worldpop.txt"));
      Scanner in2 = new Scanner(new File("worldarea.txt"));

      // Open output file
      PrintWriter out = new PrintWriter("world_pop_density.txt");

      // Read lines from each file
      while (in1.hasNextLine() && in2.hasNextLine())
      {
         CountryValue population = new CountryValue(in1.nextLine());
         CountryValue area = new CountryValue(in2.nextLine());

         // Compute and print the population density
         double density = 0;
         if (area.getValue() != 0) // Protect against division by zero
         {
            density = population.getValue() / area.getValue();
         }
         out.printf("%-40s%15.2f\n", population.getCountry(), density);
      }

      in1.close();
      in2.close();
      out.close();
   }
}
```

Worked Example 11.1

Analyzing Baby Names

In this Worked Example, you will use data from the Social Security Administration to analyze the most popular baby names.

11.3 Throwing Exceptions

There are two main aspects to exception handling: *reporting* and *recovery*. A major challenge of error handling is that the point of reporting is usually far apart from the point of recovery. For example, the get method of the ArrayList class may detect that a nonexistent element is being accessed, but it does not have enough information to decide what to do about this failure. Should the user be asked to try a different operation? Should the program be aborted after saving the user's work? These decisions must be made in a different part of the program.

In Java, *exception handling* provides a flexible mechanism for passing control from the point of error reporting to a competent recovery handler. In the remainder of this chapter, we will look into the details of this mechanism.

To signal an exceptional condition, use the throw statement to throw an exception object.

When you detect an error condition, your job is really easy. You just throw an appropriate exception object, and you are done. For example, suppose someone tries to withdraw too much money from a bank account.

```
public class BankAccount
{
   . . .
   public void withdraw(double amount)
   {
      if (amount > balance)
         // Now what?
      . . .
   }
}
```

Syntax 11.1 Throwing an Exception

Syntax throw *exceptionObject*;

Example

```
if (amount > balance)
{
   throw new IllegalArgumentException("Amount exceeds balance");
}
balance = balance - amount;
```

Most exception objects can be constructed with an error message.

A new exception object is constructed, then thrown.

This line is not executed when the exception is thrown.

First look for an appropriate exception class. The Java library provides many classes to signal all sorts of exceptional conditions. Figure 1 shows the most useful ones.

Look around for an exception type that might describe your situation. How about the `IllegalStateException`? Is the bank account in an illegal state for the

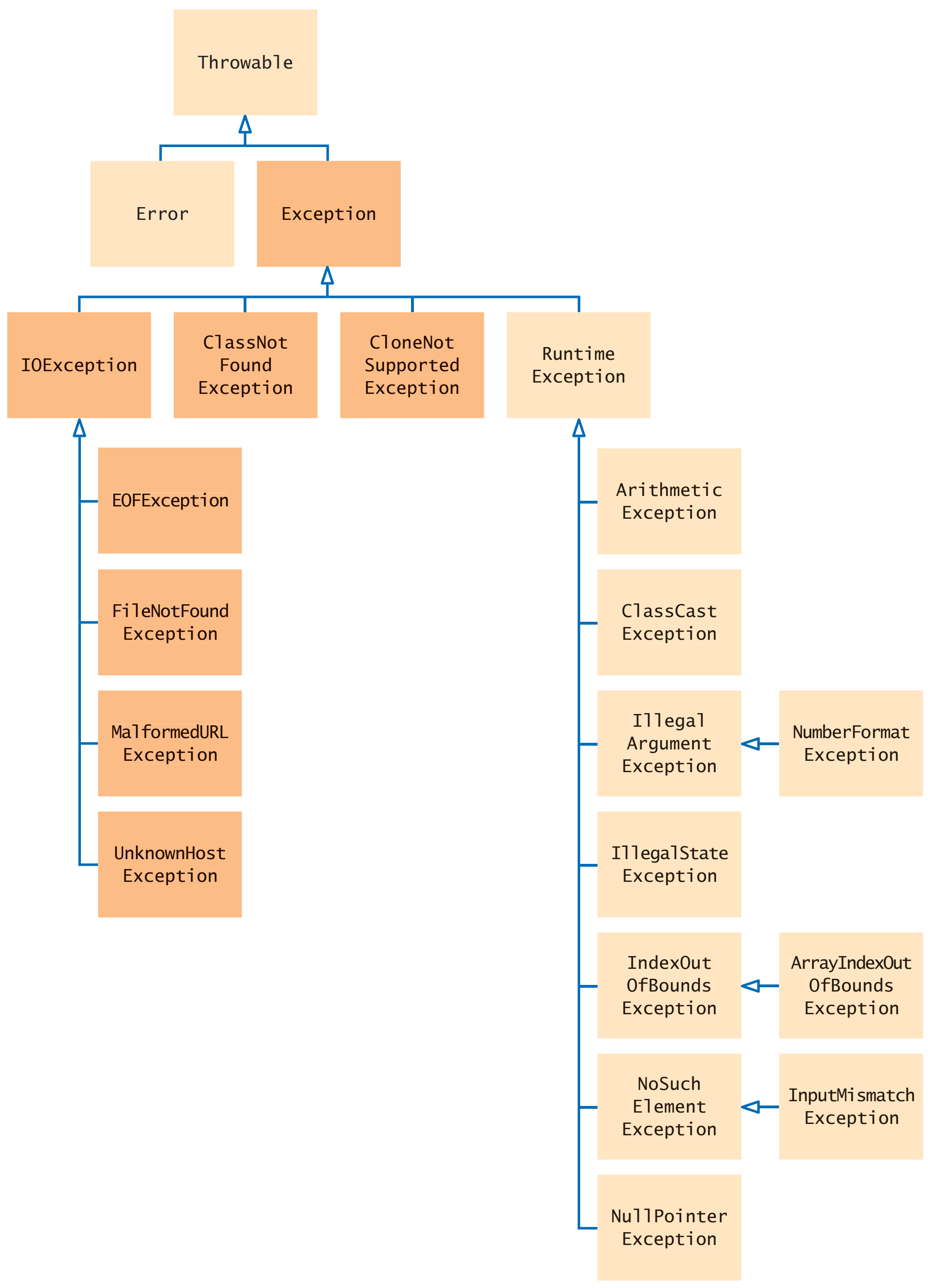


Figure 1 The Hierarchy of Exception Classes

`withdraw` operation? Not really—some `withdraw` operations could succeed. Is the parameter value illegal? Indeed it is. It is just too large. Therefore, let's throw an `IllegalArgumentException`. (The term **argument** is an alternative term for a parameter value.)

```
public class BankAccount
{
   public void withdraw(double amount)
   {
      if (amount > balance)
      {
         throw new IllegalArgumentException("Amount exceeds balance");
      }
      balance = balance - amount;
   }
   . . .
}
```

The statement

```
throw new IllegalArgumentException("Amount exceeds balance");
```

When you throw an exception, the current method terminates immediately.

constructs an object of type `IllegalArgumentException` and throws that object.

When you throw an exception, execution does not continue with the next statement but with an **exception handler**. For now, we won't worry about the handling of the exception. That is the topic of Section 11.5.

SELF CHECK

6. How should you modify the `deposit` method to ensure that the balance is never negative?
7. Suppose you construct a new bank account object with a zero balance and then call `withdraw(10)`. What is the value of `balance` afterwards?

11.4 Checked and Unchecked Exceptions

There are two kinds of exceptions: *checked* and *unchecked*. Unchecked exceptions extend the class `RuntimeException` or `Error`.

Java exceptions fall into two categories, called *checked* and *unchecked* exceptions. When you call a method that throws a **checked exception**, the compiler checks that you don't ignore it. You must tell the compiler what you are going to do about the exception if it is ever thrown. For example, all subclasses of `IOException` are checked exceptions. On the other hand, the compiler does not require you to keep track of **unchecked exceptions**. Exceptions such as `NumberFormatException`, `IllegalArgument-Exception`, and `NullPointerException` are unchecked exceptions. More generally, all exceptions that belong to subclasses of `RuntimeException` are unchecked, and all other subclasses of the class `Exception` are checked. (In Figure 1, the checked exceptions are shaded in a darker color.) There is a second category of internal errors that are reported by throwing objects of type `Error`. One example is the `OutOfMemoryError`, which is thrown when all available memory has been used up. These are fatal errors that happen rarely and are beyond your control. They too are unchecked.

Why have two kinds of exceptions? A checked exception describes a problem that is likely to occur at times, no matter how careful you are. The unchecked exceptions, on the other hand, are your fault. For example, an unexpected end of file can be caused by forces beyond your control, such as a disk error or a broken

Checked exceptions are due to external circumstances that the programmer cannot prevent. The compiler checks that your program handles these exceptions.

network connection. But you are to blame for a `NullPointerException`, because your code was wrong when it tried to use a `null` reference.

The compiler doesn't check whether you handle a `NullPointerException`, because you should test your references for `null` before using them rather than install a handler for that exception. The compiler does insist that your program be able to handle error conditions that you cannot prevent.

Actually, those categories aren't perfect. For example, the `Scanner.nextInt` method throws an unchecked `InputMismatchException` if the input does not contain a valid integer. A checked exception would have been more appropriate because the programmer cannot prevent users from entering incorrect input. (The designers of the `Scanner` class made this choice to make it easy to use for beginning programmers.)

As you can see from Figure 1, the majority of checked exceptions occur when you deal with input and output. That is a fertile ground for external failures beyond your control—a file might have been corrupted or removed, a network connection might be overloaded, a server might have crashed, and so on. Therefore, you will need to deal with checked exceptions principally when programming with files and streams.

You have seen how to use the `Scanner` class to read data from a file, by passing a `File` object to the `Scanner` constructor:

```
String filename = . . .;
File inFile = new File(filename);
Scanner in = new Scanner(inFile);
```

However, the `Scanner` constructor can throw a `FileNotFoundException`. The `FileNotFoundException` is a checked exception, so you need to tell the compiler what you are going to do about it. You have two choices. You can handle the exception, using the techniques that you will see in Section 11.5. Or you can simply tell the compiler that you are aware of this exception and that you want your method to be terminated when it occurs. The method that reads input does not usually know what to do about an unexpected error, so that is usually the better option.

To declare that a method should be terminated when a checked exception occurs within it, tag the method with a `throws` clause.

```
public void read(String filename) throws FileNotFoundException
{
   File inFile = new File(filename);
   Scanner in = new Scanner(inFile);
   . . .
}
```

Add a `throws` clause to a method that can throw a checked exception.

The `throws` clause in turn signals the caller of your method that it may encounter a `FileNotFoundException`. Then the caller needs to make the same decision—handle the exception, or tell its caller that the exception may be thrown.

If your method can throw exceptions of different types, you separate the exception class names by commas:

```
public void read(String filename)
      throws FileNotFoundException, NoSuchElementException
```

Always keep in mind that exception classes form an inheritance hierarchy. For example, `FileNotFoundException` is a subclass of `IOException`. Thus, if a method can throw both an `IOException` and a `FileNotFoundException`, you only tag it as `throws IOException`.

Syntax 11.2 The throws Clause

Syntax *accessSpecifier returnType methodName(parameterType parameterName, . . .)*
`throws` *ExceptionClass, ExceptionClass, . . .*

Example

```
public void read(String filename)
      throws FileNotFoundException, NoSuchElementException
```

You must specify all checked exceptions that this method may throw.

You may also list unchecked exceptions.

It sounds somehow irresponsible not to handle an exception when you know that it happened. Actually, though, it is usually best not to catch an exception if you don't know how to remedy the situation. After all, what can you do in a low-level `read` method? Can you tell the user? How? By sending a message to `System.out`? You don't know whether this method is called in a graphical program or an embedded system (such as a vending machine), where the user may never see `System.out`. And even if your users can see your error message, how do you know that they can understand English? Your class may be used to build an application for users in another country. If you can't tell the user, can you patch up the data and keep going? How? If you set a variable to zero, `null`, or an empty string, that may just cause the program to break later, with much greater mystery.

Of course, some methods in the program know how to communicate with the user or take other remedial action. By allowing the exception to reach those methods, you make it possible for the exception to be processed by a competent handler.

SELF CHECK

8. Suppose a method calls the `Scanner` constructor, which can throw a `FileNotFoundException`, and the `nextInt` method of the `Scanner` class, which can cause a `NoSuchElementException` or `InputMismatchException`. Which exceptions should be included in the `throws` clause?

9. Why is a `NullPointerException` not a checked exception?

11.5 Catching Exceptions

In a method that is ready to handle a particular exception type, place the statements that can cause the exception inside a `try` block, and the handler inside a `catch` clause.

Every exception should be handled somewhere in your program. If an exception has no handler, an error message is printed, and your program terminates. That may be fine for a student program. But you would not want a professionally written program to die just because some method detected an unexpected error. Therefore, you should install exception handlers for all exceptions that your program might throw.

You install an exception handler with the `try/catch` statement. Each `try` block contains one or more statements that may cause an exception. Each `catch` clause contains the handler for an exception type.

Syntax 11.3 Catching Exceptions

Syntax

```
try
{
   statement
   statement
   . . .
}
catch (ExceptionClass exceptionObject)
{
   statement
   statement
   . . .
}
```

Example

```
try
{
   Scanner in = new Scanner(new File("input.txt"));
   String input = in.next();
   process(input);
}
catch (IOException exception)
{
   System.out.println("Could not open input file");
}
```

This constructor can throw a FileNotFoundException.

This is the exception that was thrown.

When an IOException is thrown, execution resumes here.

Additional catch clauses can appear here.

A FileNotFoundException is a special case of an IOException.

Here is an example:

```
try
{
   String filename = . . .;
   File inFile = new File(filename);
   Scanner in = new Scanner(inFile);
   String input = in.next();
   int value = Integer.parseInt(input);
   . . .
}
catch (IOException exception)
{
   exception.printStackTrace();
}
catch (NumberFormatException exception)
{
   System.out.println("Input was not a number");
}
```

Three exceptions may be thrown in this `try` block: The `Scanner` constructor can throw a `FileNotFoundException`, `Scanner.next` can throw a `NoSuchElementException`, and `Integer.parseInt` can throw a `NumberFormatException`.

If any of these exceptions is actually thrown, then the rest of the instructions in the `try` block are skipped. Here is what happens for the various exception types:

- If a `FileNotFoundException` is thrown, then the `catch` clause for the `IOException` is executed. (Recall that `FileNotFoundException` is a subclass of `IOException`.)
- If a `NumberFormatException` occurs, then the second `catch` clause is executed.
- A `NoSuchElementException` is *not caught* by any of the `catch` clauses. The exception remains thrown until it is caught by another `try` block or the `main` method terminates.

When the `catch (IOException exception)` block is executed, then some method in the `try` block has failed with an `IOException`. The variable `exception` contains a reference to the exception object that was thrown. The `catch` clause can analyze that object to find out more details about the failure. For example, you can get a printout of the chain of method calls that lead to the exception, by calling

```
exception.printStackTrace()
```

In these sample `catch` clauses, we merely inform the user of the source of the problem. A better way of dealing with the exception would be to give the user another chance to provide a correct input—see Section 11.8 for a solution.

It is important to remember that you should place `catch` clauses only in methods in which you can competently handle the particular exception type.

SELF CHECK

10. Suppose the file with the given file name exists and has no contents. Trace the flow of execution in the `try` block in this section.

11. Is there a difference between catching checked and unchecked exceptions?

Quality Tip 11.1

Throw Early, Catch Late

When a method detects a problem that it cannot solve, it is better to throw an exception rather than to try to come up with an imperfect fix. For example, suppose a method expects to read a number from a file, and the file doesn't contain a number. Simply using a zero value would be a poor choice because it hides the actual problem and perhaps causes a different problem elsewhere.

Throw an exception as soon as a problem is detected. Catch it only when the problem can be handled.

Conversely, a method should only catch an exception if it can really remedy the situation. Otherwise, the best remedy is simply to have the exception propagate to its caller, allowing it to be caught by a competent handler.

These principles can be summarized with the slogan "throw early, catch late".

Quality Tip 11.2

Do Not Squelch Exceptions

When you call a method that throws a checked exception and you haven't specified a handler, the compiler complains. In your eagerness to continue your work, it is an understandable impulse to shut the compiler up by squelching the exception:

```
try
{
      File inFile = new File(filename);
      Scanner in = new Scanner(inFile);
      // Compiler complained about FileNotFoundException
      . . .
   }
   catch (Exception e) {} // So there!
```

The do-nothing exception handler fools the compiler into thinking that the exception has been handled. In the long run, this is clearly a bad idea. Exceptions were designed to transmit problem reports to a competent handler. Installing an incompetent handler simply hides an error condition that could be serious.

11.6 The finally Clause

Occasionally, you need to take some action whether or not an exception is thrown. The `finally` construct is used to handle this situation. Here is a typical situation.

It is important to close a `PrintWriter` to ensure that all output is written to the file. In the following code segment, we open a stream, call one or more methods, and then close the stream:

```
PrintWriter out = new PrintWriter(filename);
writeData(out);
out.close(); // May never get here
```

Now suppose that one of the methods before the last line throws an exception. Then the call to `close` is never executed! Solve this problem by placing the call to `close` inside a `finally` clause:

```
PrintWriter out = new PrintWriter(filename);
try
{
   writeData(out);
}
finally
{
   out.close();
}
```

Once a `try` block is entered, the statements in a `finally` clause are guaranteed to be executed, whether or not an exception is thrown.

In a normal case, there will be no problem. When the `try` block is completed, the `finally` clause is executed, and the writer is closed. However, if an exception occurs, the `finally` clause is also executed before the exception is passed to its handler.

Use the `finally` clause whenever you need to do some clean up, such as closing a file, to ensure that the clean up happens no matter how the method exits.

It is also possible to have a `finally` clause following one or more `catch` clauses. Then the code in the `finally` clause is executed whenever the `try` block is exited in any of three ways:

1. After completing the last statement of the `try` block
2. After completing the last statement of a `catch` clause, if this `try` block caught an exception
3. When an exception was thrown in the `try` block and not caught

However, we recommend that you don't mix `catch` and `finally` clauses in the same `try` block—see Quality Tip 11.3 on page 427.

Syntax 11.4 The finally Clause

Syntax

```
try
{
   statement
   statement
   . . .
}
finally
{
   statement
   statement
   . . .
}
```

Example

This variable must be declared outside the try block so that the finally clause can access it.

```
PrintWriter out = new PrintWriter(filename);
try
{
   writeData(out);
}
finally
{
   out.close();
}
```

This code may throw exceptions.

This code is always executed, even if an exception occurs.

SELF CHECK

12. Why was the out variable declared outside the try block?

13. Suppose the file with the given name does not exist. Trace the flow of execution of the code segment in this section.

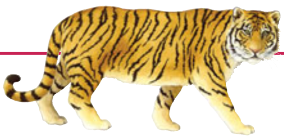
Quality Tip 11.3

Do Not Use catch and finally in the Same try Statement

It is tempting to combine catch and finally clauses, but the resulting code can be hard to understand. Instead, you should use a try/finally statement to close resources and a separate try/catch statement to handle errors. For example,

```
try
{
   PrintWriter out = new PrintWriter(filename);
   try
   {
      Write output to out
   }
   finally
   {
      out.close();
      }
   }
   catch (IOException exception)
   {
      Handle exception
   }
```

Note that the nested statements work correctly if the `PrintWriter` constructor throws an exception—see Exercise R11.18.



Special Topic 11.4

Automatic Resource Management in Java 7

In Java 7, you can use a new form of the `try` block that automatically closes an object that implements the `Closeable` interface, such as a `PrintWriter` or `Scanner`. Here is the syntax:

```
   try (PrintWriter out = new PrintWriter(filename))
   {
      Write output to out
   }
```

The `close` method is automatically invoked on the `out` object when the `try` block ends, whether or not an exception has occurred. A `finally` statement is not required.

11.7 Designing Your Own Exception Types

Sometimes none of the standard exception types describe your particular error condition well enough. In that case, you can design your own exception class. Consider a bank account. Let's report an `InsufficientFundsException` when an attempt is made to withdraw an amount from a bank account that exceeds the current balance.

```
   if (amount > balance)
   {
      throw new InsufficientFundsException(
            "withdrawal of " + amount + " exceeds balance of " + balance);
   }
```

To describe an error condition, provide a subclass of an existing exception class.

Now you need to provide the `InsufficientFundsException` class. Should it be a checked or an unchecked exception? Is it the fault of some external event, or is it the fault of the programmer? We take the position that the programmer could have prevented the exceptional condition—after all, it would have been an easy matter to check whether `amount <= account.getBalance()` before calling the `withdraw` method. Therefore, the exception should be an unchecked exception and extend the `RuntimeException` class or one of its subclasses.

It is a good idea to extend an appropriate class in the exception hierarchy. For example, we can consider an `InsufficientFundsException` a special case of an `IllegalArgumentException`. This enables other programmers to catch the exception as an `IllegalArgumentException` if they are not interested in the exact nature of the problem.

It is customary to provide two constructors for an exception class: a constructor with no parameters and a constructor that accepts a message string describing the reason for the exception. Here is the declaration of the exception class.

```
public class InsufficientFundsException extends IllegalArgumentException
{
   public InsufficientFundsException() {}

   public InsufficientFundsException(String message)
   {
      super(message);
   }
}
```

When the exception is caught, its message string can be retrieved using the `getMessage` method of the `Throwable` class.

SELF CHECK

14. What is the purpose of the call `super(message)` in the second `InsufficientFundsException` constructor?

15. Suppose you read bank account data from a file. Contrary to your expectation, the next input value is not of type `double`. You decide to implement a `BadDataException`. Which exception class should you extend?

Quality Tip 11.4

Do Throw Specific Exceptions

When throwing an exception, you should choose an exception class that describes the situation as closely as possible. For example, it would be a bad idea to simply throw a `RuntimeException` object when a bank account has insufficient funds. This would make it far too difficult to catch the exception. After all, if you caught all exceptions of type `RuntimeException`, your `catch` clause would also be activated by exceptions of the type `NullPointerException`, `ArrayIndexOutOfBoundsException`, and so on. You would then need to carefully examine the exception object and attempt to deduce whether the exception was caused by insufficient funds.

If the standard library does not have an exception class that describes your particular error situation, simply provide a new exception class.

11.8 Case Study: A Complete Example

This section walks through a complete example of a program with exception handling. The program asks a user for the name of a file. The file is expected to contain data values. The first line of the file contains the total number of values, and the remaining lines contain the data. A typical input file looks like this:

```
3
1.45
-2.1
0.05
```

What can go wrong? There are two principal risks.

- The file might not exist.
- The file might have data in the wrong format.

Who can detect these faults? The `Scanner` constructor will throw an exception when the file does not exist. The methods that process the input values need to throw an exception when they find an error in the data format.

What exceptions can be thrown? The `Scanner` constructor throws a `FileNotFoundException` when the file does not exist, which is appropriate in our situation. Finally, when the file data is in the wrong format, we will throw a `BadDataException`, a custom checked exception class. We use a checked exception because corruption of a data file is beyond the control of the programmer.

Who can remedy the faults that the exceptions report? Only the `main` method of the `DataAnalyzer` program interacts with the user. It catches the exceptions, prints appropriate error messages, and gives the user another chance to enter a correct file.

ch11/data/DataAnalyzer.java

```java
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Scanner;

/**
   This program reads a file containing numbers and analyzes its contents.
   If the file doesn't exist or contains strings that are not numbers, an
   error message is displayed.
*/
public class DataAnalyzer
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      DataSetReader reader = new DataSetReader();

      boolean done = false;
      while (!done)
      {
         try
         {
            System.out.println("Please enter the file name: ");
            String filename = in.next();

            double[] data = reader.readFile(filename);
            double sum = 0;
            for (double d : data) sum = sum + d;
            System.out.println("The sum is " + sum);
            done = true;
         }
         catch (FileNotFoundException exception)
         {
            System.out.println("File not found.");
         }
         catch (BadDataException exception)
         {
            System.out.println("Bad data: " + exception.getMessage());
         }
         catch (IOException exception)
         {
            exception.printStackTrace();
         }
      }
   }
}
```

The `catch` clauses in the `main` method give a human-readable error report if the file was not found or bad data was encountered.

The following `readFile` method of the `DataSetReader` class constructs the `Scanner` object and calls the `readData` method. It is completely unconcerned with any exceptions. If there is a problem with the input file, it simply passes the exception to its caller.

```
public double[] readFile(String filename) throws IOException
{
   File inFile = new File(filename);
   Scanner in = new Scanner(inFile);
   try
   {
      readData(in);
      return data;
   }
   finally
   {
      in.close();
   }
}
```

The method throws an `IOException`, the common superclass of `FileNotFoundException` (thrown by the `Scanner` constructor) and `BadDataException` (thrown by the `readData` method).

Next, here is the `readData` method of the `DataSetReader` class. It reads the number of values, constructs an array, and calls `readValue` for each data value.

```
private void readData(Scanner in) throws BadDataException
{
   if (!in.hasNextInt())
      throw new BadDataException("Length expected");
   int numberOfValues = in.nextInt();
   data = new double[numberOfValues];

   for (int i = 0; i < numberOfValues; i++)
      readValue(in, i);

   if (in.hasNext())
      throw new BadDataException("End of file expected");
}
```

This method checks for two potential errors. The file might not start with an integer, or it might have additional data after reading all values.

However, this method makes no attempt to catch any exceptions. Plus, if the `readValue` method throws an exception—which it will if there aren't enough values in the file—the exception is simply passed on to the caller.

Here is the `readValue` method:

```
private void readValue(Scanner in, int i) throws BadDataException
{
   if (!in.hasNextDouble())
      throw new BadDataException("Data value expected");
   data[i] = in.nextDouble();
}
```

To see the exception handling at work, look at a specific error scenario.

ANIMATION
Exception Handling

1. `DataAnalyzer.main` calls `DataSetReader.readFile`.
2. `readFile` calls `readData`.
3. `readData` calls `readValue`.
4. `readValue` doesn't find the expected value and throws a `BadDataException`.
5. `readValue` has no handler for the exception and terminates immediately.
6. `readData` has no handler for the exception and terminates immediately.
7. `readFile` has no handler for the exception and terminates immediately after executing the `finally` clause and closing the `Scanner` object.
8. `DataAnalyzer.main` has a handler for a `BadDataException`. That handler prints a message to the user. Afterwards, the user is given another chance to enter a file name. Note that the statements computing the sum of the values have been skipped.

This example shows the separation between error detection (in the `DataSetReader.readValue` method) and error handling (in the `DataAnalyzer.main` method). In between the two are the `readData` and `readFile` methods, which just pass exceptions along.

ch11/data/DataSetReader.java

```
import java.io.File;
import java.io.IOException;
import java.util.Scanner;

/**
   Reads a data set from a file. The file must have the format
   numberOfValues
   value1
   value2
   . . .
*/
public class DataSetReader
{
   private double[] data;

   /**
      Reads a data set.
      @param filename the name of the file holding the data
      @return the data in the file
   */
   public double[] readFile(String filename) throws IOException
   {
      File inFile = new File(filename);
      Scanner in = new Scanner(inFile);

```

```java
      try
      {
         readData(in);
         return data;
      }
      finally
      {
         in.close();
      }
   }

   /**
      Reads all data.
      @param in the scanner that scans the data
   */
   private void readData(Scanner in) throws BadDataException
   {
      if (!in.hasNextInt())
         throw new BadDataException("Length expected");
      int numberOfValues = in.nextInt();
      data = new double[numberOfValues];

      for (int i = 0; i < numberOfValues; i++)
         readValue(in, i);

      if (in.hasNext())
         throw new BadDataException("End of file expected");
   }

   /**
      Reads one data value.
      @param in the scanner that scans the data
      @param i the position of the value to read
   */
   private void readValue(Scanner in, int i) throws BadDataException
   {
      if (!in.hasNextDouble())
         throw new BadDataException("Data value expected");
      data[i] = in.nextDouble();
   }
}
```

ch11/data/BadDataException.java

```java
import java.io.IOException;

/**
   This class reports bad input data.
*/
public class BadDataException extends IOException
{
   public BadDataException() {}
   public BadDataException(String message)
   {
      super(message);
   }
}
```

SELF CHECK

16. Why doesn't the `DataSetReader.readFile` method catch any exceptions?
17. Suppose the user specifies a file that exists and is empty. Trace the flow of execution.

Random Fact 11.1

The Ariane Rocket Incident

Random Fact 11.1 tells the story of the Ariane 5 rocket that blew itself up due to an unhandled exception.

Summary of Learning Objectives

Read and write text that is stored in files.

- When reading text files, use the `Scanner` class.
- When writing text files, use the `PrintWriter` class.
- You must close a print stream when you are done writing output.

Choose an appropriate mechanism for processing input.

- The `next` method reads a word at a time. Call `Scanner.useDelimiter` to specify a pattern for word boundaries.
- The `nextLine` method reads a line of input and consumes the newline character at the end of the line.
- The `nextInt` and `nextDouble` methods consume white space and the next number.
- To read one character at a time, set the delimiter pattern to the empty string.

Understand when and how to throw an exception.

- To signal an exceptional condition, use the `throw` statement to throw an exception object.
- When you throw an exception, the current method terminates immediately.

Choose between checked and unchecked exceptions.

- There are two kinds of exceptions: *checked* and *unchecked*. Unchecked exceptions extend the class `RuntimeException` or `Error`.
- Checked exceptions are due to external circumstances that the programmer cannot prevent. The compiler checks that your program handles these exceptions.
- Add a `throws` clause to a method that can throw a checked exception.

Use exception handlers to decouple error detection and error reporting.

- In a method that is ready to handle a particular exception type, place the statements that can cause the exception inside a `try` block, and the handler inside a `catch` clause.
- Throw an exception as soon as a problem is detected. Catch it only when the problem can be handled.

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Use the `finally` clause to ensure that resources are released when an exception is thrown.

- Once a `try` block is entered, the statements in a `finally` clause are guaranteed to be executed, whether or not an exception is thrown.

Design exception types to describe error conditions.

- To describe an error condition, provide a subclass of an existing exception class.

Classes, Objects, and Methods Introduced in this Chapter

```
java.io.EOFException
java.io.File
java.io.FileNotFoundException
java.io.IOException
java.io.PrintWriter
   close
java.lang.Error
java.lang.IllegalArgumentException
java.lang.IllegalStateException
java.lang.NullPointerException
java.lang.NumberFormatException
java.lang.RuntimeException
java.lang.Throwable
   getMessage
   printStackTrace
java.util.NoSuchElementException
java.util.Scanner
   close
javax.swing.JFileChooser
   getSelectedFile
   showOpenDialog
   showSaveDialog
```

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** Analyzing Baby Names
- Lab Exercises
- ***Animation*** Exception Handling
- Practice Quiz
- Code Completion Exercises

Review Exercises

★★ **R11.1** What happens if you try to open a file for reading that doesn't exist? What happens if you try to open a file for writing that doesn't exist?

★★★ **R11.2** What happens if you try to open a file for writing, but the file or device is write-protected (sometimes called read-only)? Try it out with a short test program.

★ **R11.3** How do you open a file whose name contains a backslash, like `c:\temp\output.dat`?

★★★ **R11.4** What is a command line? How can a program read its command line arguments?

★★ **R11.5** Give two examples of programs on your computer that read arguments from the command line.

★★ **R11.6** If a program Woozle is started with the command

```
java Woozle -Dname=piglet -I\eeyore -v heff.txt a.txt lump.txt
```

what are the values of `args[0]`, `args[1]`, and so on?

★★ **R11.7** What is the difference between throwing an exception and catching an exception?

★★ **R11.8** What is a checked exception? What is an unchecked exception? Is a `NullPointerException` checked or unchecked? Which exceptions do you need to declare with the `throws` reserved word?

★ **R11.9** Why don't you need to declare that your method might throw a `NullPointerException`?

★★ **R11.10** When your program executes a `throw` statement, which statement is executed next?

★ **R11.11** What happens if an exception does not have a matching `catch` clause?

★ **R11.12** What can your program do with the exception object that a `catch` clause receives?

★ **R11.13** Is the type of the exception object always the same as the type declared in the `catch` clause that catches it?

★ **R11.14** What kind of values can you throw? Can you throw a string? An integer?

★★ **R11.15** What is the purpose of the `finally` clause? Give an example of how it can be used.

★★★ **R11.16** What happens when an exception is thrown, the code of a `finally` clause executes, and that code throws an exception of a different kind than the original one? Which one is caught by a surrounding `catch` clause? Write a sample program to try it out.

★★ **R11.17** Which exceptions can the `next` and `nextInt` methods of the `Scanner` class throw? Are they checked exceptions or unchecked exceptions?

★★★ **R11.18** Suppose the code in Quality Tip 11.3 on page 427 had been condensed to a single `try/catch/finally` statement:

```
PrintWriter out = new PrintWriter(filename);
try
{
   Write output
}
catch (IOException exception)
{
   Handle exception
}
finally
{
   out.close();
}
```

What is the disadvantage of this version? (*Hint:* What happens when the `PrintWriter` constructor throws an exception?) Why can't you solve the problem by moving the declaration of the out variable inside the `try` block?

★★ **R11.19** Suppose the program in Section 11.8 reads a file containing the following values:

```
0
1
2
3
```

What is the outcome? How could the program be improved to give a more accurate error report?

★★ **R11.20** Can the `readFile` method in Section 11.8 throw a `NullPointerException`? If so, how?

Programming Exercises

★★ **P11.1** Write a program that asks a user for a file name and prints the number of characters, words, and lines in that file.

★★ **P11.2** Write a program that asks the user for a file name and counts the number of characters, words, and lines in that file. Then the program asks for the name of the next file. When the user enters a file that doesn't exist, the program prints the total counts of characters, words, and lines in all processed files and exits.

★★ **P11.3** Write a program `CopyFile` that copies one file to another. The file names are specified on the command line. For example,

```
java CopyFile report.txt report.sav
```

★★ **P11.4** Write a program that *concatenates* the contents of several files into one file. For example,

```
java CatFiles chapter1.txt chapter2.txt chapter3.txt book.txt
```

makes a long file, `book.txt`, that contains the contents of the files `chapter1.txt`, `chapter2.txt`, and `chapter3.txt`. The output file is always the last file specified on the command line.

★★ **P11.5** Write a program `Find` that searches all files specified on the command line and prints out all lines containing a reserved word. For example, if you call

```
java Find ring report.txt address.txt Homework.java
```

then the program might print

```
report.txt: has broken up an international ring of DVD bootleggers that
address.txt: Kris Kringle, North Pole
address.txt: Homer Simpson, Springfield
Homework.java: String filename;
```

The reserved word is always the first command line argument.

★★ **P11.6** Write a program that checks the spelling of all words in a file. It should read each word of a file and check whether it is contained in a word list. A word list is available on most UNIX systems in the file `/usr/dict/words`. (If you don't have access to a UNIX system, your instructor should be able to get you a copy.) The program should print out all words that it cannot find in the word list.

★★ **P11.7** Write a program that replaces each line of a file with its reverse. For example, if you run

```
java Reverse HelloPrinter.java
```

then the contents of `HelloPrinter.java` are changed to

```
retnirPolleH ssalc cilbup
{
)sgra ][gnirtS(niam diov citats cilbup
{
wodniw elosnoc eht ni gniteerg a yalpsiD //

;)"!dlroW ,olleH"(nltnirp.tuo.metsyS
}
}
```

Of course, if you run `Reverse` twice on the same file, you get back the original file.

★ **P11.8** Get the data for names in prior decades from the Social Security Administration. Paste the table data in files named `babynames80s.txt`, etc. Modify the `BabyNames.java` program so that it prompts the user for a file name. The numbers in the files have comma separators, so modify the program to handle them. Can you spot a trend in the frequencies?

★ **P11.9** Write a program that reads in `babynames.txt` and produces two files `boynames.txt` and `girlnames.txt`, separating the data for the boys and girls.

★★ **P11.10** Write a program that reads a file in the same format as `babynames.txt` and prints all names that are both boy and girl names (such as Alexis or Morgan).

★★★ **P11.11** Write a program that replaces all tab characters `'\t'` in a file with the *appropriate* number of spaces. By default, the distance between tab columns should be 3 (the value we use in this book for Java programs) but it can be changed by the user. Expand tabs to the number of spaces necessary to move to the next tab column. That may be *less* than three spaces. For example, consider the line containing `"\t|\t||\t|"`. The first tab is changed to three spaces, the second to two spaces, and the third to one space. Your program should be executed as

```
java TabExpander filename
```

or

```
java TabExpander -t tabwidth filename
```

★ **P11.12** Modify the `BankAccount` class to throw an `IllegalArgumentException` when the account is constructed with a negative balance, when a negative amount is deposited, or when an amount that is not between `0` and the current balance is withdrawn. Write a test program that causes all three exceptions to occur and that catches them all.

★★ **P11.13** Repeat Exercise P11.12, but throw exceptions of three exception types that you provide.

★★ **P11.14** Write a program that asks the user to input a set of floating-point values. When the user enters a value that is not a number, give the user a second chance to enter the value. After two chances, quit reading input. Add all correctly specified values and print the sum when the user is done entering data. Use exception handling to detect improper inputs.

★★ **P11.15** Repeat Exercise P11.14, but give the user as many chances as necessary to enter a correct value. Quit the program only when the user enters a blank input.

★ **P11.16** Modify the `DataSetReader` class so that you do not call `hasNextInt` or `hasNextDouble`. Simply have `nextInt` and `nextDouble` throw a `NoSuchElementException` and catch it in the `main` method.

★★ **P11.17** Write a program that reads in a set of coin descriptions from a file. The input file has the format

```
coinName1 coinValue1
coinName2 coinValue2
. . .
```

Add a method

```
void read(Scanner in) throws FileNotFoundException
```

to the `Coin` class. Throw an exception if the current line is not properly formatted. Then implement a method

```
static ArrayList<Coin> readFile(String filename)
   throws FileNotFoundException
```

In the `main` method, call `readFile`. If an exception is thrown, give the user a chance to select another file. If you read all coins successfully, print the total value.

★★★ **P11.18** Design a class `Bank` that contains a number of bank accounts. Each account has an account number and a current balance. Add an `accountNumber` field to the `BankAccount` class. Store the bank accounts in an array list. Write a `readFile` method of the `Bank` class for reading a file with the format

```
accountNumber1  balance1
accountNumber2  balance2
. . .
```

Implement `read` methods for the `Bank` and `BankAccount` classes. Write a sample program to read in a file with bank accounts, then print the account with the highest balance. If the file is not properly formatted, give the user a chance to select another file.

Programming Projects

Project 11.1 You can read the contents of a web page with this sequence of commands.

```
String address = "http://java.sun.com/index.html";
URL u = new URL(address);
Scanner in = new Scanner(u.openStream());
. . .
```

Some of these methods may throw exceptions—check out the API documentation. Design a class `LinkFinder` that finds all hyperlinks of the form

`<a href="`*link*`">`*link text*`</a>`

Throw an exception if you find a malformed hyperlink. Extra credit if your program can follow the links that it finds and find links in those web pages as well. (This is the method that search engines such as Google use to find web sites.)

Answers to Self-Check Questions

1. When the `PrintWriter` object is created, the output file is emptied. Sadly, that is the same file as the input file. The input file is now empty and the `while` loop exits immediately.
2. The `Scanner` constructor throws a `FileNotFoundException`, and the program terminates.
3. `number` is 6, `input` is `",995.0"`
4. `price` is set to 6 because the comma is not considered a part of a floating-point number in Java. Then the call to `nextInt` causes an exception, and `quantity` is not set.

5. Read them as strings, and convert those strings to numbers that are not equal to `N/A`:

```
String input = in.next();
if (!input.equals("N/A"))
{
   double value = Double.parseDouble(input);
   Process value
}
```

6. Throw an exception if the amount being deposited is less than zero.
7. The balance is still zero because the last statement of the `withdraw` method was never executed.
8. You must include the `FileNotFoundException` and you may include the `NoSuchElementException` if you consider it important for documentation purposes. `InputMismatchException` is a subclass of `NoSuchElementException`. It is your choice whether to include it.
9. Because programmers should simply check for `null` pointers instead of trying to handle a `NullPointerException`.
10. The `Scanner` constructor succeeds, and `in` is constructed. Then the call `in.next()` throws a `NoSuchElementException`, and the `try` block is aborted. None of the catch clauses match, so none are executed. If none of the enclosing method calls catch the exception, the program terminates.
11. No—you catch both exception types in the same way, as you can see from the code example on page 424. Recall that `IOException` is a checked exception and `NumberFormatException` is an unchecked exception.
12. If it had been declared inside the `try` block, its scope would only have extended to the end of the `try` block, and the `finally` clause could not have closed it.
13. The `PrintWriter` constructor throws an exception. The assignment to `out` and the `try` block are skipped. The `finally` clause is not executed. This is the correct behavior because `out` has not been initialized.
14. To pass the exception message string to the `RuntimeException` superclass.
15. Because file corruption is beyond the control of the programmer, this should be a checked exception, so it would be wrong to extend `RuntimeException` or `IllegalArgumentException`. Because the error is related to input, `IOException` would be a good choice.
16. It would not be able to do much with them. The `DataSetReader` class is a reusable class that may be used for systems with different languages and different user interfaces. Thus, it cannot engage in a dialog with the program user.
17. `DataAnalyzer.main` calls `DataSetReader.readFile`, which calls `readData`. The call `in.hasNextInt()` returns `false`, and `readData` throws a `BadDataException`. The `readFile` method doesn't catch it, so it propagates back to `main`, where it is caught.

Chapter 12

Object-Oriented Design

CHAPTER GOALS

- To learn about the software life cycle
- To learn how to discover new classes and methods
- To understand the use of CRC cards for class discovery
- To be able to identify inheritance, aggregation, and dependency relationships between classes
- To master the use of UML class diagrams to describe class relationships
- To learn how to use object-oriented design to build complex programs

To implement a software system successfully, be it as simple as your next homework project or as complex as the next air traffic monitoring system, some amount of planning, design, and testing is required. In fact, for larger projects, the amount of time spent on planning is much higher than the amount of time spent on programming and testing.

If you find that most of your homework time is spent in front of the computer, keying in code and fixing bugs, you are probably spending more time on your homework than you should. You could cut down your total time by spending more on the planning and design phase. This chapter tells you how to approach these tasks in a systematic manner, using the object-oriented design methodology.

CHAPTER CONTENTS

12.1 The Software Life Cycle 442
RANDOM FACT 12.1: Programmer Productivity ⊕

12.2 Discovering Classes 446

12.3 Relationships Between Classes 449
HOW TO 12.1: CRC Cards and UML Diagrams 451
SPECIAL TOPIC 12.1: Attributes and Methods in UML Diagrams ⊕
SPECIAL TOPIC 12.2: Multiplicities ⊕
SPECIAL TOPIC 12.3: Aggregation and Association ⊕

12.4 Case Study: Printing an Invoice 452

12.5 Case Study: An Automatic Teller Machine 463
RANDOM FACT 12.2: Software Development—Art or Science? ⊕

12.1 The Software Life Cycle

The software life cycle encompasses all activities from initial analysis until obsolescence.

A formal process for software development describes phases of the development process and gives guidelines for how to carry out the phases.

In this section we will discuss the **software life cycle**: the activities that take place between the time a software program is first conceived and the time it is finally retired.

A software project usually starts because a customer has a problem and is willing to pay money to have it solved. The Department of Defense, the customer of many programming projects, was an early proponent of a *formal process* for software development. A formal process identifies and describes different phases and gives guidelines for carrying out the phases and when to move from one phase to the next.

Many software engineers break the development process down into the following five phases:

- Analysis
- Design
- Implementation
- Testing
- Deployment

In the *analysis* phase, you decide *what* the project is supposed to accomplish; you do not think about *how* the program will accomplish its tasks. The output of the analysis phase is a *requirements document*, which describes in complete detail what the program will be able to do once it is completed. Part of this requirements document can be a user manual that tells how the user will operate the program to derive the promised benefits. Another part sets performance criteria—how many inputs the program must be able to handle in what time, or what its maximum memory and disk storage requirements are.

In the *design* phase, you develop a plan for how you will implement the system. You discover the structures that underlie the problem to be solved. When you use object-oriented design, you decide what classes you need and what their most important methods are. The output of this phase is a description of the classes and methods, with diagrams that show the relationships among the classes.

In the *implementation* phase, you write and compile program code to implement the classes and methods that were discovered in the design phase. The output of this phase is the completed program.

In the *testing* phase, you run tests to verify that the program works correctly. The output of this phase is a report describing the tests that you carried out and their results.

In the *deployment* phase, the users of the program install it and use it for its intended purpose.

The waterfall model of software development describes a sequential process of analysis, design, implementation, testing, and deployment.

When formal development processes were first established in the early 1970s, software engineers had a very simple visual model of these phases. They postulated that one phase would run to completion, its output would spill over to the next phase, and the next phase would begin. This model is called the **waterfall model** of software development (see Figure 1).

In an ideal world the waterfall model has a lot of appeal: You figure out what to do; then you figure out how to do it; then you do it; then you verify that you did it right; then you hand the product to the customer. When rigidly applied, though, the waterfall model simply did not work. It was very difficult to come up with a perfect requirement specification. It was quite common to discover in the design phase that the requirements were inconsistent or that a small change in the requirements would lead to a system that was both easier to design and more useful for the customer, but the analysis phase was over, so the designers had no choice—they had to take the existing requirements, errors and all. This problem would repeat itself during implementation. The designers may have thought they knew how to solve the problem as efficiently as possible, but when the design was actually implemented, it turned out that the resulting program was not as fast as the designers had thought. The next transition is one with which you are surely familiar. When the program was handed to the quality assurance department for testing, many bugs were found that would best be fixed by reimplementing, or maybe even redesigning, the program, but the waterfall model did not allow for this. Finally, when the customers received the finished product, they were often not at all happy with it. Even though the customers typically were very involved in the analysis phase, often they

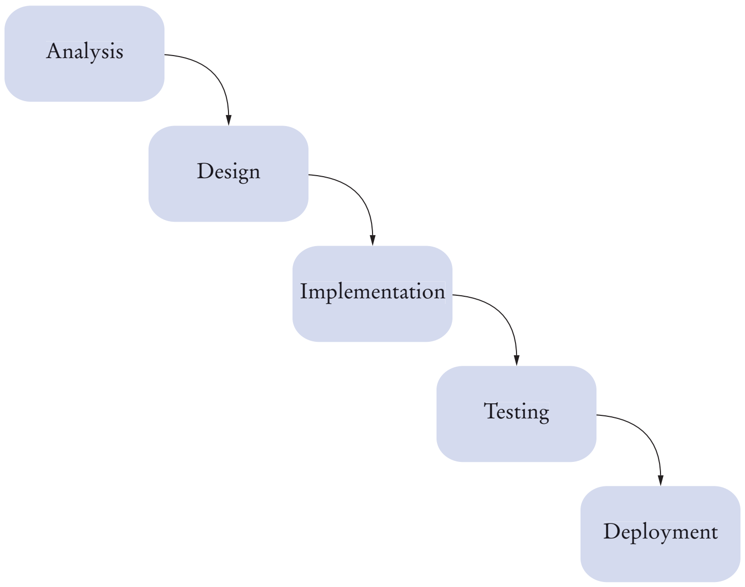


Figure 1 The Waterfall Model

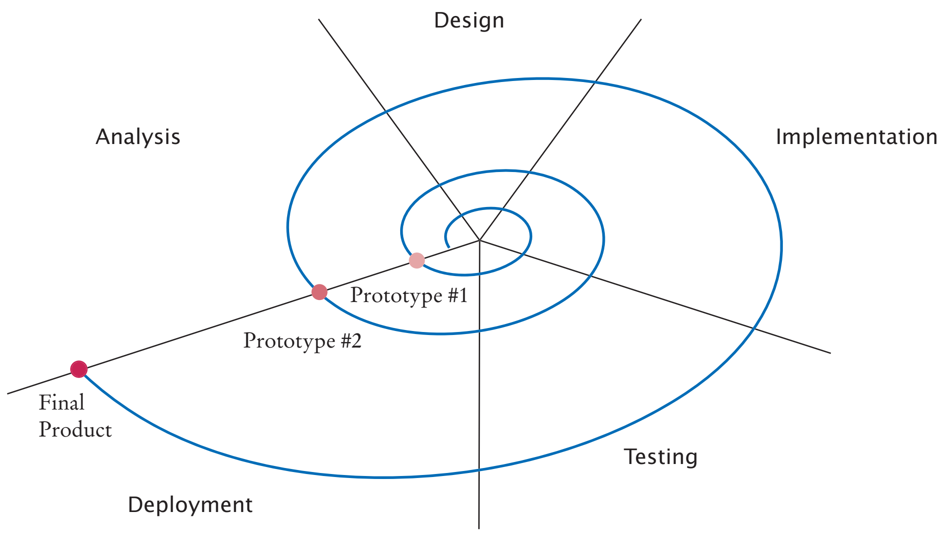


Figure 2 A Spiral Model

themselves were not sure exactly what they needed. After all, it can be very difficult to describe how you want to use a product that you have never seen before. But when the customers started using the program, they began to realize what they would have liked. Of course, then it was too late, and they had to live with what they got.

The spiral model of software development describes an iterative process in which design and implementation are repeated.

Having some level of iteration is clearly necessary. There simply must be a mechanism to deal with errors from the preceding phase. A **spiral model**, originally proposed by Barry Boehm in 1988, breaks the development process down into multiple phases (see Figure 2). Early phases focus on the construction of *prototypes.* A prototype is a small system that shows some aspects of the final system. Because prototypes model only a part of a system and do not need to withstand customer abuse, they can be implemented quickly. It is common to build a *user interface prototype* that shows the user interface in action. This gives customers an early chance to become more familiar with the system and to suggest improvements before the analysis is complete. Other prototypes can be built to validate interfaces with external systems, to test performance, and so on. Lessons learned from the development of one prototype can be applied to the next iteration of the spiral.

By building in repeated trials and feedback, a development process that follows the spiral model has a greater chance of delivering a satisfactory system. However, there is also a danger. If engineers believe that they don't have to do a good job because they can always do another iteration, then there will be many iterations, and the process will take a very long time to complete.

Extreme Programming is a development methodology that strives for simplicity by removing formal structure and focusing on best practices.

Figure 3 shows activity levels in the "Rational Unified Process", a development process methodology by the inventors of UML (see Grady Booch, James Rumbaugh, and Ivar Jacobson, *The Unified Modeling Language User Guide,* Addison-Wesley, 1999). The details are not important, but as you can see, this is a complex process involving multiple iterations.

Even complex development processes with many iterations have not always met with success. In 1999, Kent Beck published an influential book on **Extreme Programming**, a development methodology that strives for simplicity by cutting out

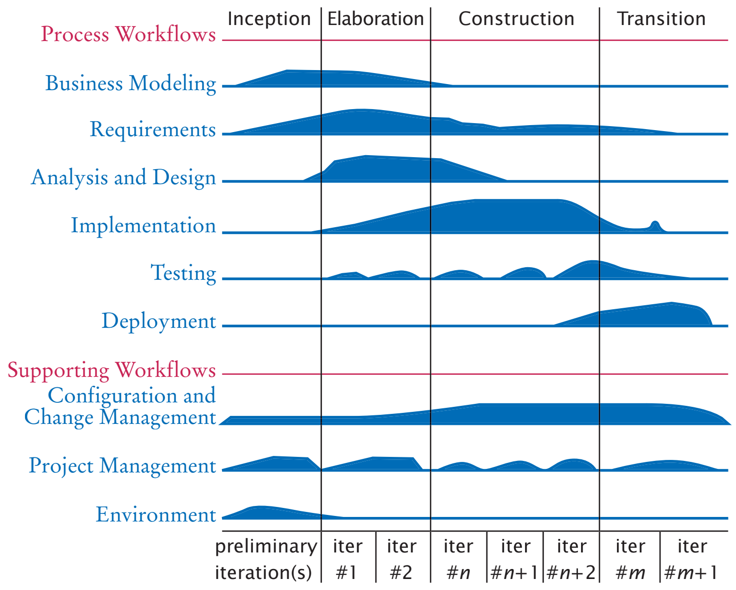


Figure 3 Activity Levels in the Rational Unified Process Methodology

most of the formal trappings of a traditional development methodology and instead focusing on a set of *practices:*

- *Realistic planning:* Customers are to make business decisions, programmers are to make technical decisions. Update the plan when it conflicts with reality.
- *Small releases:* Release a useful system quickly, then release updates on a very short cycle.
- *Metaphor:* All programmers should have a simple shared story that explains the system under development.
- *Simplicity:* Design everything to be as simple as possible instead of preparing for future complexity.
- *Testing:* Both programmers and customers are to write test cases. The system is continuously tested.
- *Refactoring:* Programmers are to restructure the system continuously to improve the code and eliminate duplication.
- *Pair programming:* Put programmers together in pairs, and require each pair to write code on a single computer.
- *Collective ownership:* All programmers have permission to change all code as it becomes necessary.
- *Continuous integration:* Whenever a task is completed, build the entire system and test it.
- *40-hour week:* Don’t cover up unrealistic schedules with bursts of heroic effort.
- *On-site customer:* An actual customer of the system is to be accessible to team members at all times.
- *Coding standards:* Programmers are to follow standards that emphasize self-documenting code.

Many of these practices are common sense. Others, such as the pair programming requirement, are surprising. Beck claims that the value of the Extreme Programming approach lies in the synergy of these practices—the sum is bigger than the parts.

In your first programming course, you will not develop systems that are so complex that you need a full-fledged methodology to solve your homework problems. This introduction to the development process should, however, show you that successful software development involves more than just coding. In the remainder of this chapter we will have a closer look at the *design phase* of the software development process.

SELF CHECK

1. Suppose you sign a contract, promising that you will, for an agreed-upon price, design, implement, and test a software package exactly as it has been specified in a requirements document. What is the primary risk you and your customer are facing with this business arrangement?
2. Does Extreme Programming follow a waterfall or a spiral model?
3. What is the purpose of the "on-site customer" in Extreme Programming?

Random Fact 12.1

Programmer Productivity

Random Fact 12.1 presents information about the productivity of individual programmers and teams.

12.2 Discovering Classes

In the design phase of software development, your task is to discover structures that make it possible to implement a set of tasks on a computer. When you use the object-oriented design process, you carry out the following tasks:

In object-oriented design, you discover classes, determine the responsibilities of classes, and describe the relationships between classes.

1. Discover classes.
2. Determine the responsibilities of each class.
3. Describe the relationships between the classes.

A class represents some useful concept. You have seen classes for concrete entities, such as bank accounts, ellipses, and products. Other classes represent abstract concepts, such as streams and windows.

Make a list of candidates for classes, starting with nouns in the task description.

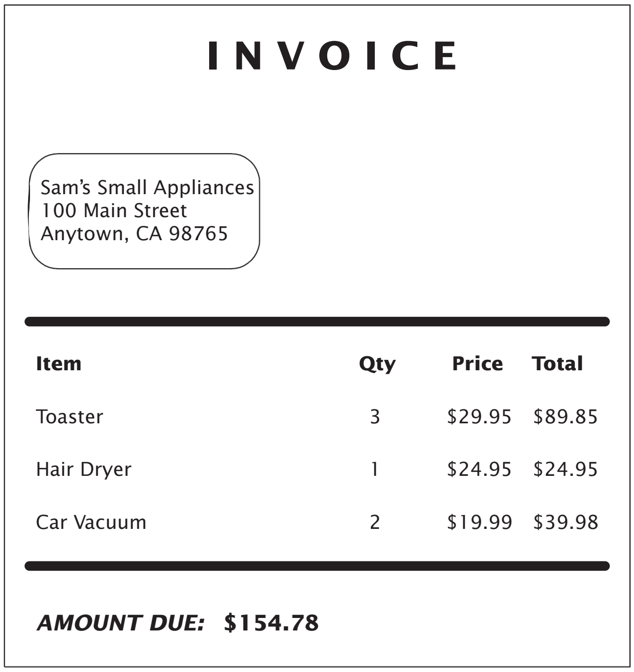
A simple rule for finding classes is to look for *nouns* in the task description. For example, suppose your job is to print an invoice such as the one in Figure 4. Obvious classes that come to mind are `Invoice`, `LineItem`, and `Customer`. It is a good idea to keep a list of *candidate classes* on a whiteboard or a sheet of paper. As you brainstorm, simply put all ideas for classes onto the list. You can always cross out the ones that weren't useful after all.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

When finding classes, keep the following points in mind:

- A class represents a set of objects with the same behavior. Entities with multiple occurrences in your problem description, such as customers or products, are good candidates for objects. Find out what they have in common, and design classes to capture those commonalities.
- Some entities should be represented as objects, others as primitive types. For example, should an address be an object of an `Address` class, or should it simply be a string? There is no perfect answer—it depends on the task that you want to solve. If your software needs to analyze addresses (for example, to determine shipping costs), then an `Address` class is an appropriate design. However, if your software will never need such a capability, you should not waste time on an overly complex design. It is your job to find a balanced design; one that is not too limiting or excessively general.
- Not all classes can be discovered in the analysis phase. Most complex programs need classes for tactical purposes, such as file or database access, user interfaces, control mechanisms, and so on.
- Some of the classes that you need may already exist, either in the standard library or in a program that you developed previously. You also may be able to use inheritance to extend existing classes into classes that match your needs.

Once a set of classes has been identified, you need to define the behavior for each class. That is, you need to find out what methods each object needs to do to solve the programming problem. A simple rule for finding these methods is to look for *verbs* in the task description, then match the verbs to the appropriate objects. For example, in the invoice program, a class needs to compute the amount due. Now you need to figure out *which class* is responsible for this method. Do customers



I N V O I C E

Sam's Small Appliances
100 Main Street
Anytown, CA 98765

Item	Qty	Price	Total
Toaster	3	$29.95	$89.85
Hair Dryer	1	$24.95	$24.95
Car Vacuum	2	$19.99	$39.98

AMOUNT DUE: **$154.78**

Figure 4
An Invoice

compute what they owe? Do invoices total up the amount due? Do the items total themselves up? The best choice is to make "compute amount due" the responsibility of the `Invoice` class.

A CRC card describes a class, its responsibilities, and its collaborating classes.

An excellent way to carry out this task is the "**CRC card** method." *CRC* stands for "*c*lasses", "*r*esponsibilities", "*c*ollaborators", and in its simplest form, the method works as follows. Use an index card for each *class* (see Figure 5). As you think about verbs in the task description that indicate methods, you pick the card of the class that you think should be responsible, and write that *responsibility* on the card.

For each responsibility, you record which other classes are needed to fulfill it. Those classes are the **collaborators**.

For example, suppose you decide that an invoice should compute the amount due. Then you write "compute amount due" on the left-hand side of an index card with the title `Invoice`.

If a class can carry out that responsibility by itself, do nothing further. But if the class needs the help of other classes, write the names of these collaborators on the right-hand side of the card.

To compute the total, the invoice needs to ask each line item about its total price. Therefore, the `LineItem` class is a collaborator.

This is a good time to look up the index card for the `LineItem` class. Does it have a "get total price" method? If not, add one.

How do you know that you are on the right track? For each responsibility, ask yourself how it can actually be done, using the responsibilities written on the various cards. Many people find it helpful to group the cards on a table so that the collaborators are close to each other, and to simulate tasks by moving a token (such as a coin) from one card to the next to indicate which object is currently active.

Keep in mind that the responsibilities that you list on the CRC card are on a *high level*. Sometimes a single responsibility may need two or more Java methods for carrying it out. Some researchers say that a CRC card should have no more than three distinct responsibilities.

The CRC card method is informal on purpose, so that you can be creative and discover classes and their properties. Once you find that you have settled on a good set of classes, you will want to know how they are related to each other. Can you find

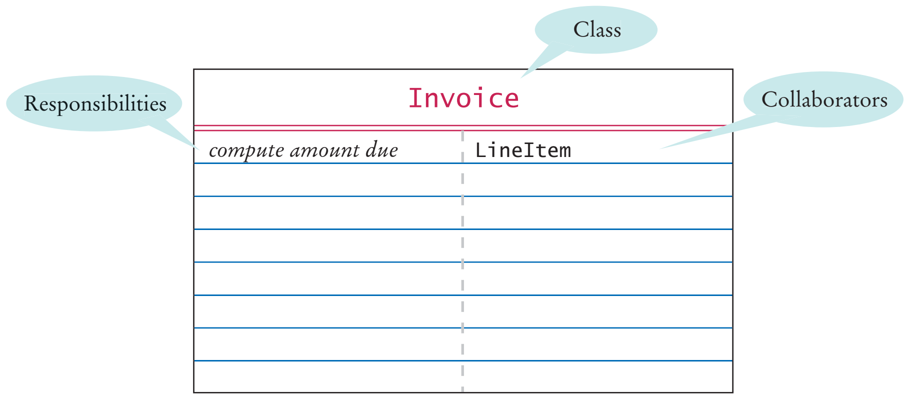


Figure 5 A CRC Card

classes with common properties, so that some responsibilities can be taken care of by a common superclass? Can you organize classes into clusters that are independent of each other? Finding class relationships and documenting them with diagrams is the topic of the next section.

SELF CHECK

4. Suppose the invoice is to be saved to a file. Name a likely collaborator.
5. Looking at the invoice in Figure 4, what is a likely responsibility of the `Customer` class?
6. What do you do if a CRC card has ten responsibilities?

12.3 Relationships Between Classes

When designing a program, it is useful to document the relationships between classes. This helps you in a number of ways. For example, if you find classes with common behavior, you can save effort by placing the common behavior into a superclass. If you know that some classes are *not* related to each other, you can assign different programmers to implement each of them, without worrying that one of them has to wait for the other.

You have seen the inheritance relationship between classes many times in this book. Inheritance is a very important relationship, but, as it turns out, it is not the only useful relationship, and it can be overused.

Inheritance is a relationship between a more general class (the superclass) and a more specialized class (the subclass). This relationship is often described as the *is-a* relationship. Every truck is a vehicle. Every savings account is a bank account. Every circle is an ellipse (with equal width and height).

Inheritance (the *is-a* relationship) is sometimes inappropriately used when the *has-a* relationship would be more appropriate.

Inheritance is sometimes abused, however. For example, consider a `Tire` class that describes a car tire. Should the class `Tire` be a subclass of a class `Circle`? It sounds convenient. There are quite a few useful methods in the `Circle` class—for example, the `Tire` class may inherit methods that compute the radius, perimeter, and center point, which should come in handy when drawing tire shapes. Though it may be convenient for the programmer, this arrangement makes no sense conceptually. It isn't true that every tire is a circle. Tires are car parts, whereas circles are geometric objects. There is a relationship between tires and circles, though. A tire *has a* circle as its boundary. Java lets us model that *has-a* relationship, too. Use an instance variable:

```
public class Tire
{
   private String rating;
   private Circle boundary;
   . . .
}
```

The technical term for this relationship is **aggregation**. Each `Tire` aggregates a `Circle` object. In general, a class aggregates another class if its objects have objects of the other class.

Aggregation (the *has-a* relationship) denotes that objects of one class contain references to objects of another class.

Here is another example. Every car *is a* vehicle. Every car *has a* tire (in fact, it has typically four or, if you count the spare, five). Thus, you would use inheritance from Vehicle and use aggregation of Tire objects:

```
public class Car extends Vehicle
{
   private Tire[] tires;
   . . .
}
```

In this book, we use the UML notation for class diagrams. You have already seen many examples of the UML notation for inheritance—an arrow with an open triangle pointing to the superclass. In the UML notation, aggregation is denoted by a solid line with a diamond-shaped symbol next to the aggregating class. Figure 6 shows a class diagram with an inheritance and an aggregation relationship.

Dependency is another name for the *uses* relationship.

The aggregation relationship is related to the **dependency** relationship, which you saw in Chapter 8. Recall that a class depends on another if one of its methods *uses* an object of the other class in some way.

For example, many of our applications depend on the Scanner class, because they use a Scanner object to read input.

You need to be able to distinguish the UML notations for inheritance, interface implementation, aggregation, and dependency.

Aggregation is a stronger form of dependency. If a class has objects of another class, it certainly uses the other class. However, the converse is not true. For example, a class may use the Scanner class without ever declaring an instance variable of class Scanner. The class may simply construct a local variable of type Scanner, or its methods may receive Scanner objects as parameters. This use is not aggregation because the objects of the class don't contain Scanner objects—they just create or receive them for the duration of a single method.

Generally, you need aggregation when an object needs to remember another object *between method calls*.

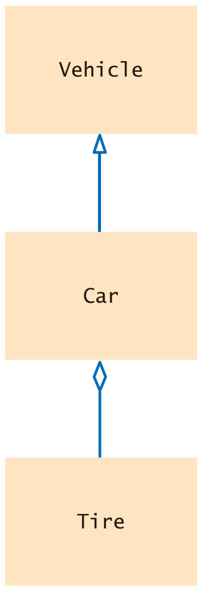


Figure 6
UML Notation for Inheritance and Aggregation

As you saw in Chapter 8, the UML notation for dependency is a dashed line with an open arrow that points to the dependent class.

The arrows in the UML notation can get confusing. Table 1 shows a summary of the four UML relationship symbols that we use in this book.

Table 1 UML Relationship Symbols

Relationship	Symbol	Line Style	Arrow Tip
Inheritance	───────▷	Solid	Triangle
Interface Implementation	- - - - - - - -▷	Dotted	Triangle
Aggregation	◇───────	Solid	Diamond
Dependency	- - - - - - - ->	Dotted	Open

SELF CHECK

7. Consider the `Bank` and `BankAccount` classes of Chapter 7. How are they related?
8. Consider the `BankAccount` and `SavingsAccount` objects of Chapter 10. How are they related?
9. Consider the `BankAccountTester` class of Chapter 3. Which classes does it depend on?

How To 12.1 CRC Cards and UML Diagrams

Before writing code for a complex problem, you need to design a solution. The methodology introduced in this chapter suggests that you follow a design process that is composed of the following tasks:

- Discover classes.
- Determine the responsibilities of each class.
- Describe the relationships between the classes.

CRC cards and UML diagrams help you discover and record this information.

Step 1 Discover classes.

Highlight the nouns in the problem description. Make a list of the nouns. Cross out those that don't seem to be reasonable candidates for classes.

Step 2 Discover responsibilities.

Make a list of the major tasks that your system needs to fulfill. From those tasks, pick one that is not trivial and that is intuitive to you. Find a class that is responsible for carrying out that task. Make an index card and write the name and the task on it. Now ask yourself how an object of the class can carry out the task. It probably needs help from other objects. Then make CRC cards for the classes to which those objects belong and write the responsibilities on them.

Don't be afraid to cross out, move, split, or merge responsibilities. Rip up cards if they become too messy. This is an informal process.

You are done when you have walked through all major tasks and are satisfied that they can all be solved with the classes and responsibilities that you discovered.

Step 3 Describe relationships.

Make a class diagram that shows the relationships between all the classes that you discovered.

Start with inheritance—the *is-a* relationship between classes. Is any class a specialization of another? If so, draw inheritance arrows. Keep in mind that many designs, especially for simple programs, don't use inheritance extensively.

The "collaborators" column of the CRC cards tell you which classes use others. Draw usage arrows for the collaborators on the CRC cards.

Some dependency relationships give rise to aggregations. For each of the dependency relationships, ask yourself: How does the object locate its collaborator? Does it navigate to it directly because it stores a reference? In that case, draw an aggregation arrow. Or is the collaborator a method parameter or return value? Then simply draw a dependency arrow.

Special Topic 12.1 – 12.3

UML Notation

Special Topics 12.1–12.3 discuss advanced features of the UML notation: attributes and methods in class diagrams, multiplicities, and the association relationship.

12.4 Case Study: Printing an Invoice

In this chapter, we discuss a five-part development process that is particularly well suited for beginning programmers:

1. Gather requirements.
2. Use CRC cards to find classes, responsibilities, and collaborators.
3. Use UML diagrams to record class relationships.
4. Use `javadoc` to document method behavior.
5. Implement your program.

There isn't a lot of notation to learn. The class diagrams are simple to draw. The deliverables of the design phase are obviously useful for the implementation phase—you simply take the source files and start adding the method code. Of course, as your projects get more complex, you will want to learn more about formal design methods. There are many techniques to describe object scenarios, call sequencing, the large-scale structure of programs, and so on, that are very beneficial even for relatively simple projects. *The Unified Modeling Language User Guide* gives a good overview of these techniques.

In this section, we will walk through the object-oriented design technique with a very simple example. In this case, the methodology may feel overblown, but it is a good introduction to the mechanics of each step. You will then be better prepared for the more complex example that follows.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

12.4.1 Requirements

Start the development process by gathering and documenting program requirements.

Before you begin designing a solution, you should gather all requirements for your program in plain English. Write down what your program should do. It is helpful to include typical scenarios in addition to a general description.

The task of our sample program is to print out an invoice. An invoice describes the charges for a set of products in certain quantities. (We omit complexities such as dates, taxes, and invoice and customer numbers.) The program simply prints the billing address, all line items, and the amount due. Each line item contains the description and unit price of a product, the quantity ordered, and the total price.

```
                    I N V O I C E

Sam's Small Appliances
100 Main Street
Anytown, CA 98765

Description                     Price  Qty  Total
Toaster                         29.95   3   89.85
Hair dryer                      24.95   1   24.95
Car vacuum                      19.99   2   39.98

AMOUNT DUE: $154.78
```

Also, in the interest of simplicity, we do not provide a user interface. We just supply a test program that adds line items to the invoice and then prints it.

12.4.2 CRC Cards

Use CRC cards to find classes, responsibilities, and collaborators.

When designing an object-oriented program, you need to discover classes. Classes correspond to nouns in the requirements description. In this problem, it is pretty obvious what the nouns are:

```
Invoice             Address
LineItem            Product
Description         Price
Quantity            Total
Amount due
```

(Of course, `Toaster` doesn't count—it is the description of a `LineItem` object and therefore a data value, not the name of a class.)

Description and price are attributes of the `Product` class. What about the quantity? The quantity is not an attribute of a `Product`. Just as in the printed invoice, let's have a class `LineItem` that records the product and the quantity (such as "3 toasters").

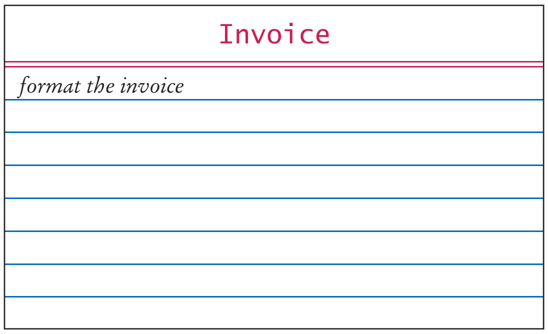
The total and amount due are computed—not stored anywhere. Thus, they don't lead to classes.

After this process of elimination, we are left with four candidates for classes:

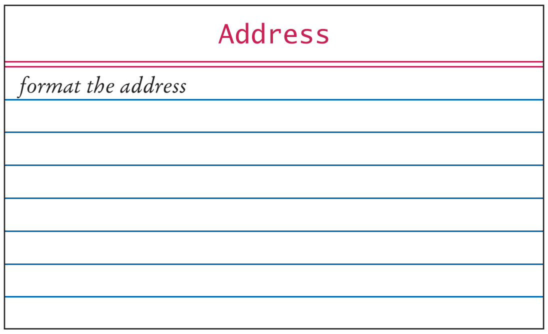
```
Invoice
Address
LineItem
Product
```

Each of them represents a useful concept, so let's make them all into classes.

The purpose of the program is to print an invoice. However, the `Invoice` class won't necessarily know whether to display the output in `System.out`, in a text area, or in a file. Therefore, let's relax the task slightly and make the invoice responsible for *formatting* the invoice. The result is a string (containing multiple lines) that can be printed out or displayed. Record that responsibility on a CRC card:

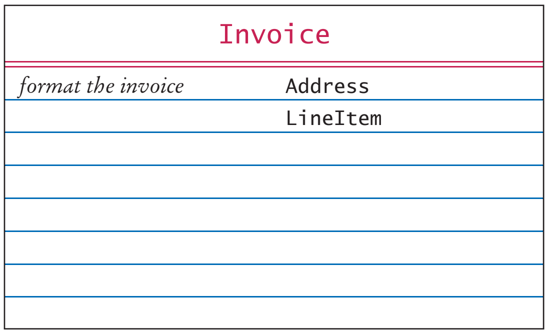


How does an invoice format itself? It must format the billing address, format all line items, and then add the amount due. How can the invoice format an address? It can't—that really is the responsibility of the `Address` class. This leads to a second CRC card:



Similarly, formatting of a line item is the responsibility of the `LineItem` class.

The `format` method of the `Invoice` class calls the `format` methods of the `Address` and `LineItem` classes. Whenever a method uses another class, you list that other class as a collaborator. In other words, `Address` and `LineItem` are collaborators of `Invoice`:



When formatting the invoice, the invoice also needs to compute the total amount due. To obtain that amount, it must ask each line item about the total price of the item.

How does a line item obtain that total? It must ask the product for the unit price, and then multiply it by the quantity. That is, the `Product` class must reveal the unit price, and it is a collaborator of the `LineItem` class.

Finally, the invoice must be populated with products and quantities, so that it makes sense to format the result. That too is a responsibility of the `Invoice` class.

We now have a set of CRC cards that completes the CRC card process.

`Product`	
get description	
get unit price	

`LineItem`	
format the item	`Product`
get total price	

`Invoice`	
format the invoice	`Address`
add a product and quantity	`LineItem`
	`Product`

12.4.3 UML Diagrams

Use UML diagrams to record class relationships.

After you have discovered classes and their relationships with CRC cards, you should record your findings in UML diagrams. The dependency relationships come from the collaboration column on the CRC cards. Each class depends on the classes with which it collaborates. In our example, the `Invoice` class collaborates with the `Address`, `LineItem`, and `Product` classes. The `LineItem` class collaborates with the `Product` class.

Now ask yourself which of these dependencies are actually aggregations. How does an invoice know about the address, line item, and product objects with which it collaborates? An invoice object must hold references to the address and the line items when it formats the invoice. But an invoice object need not hold a reference to a product object when adding a product. The product is turned into a line item, and then it is the item's responsibility to hold a reference to it.

Therefore, the `Invoice` class aggregates the `Address` and `LineItem` classes. The `LineItem` class aggregates the `Product` class. However, there is no *has-a* relationship between an invoice and a product. An invoice doesn't store products directly—they are stored in the `LineItem` objects.

There is no inheritance in this example.

Figure 7 shows the class relationships that we discovered.

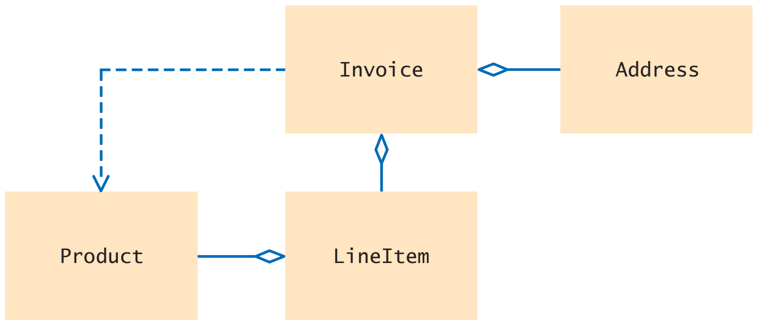


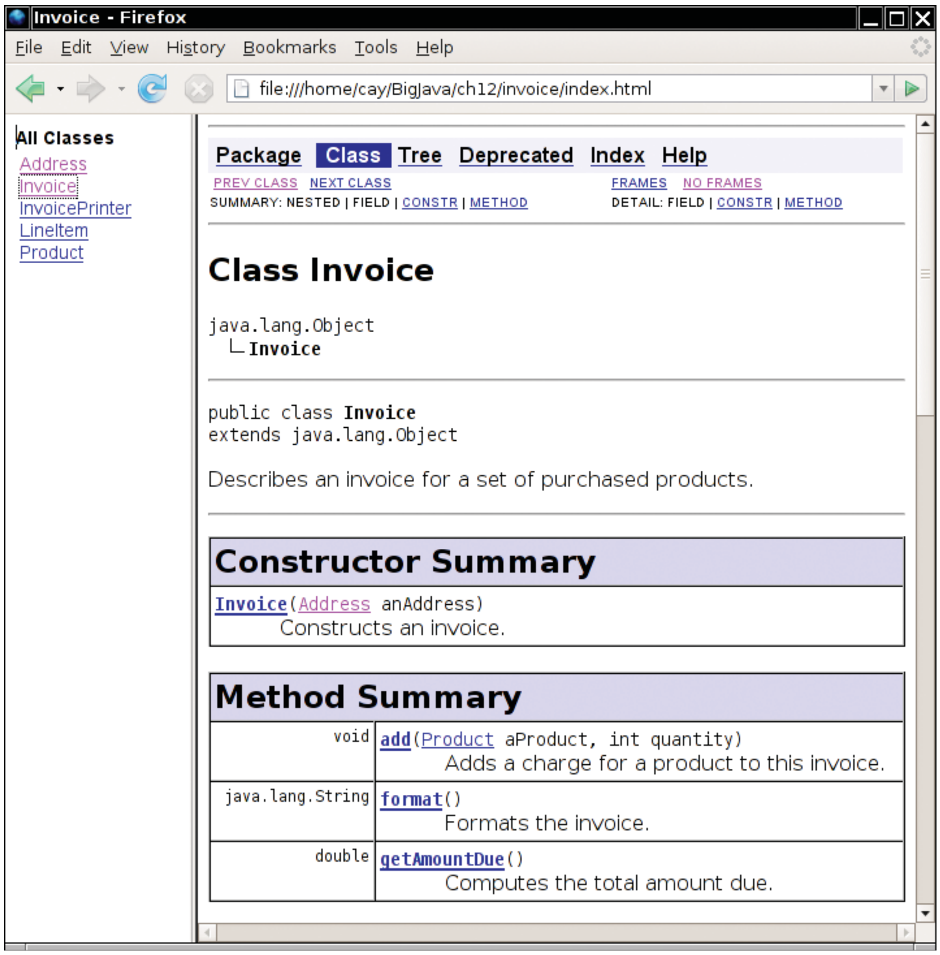
Figure 7 The Relationships Between the Invoice Classes

12.4.4 Method Documentation

Use javadoc comments (with the method bodies left blank) to record the behavior of classes.

The final step of the design phase is to write the documentation of the discovered classes and methods. Simply write a Java source file for each class, write the method comments for those methods that you have discovered, and leave the bodies of the methods blank.

```
/**
   Describes an invoice for a set of purchased products.
*/
public class Invoice
{
   /**
      Adds a charge for a product to this invoice.
      @param aProduct the product that the customer ordered
      @param quantity the quantity of the product
   */
   public void add(Product aProduct, int quantity)
   {
   }

   /**
      Formats the invoice.
      @return the formatted invoice
   */
   public String format()
   {
   }
}

/**
   Describes a quantity of an article to purchase.
*/
public class LineItem
{
   /**
      Computes the total cost of this line item.
      @return the total price
   */
   public double getTotalPrice()
   {
   }

   /**
      Formats this item.
      @return a formatted string of this item
   */
   public String format()
   {
   }
}

/**
   Describes a product with a description and a price.
*/
public class Product
{
   /**
      Gets the product description.
      @return the description
   */
   public String getDescription()
   {
   }

   /**
      Gets the product price.
      @return the unit price
   */
   public double getPrice()
   {
   }
}

/**
   Describes a mailing address.
*/
public class Address
{
   /**
      Formats the address.
      @return the address as a string with three lines
   */
   public String format()
   {
   }
}
```


Invoice - Firefox
File Edit View History Bookmarks Tools Help
file:///home/cay/BigJava/ch12/invoice/index.html
All Classes
Address
Invoice
InvoicePrinter
LineItem
Product
Package Class Tree Deprecated Index Help
PREV CLASS NEXT CLASS
FRAMES NO FRAMES
SUMMARY: NESTED | FIELD | CONSTR | METHOD
DETAIL: FIELD | CONSTR | METHOD

Class Invoice

```
java.lang.Object
  └Invoice
```

```
public class Invoice
extends java.lang.Object
```

Describes an invoice for a set of purchased products.

Constructor Summary

`Invoice(Address anAddress)`
Constructs an invoice.

Method Summary

`void`	`add(Product aProduct, int quantity)` Adds a charge for a product to this invoice.
`java.lang.String`	`format()` Formats the invoice.
`double`	`getAmountDue()` Computes the total amount due.

Figure 8 The Class Documentation in HTML Format

Then run the `javadoc` program to obtain a prettily formatted version of your documentation in HTML format (see Figure 8).

This approach for documenting your classes has a number of advantages. You can share the HTML documentation with others if you work in a team. You use a format that is immediately useful—Java source files that you can carry into the implementation phase. And, most importantly, you supply the comments of the key methods—a task that less prepared programmers leave for later, and then often neglect for lack of time.

12.4.5 Implementation

After completing the design, implement your classes.

After you have completed the object-oriented design, you are ready to implement the classes.

You already have the method parameters and comments from the previous step. Now look at the UML diagram to add instance variables. Aggregated classes yield instance variables. Start with the `Invoice` class. An invoice aggregates `Address` and

LineItem. Every invoice has one billing address, but it can have many line items. To store multiple LineItem objects, you can use an array list. Now you have the instance variables of the Invoice class:

```
public class Invoice
{
   private Address billingAddress;
   private ArrayList<LineItem> items;
   . . .
}
```

A line item needs to store a Product object and the product quantity. That leads to the following instance variables:

```
public class LineItem
{
   private int quantity;
   private Product theProduct;
   . . .
}
```

The methods themselves are now easy to implement. Here is a typical example. You already know what the getTotalPrice method of the LineItem class needs to do—get the unit price of the product and multiply it with the quantity.

```
/**
   Computes the total cost of this line item.
   @return the total price
*/
public double getTotalPrice()
{
   return theProduct.getPrice() * quantity;
}
```

We will not discuss the other methods in detail—they are equally straightforward.

Finally, you need to supply constructors, another routine task.

Here is the entire program. It is a good practice to go through it in detail and match up the classes and methods against the CRC cards and UML diagram.

ch12/invoice/InvoicePrinter.java

```
/**
   This program demonstrates the invoice classes by
   printing a sample invoice.
*/
public class InvoicePrinter
{
   public static void main(String[] args)
   {
      Address samsAddress
            = new Address("Sam's Small Appliances",
            "100 Main Street", "Anytown", "CA", "98765");

      Invoice samsInvoice = new Invoice(samsAddress);
      samsInvoice.add(new Product("Toaster", 29.95), 3);
      samsInvoice.add(new Product("Hair dryer", 24.95), 1);
      samsInvoice.add(new Product("Car vacuum", 19.99), 2);

      System.out.println(samsInvoice.format());
   }
}
```

ch12/invoice/Invoice.java

```java
import java.util.ArrayList;

/**
   Describes an invoice for a set of purchased products.
*/
public class Invoice
{
   private Address billingAddress;
   private ArrayList<LineItem> items;

   /**
      Constructs an invoice.
      @param anAddress the billing address
   */
   public Invoice(Address anAddress)
   {
      items = new ArrayList<LineItem>();
      billingAddress = anAddress;
   }

   /**
      Adds a charge for a product to this invoice.
      @param aProduct the product that the customer ordered
      @param quantity the quantity of the product
   */
   public void add(Product aProduct, int quantity)
   {
      LineItem anItem = new LineItem(aProduct, quantity);
      items.add(anItem);
   }

   /**
      Formats the invoice.
      @return the formatted invoice
   */
   public String format()
   {
      String r = "                     I N V O I C E\n\n"
            + billingAddress.format()
            + String.format("\n\n%-30s%8s%5s%8s\n",
            "Description", "Price", "Qty", "Total");

      for (LineItem item : items)
      {
         r = r + item.format() + "\n";
      }

      r = r + String.format("\nAMOUNT DUE: $%8.2f", getAmountDue());

      return r;
   }

   /**
      Computes the total amount due.
      @return the amount due
   */
   public double getAmountDue()
   {
      double amountDue = 0;
      for (LineItem item : items)
      {
         amountDue = amountDue + item.getTotalPrice();
      }
      return amountDue;
   }
}
```

ch12/invoice/LineItem.java

```
/**
   Describes a quantity of an article to purchase.
*/
public class LineItem
{
   private int quantity;
   private Product theProduct;

   /**
      Constructs an item from the product and quantity.
      @param aProduct the product
      @param aQuantity the item quantity
   */
   public LineItem(Product aProduct, int aQuantity)
   {
      theProduct = aProduct;
      quantity = aQuantity;
   }

   /**
      Computes the total cost of this line item.
      @return the total price
   */
   public double getTotalPrice()
   {
      return theProduct.getPrice() * quantity;
   }

   /**
      Formats this item.
      @return a formatted string of this line item
   */
   public String format()
   {
      return String.format("%-30s%8.2f%5d%8.2f",
            theProduct.getDescription(), theProduct.getPrice(),
            quantity, getTotalPrice());
   }
}
```

ch12/invoice/Product.java

```java
/**
   Describes a product with a description and a price.
*/
public class Product
{
   private String description;
   private double price;

   /**
      Constructs a product from a description and a price.
      @param aDescription the product description
      @param aPrice the product price
   */
   public Product(String aDescription, double aPrice)
   {
      description = aDescription;
      price = aPrice;
   }

   /**
      Gets the product description.
      @return the description
   */
   public String getDescription()
   {
      return description;
   }

   /**
      Gets the product price.
      @return the unit price
   */
   public double getPrice()
   {
      return price;
   }
}
```

ch12/invoice/Address.java

```java
/**
   Describes a mailing address.
*/
public class Address
{
   private String name;
   private String street;
   private String city;
   private String state;
   private String zip;

   /**
      Constructs a mailing address.
      @param aName the recipient name
      @param aStreet the street
      @param aCity the city
      @param aState the two-letter state code
      @param aZip the ZIP postal code
   */
   public Address(String aName, String aStreet,
         String aCity, String aState, String aZip)
   {
      name = aName;
      street = aStreet;
      city = aCity;
      state = aState;
      zip = aZip;
   }

   /**
      Formats the address.
      @return the address as a string with three lines
   */
   public String format()
   {
      return name + "\n" + street + "\n"
            + city + ", " + state + " " + zip;
   }
}
```

SELF CHECK

10. Which class is responsible for computing the amount due? What are its collaborators for this task?

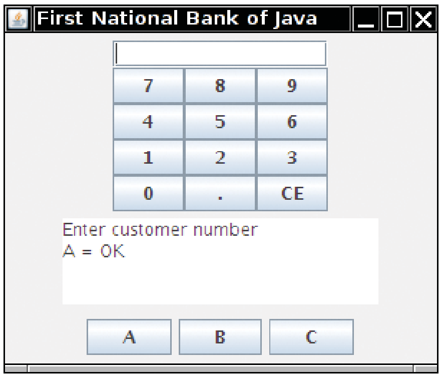
11. Why do the `format` methods return `String` objects instead of directly printing to `System.out`?

12.5 Case Study: An Automatic Teller Machine

12.5.1 Requirements

The purpose of this project is to design a simulation of an automatic teller machine (ATM). The ATM is used by the customers of a bank. Each customer has two accounts: a checking account and a savings account. Each customer also has a customer number and a personal identification number (PIN); both are required to gain access to the accounts. (In a real ATM, the customer number would be recorded on the magnetic strip of the ATM card. In this simulation, the customer will need to type it in.) With the ATM, customers can select an account (checking or savings). The balance of the selected account is displayed. Then the customer can deposit and withdraw money. This process is repeated until the customer chooses to exit.

The details of the user interaction depend on the user interface that we choose for the simulation. We will develop two separate interfaces: a graphical interface that closely mimics an actual ATM (see Figure 9), and a text-based interface that allows you to test the ATM and bank classes without being distracted by GUI programming.



Enter customer number
A = OK

Figure 9
Graphical User Interface for the Automatic Teller Machine

In the GUI interface, the ATM has a keypad to enter numbers, a display to show messages, and a set of buttons, labeled A, B, and C, whose function depends on the state of the machine.

Specifically, the user interaction is as follows. When the ATM starts up, it expects a user to enter a customer number. The display shows the following message:

```
Enter customer number
A = OK
```

The user enters the customer number on the keypad and presses the A button. The display message changes to

```
Enter PIN
A = OK
```

Next, the user enters the PIN and presses the A button again. If the customer number and ID match those of one of the customers in the bank, then the customer can proceed. If not, the user is again prompted to enter the customer number.

If the customer has been authorized to use the system, then the display message changes to

```
Select Account
A = Checking
B = Savings
C = Exit
```

If the user presses the C button, the ATM reverts to its original state and asks the next user to enter a customer number.

If the user presses the A or B buttons, the ATM remembers the selected account, and the display message changes to

`Balance =` *balance of selected account*
```
Enter amount and select transaction
A = Withdraw
B = Deposit
C = Cancel
```

If the user presses the A or B buttons, the value entered in the keypad is withdrawn from or deposited into the selected account. (This is just a simulation, so no money is dispensed and no deposit is accepted.) Afterwards, the ATM reverts to the preceding state, allowing the user to select another account or to exit.

If the user presses the C button, the ATM reverts to the preceding state without executing any transaction.

In the text-based interaction, we read input from `System.in` instead of the buttons. Here is a typical dialog:

```
Enter account number: 1
Enter PIN: 1234
A=Checking, B=Savings, C=Quit: A
Balance=0.0
A=Deposit, B=Withdrawal, C=Cancel: A
Amount: 1000
A=Checking, B=Savings, C=Quit: C
```

In our solution, only the user interface classes are affected by the choice of user interface. The remainder of the classes can be used for both solutions—they are decoupled from the user interface.

Because this is a simulation, the ATM does not actually communicate with a bank. It simply loads a set of customer numbers and PINs from a file. All accounts are initialized with a zero balance.

12.5.2 CRC Cards

We will again follow the recipe of Section 12.2 and show how to discover classes, responsibilities, and relationships and how to obtain a detailed design for the ATM program.

Recall that the first rule for finding classes is "Look for nouns in the problem description". Here is a list of the nouns:

```
ATM
User
Keypad
Display
Display message
Button
State
Bank account
Checking account
Savings account
Customer
Customer number
PIN
Bank
```

Of course, not all of these nouns will become names of classes, and we may yet discover the need for classes that aren't in this list, but it is a good start.

Users and customers represent the same concept in this program. Let's use a class `Customer`. A customer has two bank accounts, and we will require that a `Customer` object should be able to locate these accounts. (Another possible design would make the `Bank` class responsible for locating the accounts of a given customer—see Exercise P12.9.)

A customer also has a customer number and a PIN. We can, of course, require that a customer object give us the customer number and the PIN. But perhaps that isn't so secure. Instead, simply require that a customer object, when given a customer number and a PIN, will tell us whether it matches its own information or not.

Customer	
get accounts	
match number and PIN	

A bank contains a collection of customers. When a user walks up to the ATM and enters a customer number and PIN, it is the job of the bank to find the matching customer. How can the bank do this? It needs to check for each customer whether its customer number and PIN match. Thus, it needs to call the *match number and PIN* method of the `Customer` class that we just discovered. Because the *find customer* method calls a `Customer` method, it collaborates with the `Customer` class. We record that fact in the right-hand column of the CRC card.

When the simulation starts up, the bank must also be able to read account information from a file.

Bank	
find customer	`Customer`
read customers	

The `BankAccount` class is our familiar class with methods to get the balance and to deposit and withdraw money.

In this program there is nothing that distinguishes checking accounts from savings accounts. The ATM does not add interest or deduct fees. Therefore, we decide not to implement separate subclasses for checking and savings accounts.

Finally, we are left with the ATM class itself. An important notion of the ATM is the **state**. The current machine state determines the text of the prompts and the function of the buttons. For example, when you first log in, you use the A and B buttons to select an account. Next, you use the same buttons to choose between deposit and withdrawal. The ATM must remember the current state so that it can correctly interpret the buttons.

There are four states:

1. START: Enter customer ID
2. PIN: Enter PIN
3. ACCOUNT: Select account
4. TRANSACT: Select transaction

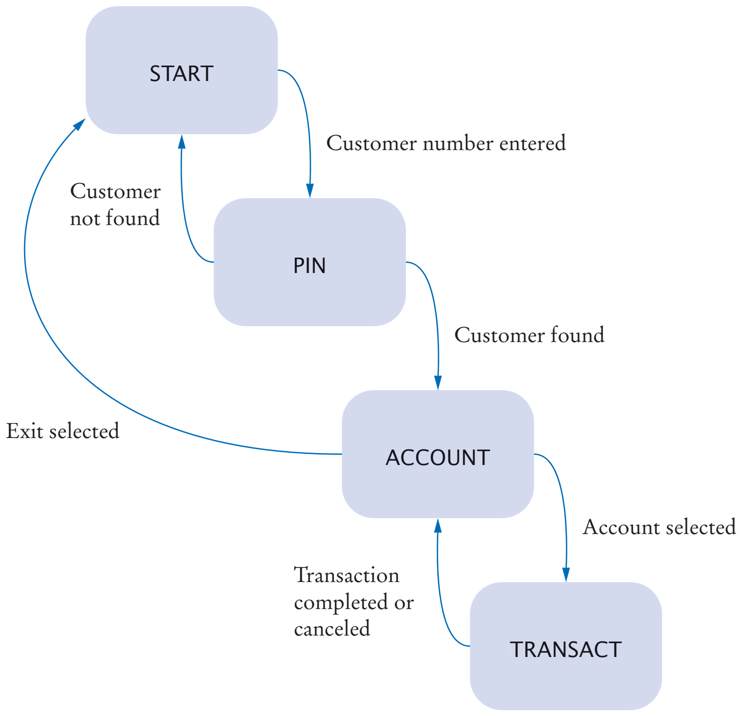


Figure 10 State Diagram for the ATM Class

To understand how to move from one state to the next, it is useful to draw a **state diagram** (Figure 10). The UML notation has standardized shapes for state diagrams. Draw states as rectangles with rounded corners. Draw state changes as arrows, with labels that indicate the reason for the change.

The user must type a valid customer number and PIN. Then the ATM can ask the bank to find the customer. This calls for a *select customer* method. It collaborates with the bank, asking the bank for the customer that matches the customer number and PIN. Next, there must be a *select account* method that asks the current customer for the checking or savings account. Finally, the ATM must carry out the selected transaction on the current account.

ATM	
manage state	Customer
select customer	Bank
select account	BankAccount
execute transaction	

Of course, discovering these classes and methods was not as neat and orderly as it appears from this discussion. When I designed these classes for this book, it took me several trials and many torn cards to come up with a satisfactory design. It is also important to remember that there is seldom one best design.

This design has several advantages. The classes describe clear concepts. The methods are sufficient to implement all necessary tasks. (I mentally walked through every ATM usage scenario to verify that.) There are not too many collaboration dependencies between the classes. Thus, I was satisfied with this design and proceeded to the next step.

12.5.3 UML Diagrams

Figure 11 shows the relationships between these classes, using the graphical user interface. (The console user interface uses a single class `ATMSimulator` instead of the `ATMFrame` and `Keypad` classes.)

To draw the dependencies, use the "collaborator" columns from the CRC cards. Looking at those columns, you find that the dependencies are as follows:

- `ATM` uses `Bank`, `Customer`, and `BankAccount`.
- `Bank` uses `Customer`.
- `Customer` uses `BankAccount`.

It is easy to see some of the aggregation relationships. A bank has customers, and each customer has two bank accounts.

Does the `ATM` class aggregate `Bank`? To answer this question, ask yourself whether an ATM object needs to store a reference to a bank object. Does it need to locate the same bank object across multiple method calls? Indeed it does. Therefore, aggregation is the appropriate relationship.

Does an ATM aggregate customers? Clearly, the ATM is not responsible for storing all of the bank's customers. That's the bank's job. But in our design, the ATM remembers the *current* customer. If a customer has logged in, subsequent commands refer to the same customer. The ATM needs to either store a reference to the customer, or ask the bank to look up the object whenever it needs the current

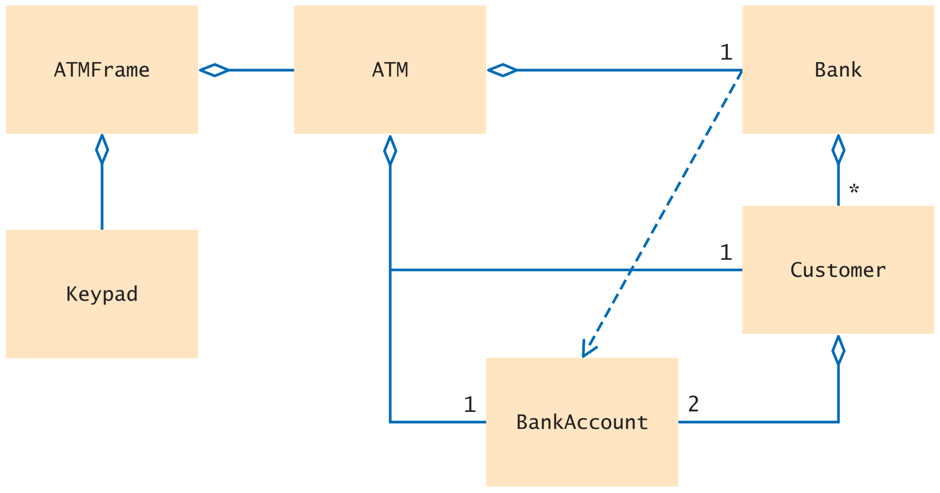


Figure 11 Relationships Between the ATM Classes

customer. It is a design decision: either store the object, or look it up when needed. We will decide to store the current customer object. That is, we will use aggregation. Note that the choice of aggregation is not an automatic consequence of the problem description—it is a design decision.

Similarly, we will decide to store the current bank account (checking or savings) that the user selects. Therefore, we have an aggregation relationship between `ATM` and `BankAccount`.

The class diagram is a good tool to visualize dependencies. Look at the GUI classes. They are completely independent from the rest of the ATM system. You can replace the GUI with a console interface, and you can take out the `Keypad` class and use it in another application. Also, the `Bank`, `BankAccount`, and `Customer` classes, although dependent on each other, don't know anything about the `ATM` class. That makes sense—you can have banks without ATMs. As you can see, when you analyze relationships, you look for both the absence and presence of relationships.

12.5.4 Method Documentation

Now you are ready for the final step of the design phase: documenting the classes and methods that you discovered. Here is a part of the documentation for the `ATM` class:

```
/**
   An ATM that accesses a bank.
*/
public class ATM
{
   . . .
   /**
      Constructs an ATM for a given bank.
      @param aBank the bank to which this ATM connects
   */
   public ATM(Bank aBank) { }

   /**
      Sets the current customer number
      and sets state to PIN.
      (Precondition: state is START)
      @param number the customer number
   */
   public void setCustomerNumber(int number) { }

   /**
      Finds customer in bank.
      If found sets state to ACCOUNT, else to START.
      (Precondition: state is PIN)
      @param pin the PIN of the current customer
   */
   public void selectCustomer(int pin) { }

   /**
      Sets current account to checking or savings. Sets
      state to TRANSACT.
      (Precondition: state is ACCOUNT or TRANSACT)
      @param account one of CHECKING or SAVINGS
   */
   public void selectAccount(int account) { }
   /**
      Withdraws amount from current account.
      (Precondition: state is TRANSACT)
      @param value the amount to withdraw
   */
   public void withdraw(double value) { }
}
```

Then run the javadoc utility to turn this documentation into HTML format.

For conciseness, we omit the documentation of the other classes.

12.5.5 Implementation

Finally, the time has come to implement the ATM simulator. The implementation phase is very straightforward and should take *much less time than the design phase.*

A good strategy for implementing the classes is to go "bottom-up". Start with the classes that don't depend on others, such as `Keypad` and `BankAccount`. Then implement a class such as `Customer` that depends only on the `BankAccount` class. This "bottom-up" approach allows you to test your classes individually. You will find the implementations of these classes at the end of this section.

The most complex class is the `ATM` class. In order to implement the methods, you need to declare the necessary instance variables. From the class diagram, you can tell that the ATM has a bank object. It becomes an instance variable of the class:

```
public class ATM
{
   private Bank theBank;
   . . .
}
```

From the description of the ATM states, it is clear that we require additional instance variables to store the current state, customer, and bank account.

```
public class ATM
{
   private int state;
   private Customer currentCustomer;
   private BankAccount currentAccount;
   . . .
}
```

Most methods are very straightforward to implement. Consider the `selectCustomer` method. From the design documentation, we have the description

```
/**
   Finds customer in bank.
   If found sets state to ACCOUNT, else to START.
   (Precondition: state is PIN)
   @param pin the PIN of the current customer
*/
```

This description can be almost literally translated to Java instructions:

```
public void selectCustomer(int pin)
{
   assert state == PIN;
   currentCustomer = theBank.findCustomer(customerNumber, pin);
```

```
      if (currentCustomer == null)
         state = START;
      else
         state = ACCOUNT;
   }
```

We won't go through a method-by-method description of the ATM program. You should take some time and compare the actual implementation against the CRC cards and the UML diagram.

ch12/atm/ATM.java

```
/**
   An ATM that accesses a bank.
*/
public class ATM
{
   public static final int CHECKING = 1;
   public static final int SAVINGS = 2;

   private int state;
   private int customerNumber;
   private Customer currentCustomer;
   private BankAccount currentAccount;
   private Bank theBank;

   public static final int START = 1;
   public static final int PIN = 2;
   public static final int ACCOUNT = 3;
   public static final int TRANSACT = 4;

   /**
      Constructs an ATM for a given bank.
      @param aBank the bank to which this ATM connects
   */
   public ATM(Bank aBank)
   {
      theBank = aBank;
      reset();
   }

   /**
      Resets the ATM to the initial state.
   */
   public void reset()
   {
      customerNumber = -1;
      currentAccount = null;
      state = START;
   }

   /**
      Sets the current customer number
      and sets state to PIN.
      (Precondition: state is START)
      @param number the customer number
   */
   public void setCustomerNumber(int number)
   {
      assert state == START;
      customerNumber = number;
      state = PIN;
   }

   /**
      Finds customer in bank.
      If found, sets state to ACCOUNT, else to START.
      (Precondition: state is PIN)
      @param pin the PIN of the current customer
   */
   public void selectCustomer(int pin)
   {
      assert state == PIN;
      currentCustomer = theBank.findCustomer(customerNumber, pin);
      if (currentCustomer == null)
         state = START;
      else
         state = ACCOUNT;
   }

   /**
      Sets current account to checking or savings. Sets
      state to TRANSACT.
      (Precondition: state is ACCOUNT or TRANSACT)
      @param account one of CHECKING or SAVINGS
   */
   public void selectAccount(int account)
   {
      assert state == ACCOUNT || state == TRANSACT;
      if (account == CHECKING)
         currentAccount = currentCustomer.getCheckingAccount();
      else
         currentAccount = currentCustomer.getSavingsAccount();
      state = TRANSACT;
   }

   /**
      Withdraws amount from current account.
      (Precondition: state is TRANSACT)
      @param value the amount to withdraw
   */
   public void withdraw(double value)
   {
      assert state == TRANSACT;
      currentAccount.withdraw(value);
   }

   /**
      Deposits amount to current account.
      (Precondition: state is TRANSACT)
      @param value the amount to deposit
   */
   public void deposit(double value)
   {
      assert state == TRANSACT;
      currentAccount.deposit(value);
   }

   /**
      Gets the balance of the current account.
      (Precondition: state is TRANSACT)
      @return the balance
   */
   public double getBalance()
   {
      assert state == TRANSACT;
      return currentAccount.getBalance();
   }

   /**
      Moves back to the previous state.
   */
   public void back()
   {
      if (state == TRANSACT)
         state = ACCOUNT;
      else if (state == ACCOUNT)
         state = PIN;
      else if (state == PIN)
         state = START;
   }

   /**
      Gets the current state of this ATM.
      @return the current state
   */
   public int getState()
   {
      return state;
   }
}
```

ch12/atm/Bank.java

```
import java.io.File;
import java.io.IOException;
import java.util.ArrayList;
import java.util.Scanner;

/**
   A bank contains customers with bank accounts.
*/
public class Bank
{
   private ArrayList<Customer> customers;

   /**
      Constructs a bank with no customers.
   */
   public Bank()
   {
      customers = new ArrayList<Customer>();
   }

   /**
      Reads the customer numbers and pins
      and initializes the bank accounts.
      @param filename the name of the customer file
   */
   public void readCustomers(String filename)
         throws IOException
   {
      Scanner in = new Scanner(new File(filename));
      while (in.hasNext())
      {
         int number = in.nextInt();
         int pin = in.nextInt();
         Customer c = new Customer(number, pin);
         addCustomer(c);
      }
      in.close();
   }

   /**
      Adds a customer to the bank.
      @param c the customer to add
   */
   public void addCustomer(Customer c)
   {
      customers.add(c);
   }

   /**
      Finds a customer in the bank.
      @param aNumber a customer number
      @param aPin a personal identification number
      @return the matching customer, or null if no customer
      matches
   */
   public Customer findCustomer(int aNumber, int aPin)
   {
      for (Customer c : customers)
      {
         if (c.match(aNumber, aPin))
            return c;
      }
      return null;
   }
}
```

ch12/atm/Customer.java

```
/**
   A bank customer with a checking and a savings account.
*/
public class Customer
{
   private int customerNumber;
   private int pin;
   private BankAccount checkingAccount;
   private BankAccount savingsAccount;

   /**
      Constructs a customer with a given number and PIN.
      @param aNumber the customer number
      @param aPin the personal identification number
   */
   public Customer(int aNumber, int aPin)
   {
      customerNumber = aNumber;
      pin = aPin;
      checkingAccount = new BankAccount();
      savingsAccount = new BankAccount();
   }

   /**
      Tests if this customer matches a customer number
      and PIN.
      @param aNumber a customer number
      @param aPin a personal identification number
      @return true if the customer number and PIN match
   */
   public boolean match(int aNumber, int aPin)
   {
      return customerNumber == aNumber && pin == aPin;
   }

   /**
      Gets the checking account of this customer.
      @return the checking account
   */
   public BankAccount getCheckingAccount()
   {
      return checkingAccount;
   }

   /**
      Gets the savings account of this customer.
      @return the checking account
   */
   public BankAccount getSavingsAccount()
   {
      return savingsAccount;
   }
}
```

The following class implements a console user interface for the ATM.

ch12/atm/ATMSimulator.java

```
import java.io.IOException;
import java.util.Scanner;

/**
   A text-based simulation of an automatic teller machine.
*/
public class ATMSimulator
{
   public static void main(String[] args)
   {
      ATM theATM;
```

```java
      try
      {
         Bank theBank = new Bank();
         theBank.readCustomers("customers.txt");
         theATM = new ATM(theBank);
      }
      catch(IOException e)
      {
         System.out.println("Error opening accounts file.");
         return;
      }

      Scanner in = new Scanner(System.in);

      while (true)
      {
         int state = theATM.getState();
         if (state == ATM.START)
         {
            System.out.print("Enter customer number: ");
            int number = in.nextInt();
            theATM.setCustomerNumber(number);
         }
         else if (state == ATM.PIN)
         {
            System.out.print("Enter PIN: ");
            int pin = in.nextInt();
            theATM.selectCustomer(pin);
         }
         else if (state == ATM.ACCOUNT)
         {
            System.out.print("A=Checking, B=Savings, C=Quit: ");
            String command = in.next();
            if (command.equalsIgnoreCase("A"))
               theATM.selectAccount(ATM.CHECKING);
            else if (command.equalsIgnoreCase("B"))
               theATM.selectAccount(ATM.SAVINGS);
            else if (command.equalsIgnoreCase("C"))
               theATM.reset();
            else
                 System.out.println("Illegal input!");
         }
         else if (state == ATM.TRANSACT)
         {
            System.out.println("Balance=" + theATM.getBalance());
            System.out.print("A=Deposit, B=Withdrawal, C=Cancel: ");
            String command = in.next();
            if (command.equalsIgnoreCase("A"))
            {
               System.out.print("Amount: ");
               double amount = in.nextDouble();
               theATM.deposit(amount);
               theATM.back();
            }
            else if (command.equalsIgnoreCase("B"))
            {
               System.out.print("Amount: ");
               double amount = in.nextDouble();
```

```
                  theATM.withdraw(amount);
                  theATM.back();
               }
               else if (command.equalsIgnoreCase("C"))
                  theATM.back();
               else
                  System.out.println("Illegal input!");
            }
         }
      }
   }
```

Program Run

```
Enter account number: 1
Enter PIN: 1234
A=Checking, B=Savings, C=Quit: A
Balance=0.0
A=Deposit, B=Withdrawal, C=Cancel: A
Amount: 1000
A=Checking, B=Savings, C=Quit: C
. . .
```

Here are the user interface classes for the GUI version of the user interface.

ch12/atm/ATMViewer.java

```
import java.io.IOException;
import javax.swing.JFrame;
import javax.swing.JOptionPane;

/**
   A graphical simulation of an automatic teller machine.
*/
public class ATMViewer
{
   public static void main(String[] args)
   {
      ATM theATM;

      try
      {
         Bank theBank = new Bank();
         theBank.readCustomers("customers.txt");
         theATM = new ATM(theBank);
      }
      catch(IOException e)
      {
         JOptionPane.showMessageDialog(null, "Error opening accounts file.");
         return;
      }

      JFrame frame = new ATMFrame(theATM);
      frame.setTitle("First National Bank of Java");
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

ch12/atm/ATMFrame.java

```java
import java.awt.FlowLayout;
import java.awt.GridLayout;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JFrame;
import javax.swing.JPanel;
import javax.swing.JTextArea;

/**
   A frame displaying the components of an ATM.
*/
public class ATMFrame extends JFrame
{
   private static final int FRAME_WIDTH = 300;
   private static final int FRAME_HEIGHT = 300;

   private JButton aButton;
   private JButton bButton;
   private JButton cButton;

   private KeyPad pad;
   private JTextArea display;

   private ATM theATM;

   /**
      Constructs the user interface of the ATM frame.
   */
   public ATMFrame(ATM anATM)
   {
      theATM = anATM;

      // Construct components
      pad = new KeyPad();

      display = new JTextArea(4, 20);

      aButton = new JButton("  A  ");
      aButton.addActionListener(new AButtonListener());

      bButton = new JButton("  B  ");
      bButton.addActionListener(new BButtonListener());

      cButton = new JButton("  C  ");
      cButton.addActionListener(new CButtonListener());

      // Add components

      JPanel buttonPanel = new JPanel();
      buttonPanel.add(aButton);
      buttonPanel.add(bButton);
      buttonPanel.add(cButton);

      setLayout(new FlowLayout());
      add(pad);
      add(display);
      add(buttonPanel);
      showState();

      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }

   /**
      Updates display message.
   */
   public void showState()
   {
      int state = theATM.getState();
      pad.clear();
      if (state == ATM.START)
         display.setText("Enter customer number\nA = OK");
      else if (state == ATM.PIN)
         display.setText("Enter PIN\nA = OK");
      else if (state == ATM.ACCOUNT)
         display.setText("Select Account\n"
               + "A = Checking\nB = Savings\nC = Exit");
      else if (state == ATM.TRANSACT)
         display.setText("Balance = "
               + theATM.getBalance()
               + "\nEnter amount and select transaction\n"
               + "A = Withdraw\nB = Deposit\nC = Cancel");
   }

   class AButtonListener implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         int state = theATM.getState();
         if (state == ATM.START)
            theATM.setCustomerNumber((int) pad.getValue());
         else if (state == ATM.PIN)
            theATM.selectCustomer((int) pad.getValue());
         else if (state == ATM.ACCOUNT)
            theATM.selectAccount(ATM.CHECKING);
         else if (state == ATM.TRANSACT)
         {
            theATM.withdraw(pad.getValue());
            theATM.back();
         }
         showState();
      }
   }

   class BButtonListener implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         int state = theATM.getState();
         if (state == ATM.ACCOUNT)
            theATM.selectAccount(ATM.SAVINGS);
         else if (state == ATM.TRANSACT)
         {
            theATM.deposit(pad.getValue());
            theATM.back();
         }
         showState();
      }
   }

   class CButtonListener implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         int state = theATM.getState();
         if (state == ATM.ACCOUNT)
            theATM.reset();
         else if (state == ATM.TRANSACT)
            theATM.back();
         showState();
      }
   }
}
```

This class uses layout managers to arrange the text field and the keypad buttons. See Chapter 18 for more information about layout managers.

ch12/atm/KeyPad.java

```
import java.awt.BorderLayout;
import java.awt.GridLayout;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JPanel;
import javax.swing.JTextField;

/**
   A component that lets the user enter a number, using
   a keypad labeled with digits.
*/
public class KeyPad extends JPanel
{
   private JPanel buttonPanel;
   private JButton clearButton;
   private JTextField display;

   /**
      Constructs the keypad panel.
   */
   public KeyPad()
   {
      setLayout(new BorderLayout());

      // Add display field

      display = new JTextField();
      add(display, "North");

      // Make button panel

      buttonPanel = new JPanel();
      buttonPanel.setLayout(new GridLayout(4, 3));

      // Add digit buttons

      addButton("7");
      addButton("8");
      addButton("9");
      addButton("4");
      addButton("5");
      addButton("6");
      addButton("1");
      addButton("2");
      addButton("3");
      addButton("0");
      addButton(".");

      // Add clear entry button

      clearButton = new JButton("CE");
      buttonPanel.add(clearButton);

      class ClearButtonListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            display.setText("");
         }
      }
      ActionListener listener = new ClearButtonListener();

      clearButton.addActionListener(new
            ClearButtonListener());

      add(buttonPanel, "Center");
   }

   /**
      Adds a button to the button panel.
      @param label the button label
   */
   private void addButton(final String label)
   {
      class DigitButtonListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {

            // Don't add two decimal points
            if (label.equals(".")
                  && display.getText().indexOf(".") != -1)
               return;

            // Append label text to button
            display.setText(display.getText() + label);
         }
      }

      JButton button = new JButton(label);
      buttonPanel.add(button);
      ActionListener listener = new DigitButtonListener();
      button.addActionListener(listener);
   }

   /**
      Gets the value that the user entered.
      @return the value in the text field of the keypad
   */
   public double getValue()
   {
      return Double.parseDouble(display.getText());
   }

   /**
      Clears the display.
   */
   public void clear()
   {
      display.setText("");
   }
}
```

In this chapter, you learned a systematic approach for building a relatively complex program. However, object-oriented design is definitely not a spectator sport. To really learn how to design and implement programs, you have to gain experience by repeating this process with your own projects. It is quite possible that you don't immediately home in on a good solution and that you need to go back and reorganize your classes and responsibilities. That is normal and only to be expected. The purpose of the object-oriented design process is to spot these problems in the design phase, when they are still easy to rectify, instead of in the implementation phase, when massive reorganization is more difficult and time consuming.

SELF CHECK

12. Why does the Bank class in this example not store an array list of bank accounts?
13. Suppose the requirements change—you need to save the current account balances to a file after every transaction and reload them when the program starts. What is the impact of this change on the design?

Random Fact 12.2

Software Development—Art or Science?

Random Fact 12.2 discusses whether software developers are best characterized as artists, craftspeople, scientists, or engineers.

Available online in WileyPLUS and at www.wiley.com/college/horstmann.

Summary of Learning Objectives

Describe the software life cycle alternatives for the software development process.

- The software life cycle encompasses all activities from initial analysis until obsolescence.
- A formal process for software development describes phases of the development process and gives guidelines for how to carry out the phases.
- The waterfall model of software development describes a sequential process of analysis, design, implementation, testing, and deployment.
- The spiral model of software development describes an iterative process in which design and implementation are repeated.
- Extreme Programming is a development methodology that strives for simplicity by removing formal structure and focusing on best practices.

Recognize how to discover classes and their responsibilities.

- In object-oriented design, you discover classes, determine the responsibilities of classes, and describe the relationships between classes.
- Make a list of candidates for classes, starting with nouns in the task description.
- A CRC card describes a class, its responsibilities, and its collaborating classes.

Categorize relationships between classes and produce UML diagrams that describe them.

- Inheritance (the *is-a* relationship) is sometimes inappropriately used when the *has-a* relationship would be more appropriate.
- Aggregation (the *has-a* relationship) denotes that objects of one class contain references to objects of another class.
- Dependency is another name for the *uses* relationship.
- You need to be able to distinguish the UML notations for inheritance, interface implementation, aggregation, and dependency.

Apply an object-oriented development process to designing a program.

- Start the development process by gathering and documenting program requirements.
- Use CRC cards to find classes, responsibilities, and collaborators.
- Use UML diagrams to record class relationships.
- Use `javadoc` comments (with the method bodies left blank) to record the behavior of classes.
- After completing the design, implement your classes.

Media Resources

WILEY PLUS

www.wiley.com/college/horstmann

- Lab Exercises
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★ **R12.1** What is the software life cycle?

★★ **R12.2** List the steps in the process of object-oriented design that this chapter recommends for student use.

★ **R12.3** Give a rule of thumb for how to find classes when designing a program.

★ **R12.4** Give a rule of thumb for how to find methods when designing a program.

★★ **R12.5** After discovering a method, why is it important to identify the object that is *responsible* for carrying out the action?

★ **R12.6** What relationship is appropriate between the following classes: aggregation, inheritance, or neither?

a. `University-Student`
b. `Student-TeachingAssistant`
c. `Student-Freshman`
d. `Student-Professor`
e. `Car-Door`
f. `Truck-Vehicle`
g. `Traffic-TrafficSign`
h. `TrafficSign-Color`

★★ **R12.7** Every BMW is a vehicle. Should a class `BMW` inherit from the class `Vehicle`? BMW is a vehicle manufacturer. Does that mean that the class `BMW` should inherit from the class `VehicleManufacturer`?

★★ **R12.8** Some books on object-oriented programming recommend using inheritance so that the class `Circle` extends the class `Point`. Then the `Circle` class inherits the `setLocation` method from the `Point` superclass. Explain why the `setLocation` method need not be overridden in the subclass. Why is it nevertheless not a good idea to have `Circle` inherit from `Point`? Conversely, would inheriting `Point` from `Circle` fulfill the *is-a* rule? Would it be a good idea?

★ **R12.9** Write CRC cards for the `Coin` and `CashRegister` classes described in Section 8.2.

★ **R12.10** Write CRC cards for the `Bank` and `BankAccount` classes in Section 7.2.

★★ **R12.11** Draw a UML diagram for the `Coin` and `CashRegister` classes described in Section 8.2.

★★★ **R12.12** A file contains a set of records describing countries. Each record consists of the name of the country, its population, and its area. Suppose your task is to write a program that reads in such a file and prints

- The country with the largest area
- The country with the largest population
- The country with the largest population density (people per square kilometer)

Think through the problems that you need to solve. What classes and methods will you need? Produce a set of CRC cards, a UML diagram, and a set of `javadoc` comments.

★★★ **R12.13** Discover classes and methods for generating a student report card that lists all classes, grades, and the grade point average for a semester. Produce a set of CRC cards, a UML diagram, and a set of `javadoc` comments.

★★★ **R12.14** Consider a quiz grading system that grades student responses to quizzes. A quiz consists of questions. There are different types of questions, including essay questions and multiple-choice questions. Students turn in submissions for quizzes, and the grading system grades them. Draw a UML diagram for classes `Quiz`, `Question`, `EssayQuestion`, `MultipleChoiceQuestion`, `Student`, and `Submission`.

Programming Exercises

★★ **P12.1** Enhance the invoice-printing program by providing for two kinds of line items: One kind describes products that are purchased in certain numerical quantities (such as "3 toasters"), another describes a fixed charge (such as "shipping: $5.00"). *Hint:* Use inheritance. Produce a UML diagram of your modified implementation.

★★ **P12.2** The invoice-printing program is somewhat unrealistic because the formatting of the `LineItem` objects won't lead to good visual results when the prices and quantities have varying numbers of digits. Enhance the `format` method in two ways: Accept an `int[]` array of column widths as a parameter. Use the `NumberFormat` class to format the currency values.

★★ **P12.3** The invoice-printing program has an unfortunate flaw—it mixes "application logic", the computation of total charges, and "presentation", the visual appearance of the invoice. To appreciate this flaw, imagine the changes that would be necessary to draw the invoice in HTML for presentation on the Web. Reimplement the program, using a separate `InvoiceFormatter` class to format the invoice. That is, the `Invoice` and `LineItem` methods are no longer responsible for formatting. However, they will acquire other responsibilities, because the `InvoiceFormatter` class needs to query them for the values that it requires.

★★★ **P12.4** Write a program that teaches arithmetic to a young child. The program tests addition and subtraction. In level 1 it tests only addition of numbers less than 10 whose sum is less than 10. In level 2 it tests addition of arbitrary one-digit numbers. In level 3 it tests subtraction of one-digit numbers with a nonnegative difference. Generate random problems and get the player input. The player gets up to two tries per problem. Advance from one level to the next when the player has achieved a score of five points.

★★★ **P12.5** Design a simple e-mail messaging system. A message has a recipient, a sender, and a message text. A mailbox can store messages. Supply a number of mailboxes for different users and a user interface for users to log in, send messages to other users, read their own messages, and log out. Follow the design process that was described in this chapter.

★★ **P12.6** Write a program that simulates a vending machine. Products can be purchased by inserting coins with a value at least equal to the cost of the product. A user selects a product from a list of available products, adds coins, and either gets the product or gets the coins returned if insufficient money was supplied or if the product is sold out. The machine does not give change if too much money was added. Products can be restocked and money removed by an operator. Follow the design process that was described in this chapter. Your solution should include a class `VendingMachine` that is not coupled with the `Scanner` or `PrintStream` classes.

★★★ **P12.7** Write a program to design an appointment calendar. An appointment includes the date, starting time, ending time, and a description; for example,

```
Dentist 2007/10/1 17:30 18:30
CS1 class 2007/10/2 08:30 10:00
```

Supply a user interface to add appointments, remove canceled appointments, and print out a list of appointments for a particular day. Follow the design process that was described in this chapter. Your solution should include a class `AppointmentCalendar` that is not coupled with the `Scanner` or `PrintStream` classes.

★★★ **P12.8** *Airline seating.* Write a program that assigns seats on an airplane. Assume the airplane has 20 seats in first class (5 rows of 4 seats each, separated by an aisle) and 90 seats in economy class (15 rows of 6 seats each, separated by an aisle). Your program should take three commands: add passengers, show seating, and quit. When passengers are added, ask for the class (first or economy), the number of passengers traveling together (1 or 2 in first class; 1 to 3 in economy), and the seating preference (aisle or window in first class; aisle, center, or window in economy). Then try to find a match and assign the seats. If no match exists, print a message. Your solution should include a class `Airplane` that is not coupled with the `Scanner` or `PrintStream` classes. Follow the design process that was described in this chapter.

★★ **P12.9** Modify the implementations of the classes in the ATM example so that the bank manages a collection of bank accounts and a separate collection of customers. Allow joint accounts in which some accounts can have more than one customer.

★★★ **P12.10** Write a program that administers and grades quizzes. A quiz consists of questions. There are four types of questions: text questions, number questions, choice questions with a single answer, and choice questions with multiple answers. When grading a text question, ignore leading or trailing spaces and letter case. When grading a numeric question, accept a response that is approximately the same as the answer.

A quiz is specified in a text file. Each question starts with a letter indicating the question type (T, N, S, M), followed by a line containing the question text. The next line of a non-choice question contains the answer. Choice questions have a list of choices that is terminated by a blank line. Each choice starts with + (correct) or - (incorrect). Here is a sample file:

```
T
Which Java reserved word is used to declare a subclass?
extends
S
What is the original name of the Java language?
- *7
- C--
+ Oak
- Gosling

M
Which of the following types are supertypes of Rectangle?
- PrintStream
+ Shape
+ RectangularShape
+ Object
- String

N
What is the square root of 2?
1.41421356
```

Your program should read in a quiz file, prompt the user for responses to all questions, and grade the responses. Follow the design process that was described in this chapter.

★★★G **P12.11** Implement a program to teach a young child to read the clock. In the game, present an analog clock, such as the one in Figure 12. Generate random times and display the clock. Accept guesses from the player. Reward the player for correct guesses. After two incorrect guesses, display the correct answer and make a new random time. Implement several levels of play. In level 1, only show full hours. In level 2, show quarter hours. In level 3, show five-minute multiples, and in level 4, show any number of minutes. After a player has achieved five correct guesses at one level, advance to the next level.

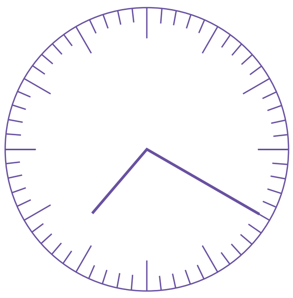


Figure 12 An Analog Clock

★★★G **P12.12** Write a program that can be used to design a suburban scene, with houses, streets, and cars. Users can add houses and cars of various colors to a street. Write more specific requirements that include a detailed description of the user interface. Then, discover classes and methods, provide UML diagrams, and implement your program.

★★★G **P12.13** Write a simple graphics editor that allows users to add a mixture of shapes (ellipses, rectangles, and lines in different colors) to a panel. Supply commands to load and save the picture. Discover classes, supply a UML diagram, and implement your program.

Programming Projects

Project 12.1 Produce a requirements document for a program that allows a company to send out personalized mailings, either by e-mail or through the postal service. Template files contain the message text, together with variable fields (such as Dear [Title] [Last Name] . . .). A database (stored as a text file) contains the field values for each recipient. Use HTML as the output file format. Then design and implement the program.

Project 12.2 Write a tic-tac-toe game that allows a human player to play against the computer. Your program will play many turns against a human opponent, and it will learn. When it is the computer's turn, the computer randomly selects an empty field, except that it won't ever choose a losing combination. For that purpose, your program must keep an array of losing combinations. Whenever the human wins, the immediately preceding combination is stored as losing. For example, suppose that `X` = computer and `O` = human. Suppose the current combination is

O	X	X
	O	

Now it is the human's turn, who will of course choose

O	X	X
	O	
		O

The computer should then remember the preceding combination

O	X	X
	O	

as a losing combination. As a result, the computer will never again choose that combination from

O	X	
	O	

or

O		X
	O	

Discover classes and supply a UML diagram before you begin to program.

Answers to Self-Check Questions

1. It is unlikely that the customer did a perfect job with the requirements document. If you don't accommodate changes, your customer may not like the outcome. If you charge for the changes, your customer may not like the cost.
2. An "extreme" spiral model, with lots of iterations.
3. To give frequent feedback as to whether the current iteration of the product fits customer needs.
4. `PrintStream`
5. To produce the shipping address of the customer.
6. Reword the responsibilities so that they are at a higher level, or come up with more classes to handle the responsibilities.
7. Through aggregation. The bank manages bank account objects.
8. Through inheritance.
9. The `BankAccount`, `System`, and `PrintStream` classes.
10. The `Invoice` class is responsible for computing the amount due. It collaborates with the `LineItem` class.
11. This design decision reduces coupling. It enables us to reuse the classes when we want to show the invoice in a dialog box or on a web page.
12. The bank needs to store the list of customers so that customers can log in. We need to locate all bank accounts of a customer, and we chose to simply store them in the customer class. In this program, there is no further need to access bank accounts.
13. The `Bank` class needs to have an additional responsibility: to load and save the accounts. The bank can carry out this responsibility because it has access to the customer objects and, through them, to the bank accounts.

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Chapter 13 Recursion

CHAPTER GOALS

- To learn about the technique of recursion
- To understand the relationship between recursion and iteration
- To analyze problems that are much easier to solve by recursion than by iteration
- To learn to "think recursively"
- To be able to use recursive helper methods
- To understand when the use of recursion affects the efficiency of an algorithm

Recursion is a powerful technique for reducing complex computational problems to simpler ones. The term "recursion" refers to the fact that the same computation recurs, or occurs repeatedly, as the problem is solved. Recursion is often the most natural way of thinking about a problem, and there are some computations that are very difficult to perform without recursion. This chapter shows you simple and complex examples of recursion and teaches you how to "think recursively".

CHAPTER CONTENTS

13.1 Triangle Numbers 492
Common Error 13.1: Infinite Recursion 495
Common Error 13.2: Tracing Through Recursive Methods 496
How To 13.1: Thinking Recursively 497
Worked Example 13.1: Finding Files ⊕

13.2 Recursive Helper Methods 500

13.3 The Efficiency of Recursion 502

13.4 Permutations 507
Random Fact 13.1: The Limits of Computation ⊕

13.5 Mutual Recursions 510

13.1 Triangle Numbers

We begin this chapter with a very simple example that demonstrates the power of thinking recursively. In this example, we will look at triangle shapes such as this one:

```
[]
[][]
[][][]
```

We'd like to compute the area of a triangle of width *n*, assuming that each `[]` square has area 1. This value is sometimes called the *n^{th} triangle number*. For example, as you can tell from looking at the triangle above, the third triangle number is 6.

You may know that there is a very simple formula to compute these numbers, but you should pretend for now that you don't know about it. The ultimate purpose of this section is not to compute triangle numbers, but to learn about the concept of **recursion** by working through a simple example.

Here is the outline of the class that we will develop:

```
public class Triangle
{
   private int width;

   public Triangle(int aWidth)
   {
      width = aWidth;
   }

   public int getArea()
   {
      . . .
   }
}
```

If the width of the triangle is 1, then the triangle consists of a single square, and its area is 1. Let's take care of this case first.

```
public int getArea()
{
   if (width == 1) { return 1; }
   . . .
}
```

To deal with the general case, consider this picture.

```
[]
[][]
[][][]
[][][][]
```

Suppose we knew the area of the smaller, colored triangle. Then we could easily compute the area of the larger triangle as

```
smallerArea + width
```

How can we get the smaller area? Let's make a smaller triangle and ask it!

```
Triangle smallerTriangle = new Triangle(width - 1);
int smallerArea = smallerTriangle.getArea();
```

Now we can complete the `getArea` method:

```
public int getArea()
{
   if (width == 1) { return 1; }
   Triangle smallerTriangle = new Triangle(width - 1);
   int smallerArea = smallerTriangle.getArea();
   return smallerArea + width;
}
```

A recursive computation solves a problem by using the solution of the same problem with simpler values.

Here is an illustration of what happens when we compute the area of a triangle of width 4.

- The `getArea` method makes a smaller triangle of width 3.
- It calls `getArea` on that triangle.
  - That method makes a smaller triangle of width 2.
  - It calls `getArea` on that triangle.
    - That method makes a smaller triangle of width 1.
    - It calls `getArea` on that triangle.
      - That method returns 1.
    - The method returns `smallerArea + width` = 1 + 2 = 3.
  - The method returns `smallerArea + width` = 3 + 3 = 6.
- The method returns `smallerArea + width` = 6 + 4 = 10.

This solution has one remarkable aspect. To solve the area problem for a triangle of a given width, we use the fact that we can solve the same problem for a lesser width. This is called a *recursive* solution.

The call pattern of a **recursive method** looks complicated, and the key to the successful design of a recursive method is *not to think about it.* Instead, look at the `getArea` method one more time and notice how utterly reasonable it is. If the width is 1, then, of course, the area is 1. The next part is just as reasonable. Compute the area of the smaller triangle *and don't think about why that works*. Then the area of the larger triangle is clearly the sum of the smaller area and the width.

There are two key requirements to make sure that the recursion is successful:

- Every recursive call must simplify the computation in some way.
- There must be special cases to handle the simplest computations directly.

For a recursion to terminate, there must be special cases for the simplest values.

The `getArea` method calls itself again with smaller and smaller width values. Eventually the width must reach 1, and there is a special case for computing the area of a triangle with width 1. Thus, the `getArea` method always succeeds.

Actually, you have to be careful. What happens when you call the area of a triangle with width –1? It computes the area of a triangle with width –2, which computes the area of a triangle with width –3, and so on. To avoid this, the `getArea` method should return `0` if the width is ≤ `0`.

Recursion is not really necessary to compute the triangle numbers. The area of a triangle equals the sum

```
1 + 2 + 3 + . . . + width
```

Of course, we can program a simple loop:

```
double area = 0;
for (int i = 1; i <= width; i++)
{
   area = area + i;
}
```

Many simple recursions can be computed as loops. However, loop equivalents for more complex recursions—such as the one in our next example—can be complex.

Actually, in this case, you don't even need a loop to compute the answer. The sum of the first n integers can be computed as

$$1 + 2 + \cdots + n = n \times (n+1)/2$$

Thus, the area equals

```
width * (width + 1) / 2
```

Therefore, neither recursion nor a loop is required to solve this problem. The recursive solution is intended as a "warm-up" to introduce you to the concept of recursion.

ANIMATION
Tracing a Recursion

ch13/triangle/Triangle.java

```
/**
   A triangular shape composed of stacked unit squares like this:
   []
   [][]
   [][][]
   . . .
*/
public class Triangle
{
   private int width;

   /**
      Constructs a triangular shape.
      @param aWidth the width (and height) of the triangle
   */
   public Triangle(int aWidth)
   {
      width = aWidth;
   }

   /**
      Computes the area of the triangle.
      @return the area
   */
   public int getArea()
   {
      if (width <= 0) { return 0; }
      if (width == 1) { return 1; }
      Triangle smallerTriangle = new Triangle(width - 1);
      int smallerArea = smallerTriangle.getArea();
      return smallerArea + width;
   }
}
```

ch13/triangle/TriangleTester.java

```
public class TriangleTester
{
   public static void main(String[] args)
   {
      Triangle t = new Triangle(10);
      int area = t.getArea();
      System.out.println("Area: " + area);
      System.out.println("Expected: 55");
   }
}
```

Program Run

```
Enter width: 10
Area: 55
Expected: 55
```

SELF CHECK

1. Why is the statement `if (width == 1) { return 1; }` in the `getArea` method unnecessary?
2. How would you modify the program to recursively compute the area of a square?

Common Error 13.1

Infinite Recursion

A common programming error is an infinite recursion: a method calling itself over and over with no end in sight. The computer needs some amount of memory for bookkeeping for each call. After some number of calls, all memory that is available for this purpose is exhausted. Your program shuts down and reports a "stack overflow".

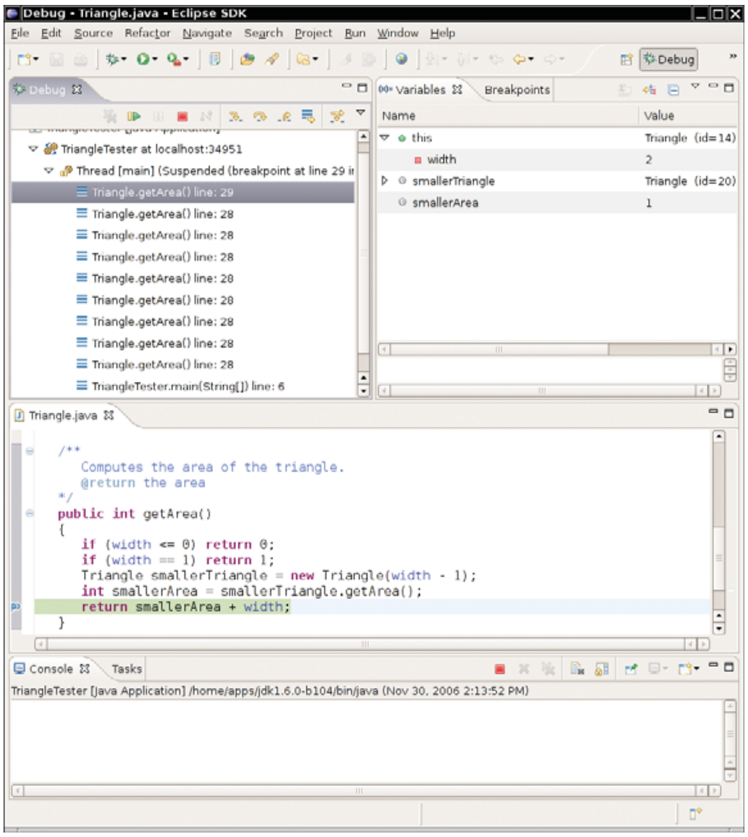
Infinite recursion happens either because the parameter values don't get simpler or because a special terminating case is missing. For example, suppose the `getArea` method was allowed to compute the area of a triangle with width `0`. If it weren't for the special test, the method would construct triangles with width –1, –2, –3, and so on.

Common Error 13.2

Tracing Through Recursive Methods

Debugging a recursive method can be somewhat challenging. When you set a **breakpoint** in a recursive method, the program stops as soon as that program line is encountered in *any call to the recursive method.* Suppose you want to debug the recursive `getArea` method of the `Triangle` class. Debug the `TriangleTester` program and run until the beginning of the `getArea` method. Inspect the `width` instance variable. It is 10.

Remove the breakpoint and now run until the statement `return smallerArea + width;` (see Figure 1). When you inspect `width` again, its value is 2! That makes no sense. There was no instruction that changed the value of `width`. Is that a bug with the debugger?


Debug - Triangle.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
Debug
Variables
Breakpoints
Triangle.java
Console
Tasks

```
TriangleTester at localhost:34951
  Thread [main] (Suspended (breakpoint at line 29 i
    Triangle.getArea() line: 29
    Triangle.getArea() line: 28
    Triangle.getArea() line: 28
    Triangle.getArea() line: 28
    Triangle.getArea() line: 28
    Triangle.getArea() line: 28
    Triangle.getArea() line: 28
    Triangle.getArea() line: 28
    Triangle.getArea() line: 28
    TriangleTester.main(String[]) line: 6
```

```
Name                 Value
this                 Triangle (id=14)
   width             2
smallerTriangle      Triangle (id=20)
smallerArea          1
```

```
/**
   Computes the area of the triangle.
   @return the area
*/
public int getArea()
{
   if (width <= 0) return 0;
   if (width == 1) return 1;
   Triangle smallerTriangle = new Triangle(width - 1);
   int smallerArea = smallerTriangle.getArea();
   return smallerArea + width;
}
```

```
TriangleTester [Java Application] /home/apps/jdk1.6.0-b104/bin/java (Nov 30, 2006 2:13:52 PM)
```

Figure 1 Debugging a Recursive Method

No. The program stopped in the first recursive call to `getArea` that reached the `return` statement. If you are confused, look at the **call stack** (top left in the figure). You will see that nine calls to `getArea` are pending.

You can debug recursive methods with the debugger. You just need to be particularly careful, and watch the call stack to understand which nested call you currently are in.

How To 13.1 Thinking Recursively

To solve a problem recursively requires a different mindset than to solve it by programming a loop. In fact, it helps if you pretend to be a bit lazy, asking others to do most of the work for you. If you need to solve a complex problem, pretend that "someone else" will do most of the heavy lifting and solve the problem for simpler inputs. Then you only need to figure out how you can turn the solutions with simpler inputs into a solution for the whole problem.

To illustrate the technique of recursion, let us consider the following problem. We want to test whether a sentence is a *palindrome*—a string that is equal to itself when you reverse all characters. Typical examples of palindromes are

- A man, a plan, a canal—Panama!
- Go hang a salami, I'm a lasagna hog

and, of course, the oldest palindrome of all:

- Madam, I'm Adam

When testing for a palindrome, we match upper- and lowercase letters, and ignore all spaces and punctuation marks.

We want to implement the `isPalindrome` method in the following class:

```
public class Sentence
{
   private String text;

   /**
      Constructs a sentence.
      @param aText a string containing all characters of the sentence
   */
   public Sentence(String aText)
   {
       text = aText;
   }

   /**
      Tests whether this sentence is a palindrome.
      @return true if this sentence is a palindrome, false otherwise
   */
   public boolean isPalindrome()
   {
      . . .
   }
}
```

Step 1 Consider various ways to simplify inputs.

In your mind, fix a particular input or set of inputs for the problem that you want to solve.

Think how you can simplify the inputs in such a way that the same problem can be applied to the simpler input.

When you consider simpler inputs, you may want to remove just a little bit from the original input—maybe remove one or two characters from a string, or remove a small portion of a geometric shape. But sometimes it is more useful to cut the input in half and then see what it means to solve the problem for both halves.

In the palindrome test problem, the input is the string that we need to test. How can you simplify the input? Here are several possibilities:

- Remove the first character.
- Remove the last character.
- Remove both the first and last characters.

- Remove a character from the middle.
- Cut the string into two halves.

These simpler inputs are all potential inputs for the palindrome test.

Step 2 Combine solutions with simpler inputs into a solution of the original problem.

In your mind, consider the solutions of your problem for the simpler inputs that you discovered in Step 1. Don't worry *how* those solutions are obtained. Simply have faith that the solutions are readily available. Just say to yourself: These are simpler inputs, so someone else will solve the problem for me.

Now think how you can turn the solution for the simpler inputs into a solution for the input that you are currently thinking about. Maybe you need to add a small quantity, related to the quantity that you lopped off to arrive at the simpler input. Maybe you cut the original input in half and have solutions for each half. Then you may need to add both solutions to arrive at a solution for the whole.

Consider the methods for simplifying the inputs for the palindrome test. Cutting the string in half doesn't seem a good idea. If you cut

```
"Madam, I'm Adam"
```

in half, you get two strings:

```
"Madam, I"
```

and

```
"'m Adam"
```

Neither of them is a palindrome. Cutting the input in half and testing whether the halves are palindromes seems a dead end.

The most promising simplification is to remove the first *and* last characters. Removing the `M` at the front and the `m` at the back yields

```
"adam, I'm Ada"
```

Suppose you can verify that the shorter string is a palindrome. Then *of course* the original string is a palindrome—we put the same letter in the front and the back. That's extremely promising. A word is a palindrome if

- The first and last letters match (ignoring letter case)

and

- The word obtained by removing the first and last letters is a palindrome.

Again, don't worry how the test works for the shorter string. It just works.

There is one other case to consider. What if the first or last letter of the word is not a letter? For example, the string

```
"A man, a plan, a canal, Panama!"
```

ends in a `!` character, which does not match the `A` in the front. But we should ignore nonletters when testing for palindromes. Thus, when the last character is not a letter but the first character is a letter, it doesn't make sense to remove both the first and the last characters. That's not a problem. Remove only the last character. If the shorter string is a palindrome, then it stays a palindrome when you attach a nonletter.

The same argument applies if the first character is not a letter. Now we have a complete set of cases.

- If the first and last characters are both letters, then check whether they match. If so, remove both and test the shorter string.
- Otherwise, if the last character isn't a letter, remove it and test the shorter string.
- Otherwise, the first character isn't a letter. Remove it and test the shorter string.

In all three cases, you can use the solution to the simpler problem to arrive at a solution to your problem.

Step 3 Find solutions to the simplest inputs.

A recursive computation keeps simplifying its inputs. Eventually it arrives at very simple inputs. To make sure that the recursion comes to a stop, you must deal with the simplest inputs separately. Come up with special solutions for them, which is usually very easy.

However, sometimes you get into philosophical questions dealing with *degenerate* inputs: empty strings, shapes with no area, and so on. Then you may want to investigate a slightly larger input that gets reduced to such a trivial input and see what value you should attach to the degenerate inputs so that the simpler value, when used according to the rules you discovered in Step 2, yields the correct answer.

Let's look at the simplest strings for the palindrome test:

- Strings with two characters
- Strings with a single character
- The empty string

We don't have to come up with a special solution for strings with two characters. Step 2 still applies to those strings—either or both of the characters are removed. But we do need to worry about strings of length `0` and 1. In those cases, Step 2 can't apply. There aren't two characters to remove.

The empty string is a palindrome—it's the same string when you read it backwards. If you find that too artificial, consider a string `"mm"`. According to the rule discovered in Step 2, this string is a palindrome if the first and last characters of that string match and the remainder—that is, the empty string—is also a palindrome. Therefore, it makes sense to consider the empty string a palindrome.

A string with a single letter, such as `"I"`, is a palindrome. How about the case in which the character is not a letter, such as `"!"`? Removing the `!` yields the empty string, which is a palindrome. Thus, we conclude that all strings of length `0` or 1 are palindromes.

Step 4 Implement the solution by combining the simple cases and the reduction step.

Now you are ready to implement the solution. Make separate cases for the simple inputs that you considered in Step 3. If the input isn't one of the simplest cases, then implement the logic you discovered in Step 2.

Here is the `isPalindrome` method.

```
public boolean isPalindrome()
{
   int length = text.length();

   // Separate case for shortest strings.
   if (length <= 1) { return true; }

   // Get first and last characters, converted to lowercase.
   char first = Character.toLowerCase(text.charAt(0));
   char last = Character.toLowerCase(text.charAt(length - 1));

   if (Character.isLetter(first) && Character.isLetter(last))
   {
      // Both are letters.
      if (first == last)
      {
         // Remove both first and last character.
         Sentence shorter = new Sentence(text.substring(1, length - 1));
         return shorter.isPalindrome();
      }
      else
      {
         return false;
         }
      }
      else if (!Character.isLetter(last))
      {
         // Remove last character.
         Sentence shorter = new Sentence(text.substring(0, length - 1));
         return shorter.isPalindrome();
      }
      else
      {
         // Remove first character.
         Sentence shorter = new Sentence(text.substring(1));
         return shorter.isPalindrome();
      }
   }
```

Worked Example 13.1

Finding Files

In this Worked Example, we find all files with a given extension in a directory tree.

13.2 Recursive Helper Methods

Sometimes it is easier to find a recursive solution if you make a slight change to the original problem.

Sometimes it is easier to find a recursive solution if you change the original problem slightly. Then the original problem can be solved by calling a recursive helper method.

Here is a typical example. Consider the palindrome test of How To 13.1. It is a bit inefficient to construct new `Sentence` objects in every step. Now consider the following change in the problem. Rather than testing whether the entire sentence is a palindrome, let's check whether a substring is a palindrome:

```
/**
   Tests whether a substring of the sentence is a palindrome.
   @param start the index of the first character of the substring
   @param end the index of the last character of the substring
   @return true if the substring is a palindrome
*/
public boolean isPalindrome(int start, int end)
```

This method turns out to be even easier to implement than the original test. In the recursive calls, simply adjust the `start` and `end` parameters to skip over matching letter pairs and characters that are not letters. There is no need to construct new `Sentence` objects to represent the shorter strings.

```
public boolean isPalindrome(int start, int end)
{
   // Separate case for substrings of length 0 and 1.
   if (start >= end) { return true; }
```

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

```
   // Get first and last characters, converted to lowercase.
   char first = Character.toLowerCase(text.charAt(start));
   char last = Character.toLowerCase(text.charAt(end));

   if (Character.isLetter(first) && Character.isLetter(last))
   {
      if (first == last)
      {
         // Test substring that doesn't contain the matching letters.
         return isPalindrome(start + 1, end - 1);
      }
      else
      {
         return false;
      }
   }
   else if (!Character.isLetter(last))
   {
      // Test substring that doesn't contain the last character.
      return isPalindrome(start, end - 1);
   }
   else
   {
      // Test substring that doesn't contain the first character.
      return isPalindrome(start + 1, end);
   }
}
```

You should still supply a method to solve the whole problem—the user of your method shouldn't have to know about the trick with the substring positions. Simply call the helper method with positions that test the entire string:

```
public boolean isPalindrome()
{
   return isPalindrome(0, text.length() - 1);
}
```

Note that this call is *not* a recursive method. The `isPalindrome()` method calls the helper method `isPalindrome(int, int)`. In this example, we use overloading to declare two methods with the same name. The `isPalindrome` method without parameters is the method that we expect the public to use. The second method, with two `int` parameters, is the recursive helper method. If you prefer, you can avoid overloaded methods by choosing a different name for the helper method, such as `substringIsPalindrome`.

Use the technique of recursive helper methods whenever it is easier to solve a recursive problem that is equivalent to the original problem—but more amenable to a recursive solution.

SELF CHECK

3. Do we have to give the same name to both `isPalindrome` methods?
4. When does the recursive `isPalindrome` method stop calling itself?

13.3 The Efficiency of Recursion

As you have seen in this chapter, recursion can be a powerful tool to implement complex algorithms. On the other hand, recursion can lead to algorithms that perform poorly. In this section, we will analyze the question of when recursion is beneficial and when it is inefficient.

Consider the Fibonacci sequence: a sequence of numbers defined by the equation

$$\begin{aligned} f_1 &= 1 \\ f_2 &= 1 \\ f_n &= f_{n-1} + f_{n-2} \end{aligned}$$

That is, each value of the sequence is the sum of the two preceding values. The first ten terms of the sequence are

1, 1, 2, 3, 5, 8, 13, 21, 34, 55

It is easy to extend this sequence indefinitely. Just keep appending the sum of the last two values of the sequence. For example, the next entry is 34 + 55 = 89.

We would like to write a function that computes f_n for any value of n. Let us translate the definition directly into a recursive method:

ch13/fib/RecursiveFib.java

```java
import java.util.Scanner;

/**
   This program computes Fibonacci numbers using a recursive method.
*/
public class RecursiveFib
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      System.out.print("Enter n: ");
      int n = in.nextInt();

      for (int i = 1; i <= n; i++)
      {
         long f = fib(i);
         System.out.println("fib(" + i + ") = " + f);
      }
   }

   /**
      Computes a Fibonacci number.
      @param n an integer
      @return the nth Fibonacci number
   */
   public static long fib(int n)
   {
      if (n <= 2) { return 1; }
      else return fib(n - 1) + fib(n - 2);
   }
}
```

Program Run

```
Enter n: 50
fib(1) = 1
fib(2) = 1
fib(3) = 2
fib(4) = 3
fib(5) = 5
fib(6) = 8
fib(7) = 13
. . .
fib(50) = 12586269025
```

That is certainly simple, and the method will work correctly. But watch the output closely as you run the test program. The first few calls to the `fib` method are fast. For larger values, though, the program pauses an amazingly long time between outputs.

That makes no sense. Armed with pencil, paper, and a pocket calculator you could calculate these numbers pretty quickly, so it shouldn't take the computer anywhere near that long.

To find out the problem, let us insert **trace messages** into the method:

ch13/fib/RecursiveFibTracer.java

```java
import java.util.Scanner;

/**
   This program prints trace messages that show how often the
   recursive method for computing Fibonacci numbers calls itself.
*/
public class RecursiveFibTracer
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      System.out.print("Enter n: ");
      int n = in.nextInt();

      long f = fib(n);

      System.out.println("fib(" + n + ") = " + f);
   }

   /**
      Computes a Fibonacci number.
      @param n an integer
      @return the nth Fibonacci number
   */
   public static long fib(int n)
   {
      System.out.println("Entering fib: n = " + n);
      long f;
      if (n <= 2) { f = 1; }
      else { f = fib(n - 1) + fib(n - 2); }
      System.out.println("Exiting fib: n = " + n
            + " return value = " + f);
      return f;
   }
}
```

Program Run

```
Enter n: 6
Entering fib: n = 6
Entering fib: n = 5
Entering fib: n = 4
Entering fib: n = 3
Entering fib: n = 2
Exiting fib: n = 2 return value = 1
Entering fib: n = 1
Exiting fib: n = 1 return value = 1
Exiting fib: n = 3 return value = 2
Entering fib: n = 2
Exiting fib: n = 2 return value = 1
Exiting fib: n = 4 return value = 3
Entering fib: n = 3
Entering fib: n = 2
Exiting fib: n = 2 return value = 1
Entering fib: n = 1
Exiting fib: n = 1 return value = 1
Exiting fib: n = 3 return value = 2
Exiting fib: n = 5 return value = 5
Entering fib: n = 4
Entering fib: n = 3
Entering fib: n = 2
Exiting fib: n = 2 return value = 1
Entering fib: n = 1
Exiting fib: n = 1 return value = 1
Exiting fib: n = 3 return value = 2
Entering fib: n = 2
Exiting fib: n = 2 return value = 1
Exiting fib: n = 4 return value = 3
Exiting fib: n = 6 return value = 8
fib(6) = 8
```

Figure 2 shows the call tree for computing `fib(6)`. Now it is becoming apparent why the method takes so long. It is computing the same values over and over. For example, the computation of `fib(6)` calls `fib(4)` twice and `fib(3)` three times. That is very different from the computation we would do with pencil and paper. There we would just write down the values as they were computed and add up the last two to

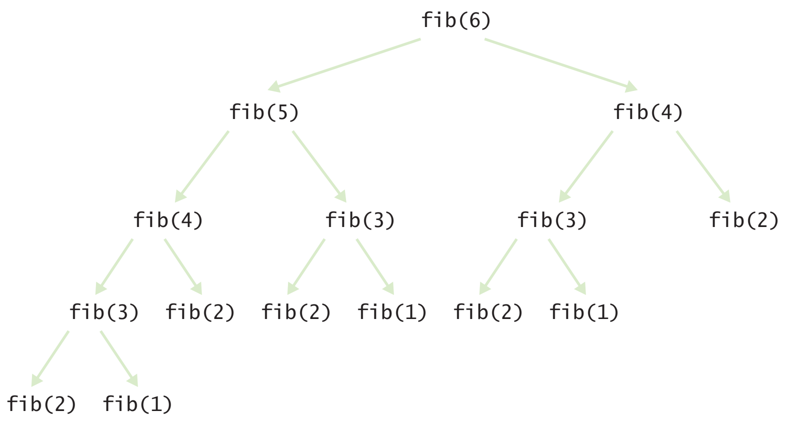


Figure 2 Call Pattern of the Recursive `fib` Method

get the next one until we reached the desired entry; no sequence value would ever be computed twice.

If we imitate the pencil-and-paper process, then we get the following program.

ch13/fib/LoopFib.java

```java
import java.util.Scanner;

/**
   This program computes Fibonacci numbers using an iterative method.
*/
public class LoopFib
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      System.out.print("Enter n: ");
      int n = in.nextInt();

      for (int i = 1; i <= n; i++)
      {
         long f = fib(i);
         System.out.println("fib(" + i + ") = " + f);
      }
   }

   /**
      Computes a Fibonacci number.
      @param n an integer
      @return the nth Fibonacci number
   */
   public static long fib(int n)
   {
      if (n <= 2) { return 1; }
      long olderValue = 1;
      long oldValue = 1;
      long newValue = 1;
      for (int i = 3; i <= n; i++)
      {
         newValue = oldValue + olderValue;
         olderValue = oldValue;
         oldValue = newValue;
      }
      return newValue;
   }
}
```

Program Run

```
Enter n: 50
fib(1) = 1
fib(2) = 1
fib(3) = 2
fib(4) = 3
fib(5) = 5
fib(6) = 8
fib(7) = 13
. . .
fib(50) = 12586269025
```

This method runs *much* faster than the recursive version.

In this example of the fib method, the recursive solution was easy to program because it exactly followed the mathematical definition, but it ran far more slowly than the iterative solution, because it computed many intermediate results multiple times.

Occasionally, a recursive solution runs much slower than its iterative counterpart. However, in most cases, the recursive solution is only slightly slower.

Can you always speed up a recursive solution by changing it into a loop? Frequently, the iterative and recursive solution have essentially the same performance. For example, here is an iterative solution for the palindrome test.

```
public boolean isPalindrome()
{
   int start = 0;
   int end = text.length() - 1;
   while (start < end)
   {
      char first = Character.toLowerCase(text.charAt(start));
      char last = Character.toLowerCase(text.charAt(end);

      if (Character.isLetter(first) && Character.isLetter(last))
      {
         // Both are letters.
         if (first == last)
         {
            start++;
            end--;
         }
         else
         {
            return false;
         }
      }
      if (!Character.isLetter(last)) { end--; }
      if (!Character.isLetter(first)) { start++; }
   }
   return true;
}
```

This solution keeps two index variables: start and end. The first index starts at the beginning of the string and is advanced whenever a letter has been matched or a nonletter has been ignored. The second index starts at the end of the string and moves toward the beginning. When the two index variables meet, the iteration stops.

Both the iteration and the recursion run at about the same speed. If a palindrome has n characters, the iteration executes the loop between $n/2$ and n times, depending on how many of the characters are letters, since one or both index variables are moved in each step. Similarly, the recursive solution calls itself between $n/2$ and n times, because one or two characters are removed in each step.

In such a situation, the iterative solution tends to be a bit faster, because each recursive method call takes a certain amount of processor time. In principle, it is possible for a smart compiler to avoid recursive method calls if they follow simple patterns, but most compilers don't do that. From that point of view, an iterative solution is preferable.

In many cases, a recursive solution is easier to understand and implement correctly than an iterative solution.

However, many problems have recursive solutions that are easier to understand and implement correctly than their iterative counterparts. Sometimes there is no obvious iterative solution at all—see the example in the next section. There is a certain elegance and economy of thought to recursive solutions that makes them more appealing. As the computer scientist (and creator of the GhostScript interpreter for the PostScript graphics description language) L. Peter Deutsch put it: "To iterate is human, to recurse divine."

SELF CHECK

5. Is it faster to compute the triangle numbers recursively, as shown in Section 13.1, or is it faster to use a loop that computes `1 + 2 + 3 + . . . + width`?
6. You can compute the factorial function either with a loop, using the definition that $n! = 1 \times 2 \times \ldots \times n$, or recursively, using the definition that $0! = 1$ and $n! = (n - 1)! \times n$. Is the recursive approach inefficient in this case?

13.4 Permutations

The permutations of a string can be obtained more naturally through recursion than with a loop.

In this section, we will study a more complex example of recursion that would be difficult to program with a simple loop. (As Exercise P13.11 shows, it is possible to avoid the recursion, but the resulting solution is quite complex, and no faster).

We will design a class that lists all permutations of a string. A permutation is simply a rearrangement of the letters in the string. For example, the string `"eat"` has six permutations (including the original string itself):

```
"eat"
"eta"
"aet"
"ate"
"tea"
"tae"
```

As in the preceding section, we will declare a class that is in charge of computing the answer. In this case, the answer is not a single number but a collection of permuted strings. Here is our generator class:

```
public class PermutationGenerator
{
   public PermutationGenerator(String aWord) { . . . }
   ArrayList<String> getPermutations() { . . . }
}
```

And here is the program that prints out all permutations of the string `"eat"`:

ch13/permute/PermutationGeneratorDemo.java

```
import java.util.ArrayList;

/**
   This program demonstrates the permutation generator.
*/
public class PermutationGeneratorDemo
{
   public static void main(String[] args)
   {
      PermutationGenerator generator = new PermutationGenerator("eat");
      ArrayList<String> permutations = generator.getPermutations();
      for (String s : permutations)
      {
            System.out.println(s);
        }
    }
}
```

Program Run

```
eat
eta
aet
ate
tea
tae
```

Now we need a way to generate the permutations recursively. Consider the string "eat". Let's simplify the problem. First, we'll generate all permutations that start with the letter 'e', then those that start with 'a', and finally those that start with 't'. How do we generate the permutations that start with 'e'? We need to know the permutations of the substring "at". But that's the same problem—to generate all permutations—with a simpler input, namely the shorter string "at". Thus, we can use recursion. Generate the permutations of the substring "at". They are

```
"at"
"ta"
```

For each permutation of that substring, prepend the letter 'e' to get the permutations of "eat" that start with 'e', namely

```
"eat"
"eta"
```

Now let's turn our attention to the permutations of "eat" that start with 'a'. We need to produce the permutations of the remaining letters, "et". They are:

```
"et"
"te"
```

We add the letter 'a' to the front of the strings and obtain

```
"aet"
"ate"
```

We generate the permutations that start with 't' in the same way.

That's the idea. The implementation is fairly straightforward. In the getPermutations method, we loop through all positions in the word to be permuted. For each of them, we compute the shorter word that is obtained by removing the ith letter:

```
String shorterWord = word.substring(0, i) + word.substring(i + 1);
```

We construct a permutation generator to get the permutations of the shorter word, and ask it to give us all permutations of the shorter word.

```
PermutationGenerator shorterPermutationGenerator
      = new PermutationGenerator(shorterWord);
ArrayList<String> shorterWordPermutations
      = shorterPermutationGenerator.getPermutations();
```

Finally, we add the removed letter to the front of all permutations of the shorter word.

```
for (String s : shorterWordPermutations)
{
      permutations.add(word.charAt(i) + s);
   }
```

As always, we have to provide a special case for the simplest strings. The simplest possible string is the empty string, which has a single permutation—itself.

Here is the complete `PermutationGenerator` class.

ch13/permute/PermutationGenerator.java

```
import java.util.ArrayList;

/**
   This class generates permutations of a word.
*/
public class PermutationGenerator
{
   private String word;

   /**
      Constructs a permutation generator.
      @param aWord the word to permute
   */
   public PermutationGenerator(String aWord)
   {
      word = aWord;
   }

   /**
      Gets all permutations of a given word.
   */
   public ArrayList<String> getPermutations()
   {
      ArrayList<String> permutations = new ArrayList<String>();

      // The empty string has a single permutation: itself
      if (word.length() == 0)
      {
         permutations.add(word);
         return permutations;
      }

      // Loop through all character positions
      for (int i = 0; i < word.length(); i++)
      {
         // Form a simpler word by removing the ith character
         String shorterWord = word.substring(0, i)
               + word.substring(i + 1);

         // Generate all permutations of the simpler word
         PermutationGenerator shorterPermutationGenerator
               = new PermutationGenerator(shorterWord);
         ArrayList<String> shorterWordPermutations
               = shorterPermutationGenerator.getPermutations();

         // Add the removed character to the front of
         // each permutation of the simpler word
         for (String s : shorterWordPermutations)
         {
            permutations.add(word.charAt(i) + s);
            }
        }
        // Return all permutations
        return permutations;
    }
}
```

Compare the `PermutationGenerator` and `Triangle` classes. Both of them work on the same principle. When they work on a more complex input, they first solve the problem for a simpler input. Then they combine the result for the simpler input with additional work to deliver the results for the more complex input. There really is no particular complexity behind that process as long as you think about the solution on that level only. However, behind the scenes, the simpler input creates even simpler input, which creates yet another simplification, and so on, until one input is so simple that the result can be obtained without further help. It is interesting to think about this process, but it can also be confusing. What's important is that you can focus on the one level that matters—putting a solution together from the slightly simpler problem, ignoring the fact that the simpler problem also uses recursion to get its results.

SELF CHECK

7. What are all permutations of the four-letter word `beat`?
8. Our recursion for the permutation generator stops at the empty string. What simple modification would make the recursion stop at strings of length `0` or `1`?
9. Why isn't it easy to develop an iterative solution for the permutation generator?

Random Fact 13.1

The Limits of Computation

Random Fact 13.1 discusses problems that are intrinsically beyond the capabilities of any computer. For example, theoretical computer scientists have proven that it is impossible to write a program that can grade your programming homework by comparing your program against the instructor's solution and telling with certainty whether these two programs always produce the same results when given the same inputs.

13.5 Mutual Recursions

In a mutual recursion, a set of cooperating methods calls each other repeatedly.

In the preceding examples, a method called itself to solve a simpler problem. Sometimes, a set of cooperating methods calls each other in a recursive fashion. In this section, we will explore a typical situation of such a mutual recursion. This technique is significantly more advanced than the simple recursion that we discussed in the preceding sections.

We will develop a program that can compute the values of arithmetic expressions such as

```
3+4*5
(3+4)*5
1-(2-(3-(4-5)))
```

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

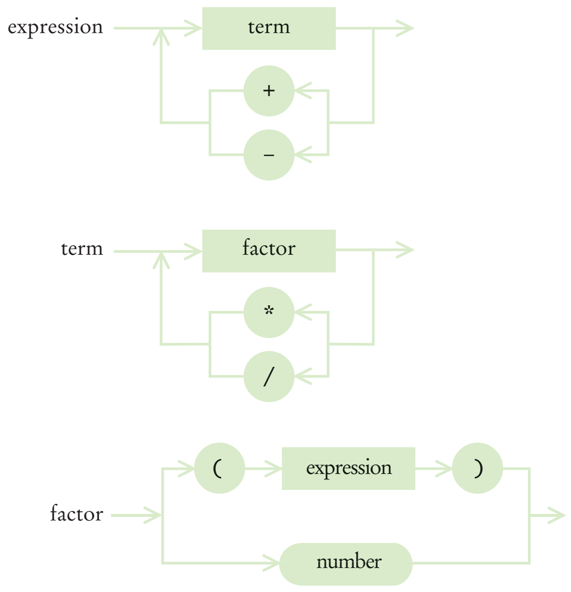


Figure 3 Syntax Diagrams for Evaluating an Expression

Computing such an expression is complicated by the fact that * and / bind more strongly than + and -, and that parentheses can be used to group subexpressions.

Figure 3 shows a set of **syntax diagrams** that describes the syntax of these expressions. To see how the syntax diagrams work, consider the expression 3+4*5. When you enter the *expression* syntax diagram, the arrow points directly to *term*, giving you no alternative but to enter the *term* syntax diagram. The arrow points to *factor*, again giving you no choice. You enter the *factor* diagram, and now you have two choices: to follow the top branch or the bottom branch. Because the first input token is the number 3 and not a (, you must follow the bottom branch. You accept the input token because it matches the *number*. Follow the arrow out of *number* to the end of *factor*. Just like in a method call, you now back up, returning to the end of the *factor* element of the *term* diagram. Now you have another choice—to loop back in the *term* diagram, or to exit. The next input token is a +, and it matches neither the * or the / that would be required to loop back. So you exit, returning to *expression*. Again, you have a choice, to loop back or to exit. Now the + matches one of the choices in the loop. Accept the + in the input and move back to the *term* element.

In this fashion, an expression is broken down into a sequence of terms, separated by + or -, each term is broken down into a sequence of factors, each separated by * or /, and each factor is either a parenthesized expression or a number. You can draw this breakdown as a tree. Figure 4 shows how the expressions 3+4*5 and (3+4)*5 are derived from the syntax diagram.

Why do the syntax diagrams help us compute the value of the tree? If you look at the syntax trees, you will see that they accurately represent which operations should be carried out first. In the first tree, 4 and 5 should be multiplied, and then the result should be added to 3. In the second tree, 3 and 4 should be added, and the result should be multiplied by 5.

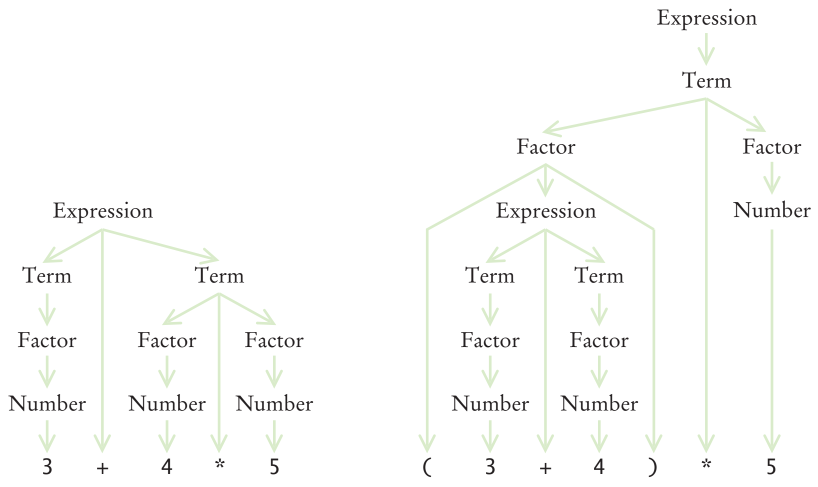


Figure 4 Syntax Trees for Two Expressions

At the end of this section, you will find the implementation of the `Evaluator` class, which evaluates these expressions. The `Evaluator` makes use of an `Expression-Tokenizer` class, which breaks up an input string into tokens—numbers, operators, and parentheses. (For simplicity, we only accept positive integers as numbers, and we don't allow spaces in the input.)

When you call `nextToken`, the next input token is returned as a string. We also supply another method, `peekToken`, which allows you to see the next token without consuming it. To see why the `peekToken` method is necessary, consider the syntax diagram of the factor type. If the next token is a "*" or "/", you want to continue adding and subtracting terms. But if the next token is another character, such as a "+" or "-", you want to stop without actually consuming it, so that the token can be considered later.

To compute the value of an expression, we implement three methods: `get-ExpressionValue`, `getTermValue`, and `getFactorValue`. The `getExpressionValue` method first calls `getTermValue` to get the value of the first term of the expression. Then it checks whether the next input token is one of `+` or `-`. If so, it calls `getTermValue` again and adds or subtracts it.

```
public int getExpressionValue()
{
   int value = getTermValue();
   boolean done = false;
   while (!done)
   {
      String next = tokenizer.peekToken();
      if ("+".equals(next) || "-".equals(next))
      {
         tokenizer.nextToken(); // Discard "+" or "-"
         int value2 = getTermValue();
         if ("+".equals(next)) value = value + value2;
         else value = value - value2;
         }
         else
         {
            done = true;
         }
      }
      return value;
   }
```

The `getTermValue` method calls `getFactorValue` in the same way, multiplying or dividing the factor values.

Finally, the `getFactorValue` method checks whether the next input is a number, or whether it begins with a `(` token. In the first case, the value is simply the value of the number. However, in the second case, the `getFactorValue` method makes a recursive call to `getExpressionValue`. Thus, the three methods are mutually recursive.

```
   public int getFactorValue()
   {
      int value;
      String next = tokenizer.peekToken();
      if ("(".equals(next))
      {
         tokenizer.nextToken(); // Discard "("
         value = getExpressionValue();
         tokenizer.nextToken(); // Discard ")"
      }
      else
      {
         value = Integer.parseInt(tokenizer.nextToken());
      }
      return value;
   }
```

To see the mutual recursion clearly, trace through the expression `(3+4)*5`:

- `getExpressionValue` calls `getTermValue`
    - `getTermValue` calls `getFactorValue`
        - `getFactorValue` consumes the `(` input
        - `getFactorValue` calls `getExpressionValue`
            - `getExpressionValue` returns eventually with the value of `7`, having consumed `3 + 4`. This is the recursive call.
        - `getFactorValue` consumes the `)` input
        - `getFactorValue` returns `7`
    - `getTermValue` consumes the inputs `*` and `5` and returns `35`
- `getExpressionValue` returns `35`

As always with a recursive solution, you need to ensure that the recursion terminates. In this situation, that is easy to see when you consider the situation in which `getExpressionValue` calls itself. The second call works on a shorter subexpression than the original expression. At each recursive call, at least some of the tokens of the input string are consumed, so eventually the recursion must come to an end.

ch13/expr/Evaluator.java

```java
/**
   A class that can compute the value of an arithmetic expression.
*/
public class Evaluator
{
    private ExpressionTokenizer tokenizer;

   /**
      Constructs an evaluator.
      @param anExpression a string containing the expression
      to be evaluated
   */
   public Evaluator(String anExpression)
   {
      tokenizer = new ExpressionTokenizer(anExpression);
   }

   /**
      Evaluates the expression.
      @return the value of the expression
   */
   public int getExpressionValue()
   {
      int value = getTermValue();
      boolean done = false;
      while (!done)
      {
         String next = tokenizer.peekToken();
         if ("+".equals(next) || "-".equals(next))
         {
            tokenizer.nextToken(); // Discard "+" or "-"
            int value2 = getTermValue();
            if ("+".equals(next)) { value = value + value2; }
            else { value = value - value2; }
         }
         else
         {
            done = true;
         }
      }
      return value;
   }

   /**
      Evaluates the next term found in the expression.
      @return the value of the term
   */
   public int getTermValue()
   {
      int value = getFactorValue();
      boolean done = false;
      while (!done)
      {
         String next = tokenizer.peekToken();
         if ("*".equals(next) || "/".equals(next))
         {
            tokenizer.nextToken();
            int value2 = getFactorValue();
            if ("*".equals(next)) { value = value * value2; }
            else { value = value / value2; }
         }
         else
         {
            done = true;
         }
      }
      return value;
   }

   /**
      Evaluates the next factor found in the expression.
      @return the value of the factor
   */
   public int getFactorValue()
   {
      int value;
      String next = tokenizer.peekToken();
      if ("(".equals(next))
      {
         tokenizer.nextToken(); // Discard "("
         value = getExpressionValue();
         tokenizer.nextToken(); // Discard ")"
      }
      else
      {
         value = Integer.parseInt(tokenizer.nextToken());
      }
      return value;
   }
}
```

ch13/expr/ExpressionTokenizer.java

```
/**
   This class breaks up a string describing an expression
   into tokens: numbers, parentheses, and operators.
*/
public class ExpressionTokenizer
{
   private String input;
   private int start; // The start of the current token
   private int end; // The position after the end of the current token

   /**
      Constructs a tokenizer.
      @param anInput the string to tokenize
   */
   public ExpressionTokenizer(String anInput)
   {
      input = anInput;
      start = 0;
      end = 0;
      nextToken(); // Find the first token
   }

   /**
      Peeks at the next token without consuming it.
      @return the next token or null if there are no more tokens
   */
   public String peekToken()
   {
      if (start >= input.length()) { return null; }
      else { return input.substring(start, end); }
   }

   /**
      Gets the next token and moves the tokenizer to the following token.
      @return the next token or null if there are no more tokens
   */
   public String nextToken()
   {
      String r = peekToken();
      start = end;
      if (start >= input.length()) { return r; }
      if (Character.isDigit(input.charAt(start)))
      {
         end = start + 1;
         while (end < input.length()
               && Character.isDigit(input.charAt(end)))
         {
            end++;
         }
      }
      else
      {
         end = start + 1;
      }
      return r;
   }
}
```

ch13/expr/ExpressionCalculator.java

```
import java.util.Scanner;

/**
   This program calculates the value of an expression
   consisting of numbers, arithmetic operators, and parentheses.
*/
public class ExpressionCalculator
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      System.out.print("Enter an expression: ");
      String input = in.nextLine();
      Evaluator e = new Evaluator(input);
      int value = e.getExpressionValue();
      System.out.println(input + "=" + value);
   }
}
```

Program Run

```
Enter an expression: 3+4*5
3+4*5=23
```

SELF CHECK

10. What is the difference between a term and a factor? Why do we need both concepts?

11. Why does the expression parser use mutual recursion?

12. What happens if you try to parse the illegal expression `3+4*)5`? Specifically, which method throws an exception?

Summary of Learning Objectives

Understand the control flow in a recursive computation.

- A recursive computation solves a problem by using the solution of the same problem with simpler values.
- For a recursion to terminate, there must be special cases for the simplest values.

Identify recursive helper methods for solving a problem.

- Sometimes it is easier to find a recursive solution if you make a slight change to the original problem.

Contrast the efficiency of recursive and non-recursive algorithms.

- Occasionally, a recursive solution runs much slower than its iterative counterpart. However, in most cases, the recursive solution is only slightly slower.
- In many cases, a recursive solution is easier to understand and implement correctly than an iterative solution.

Review a complex recursion example that cannot be solved with a simple loop.

- The permutations of a string can be obtained more naturally through recursion than with a loop.

Recognize the phenomenon of mutual recursion in a parsing application.

- In a mutual recursion, a set of cooperating methods calls each other repeatedly.

Media Resources

WILEY PLUS

www.wiley.com/college/horstmann

- ***Worked Example*** Finding Files
- Lab Exercises
- ***Animation*** Tracing a Recursion
- Practice Quiz
- Code Completion Exercises

Review Exercises

★ **R13.1** Define the terms

a. Recursion

b. Iteration

c. Infinite recursion

d. Recursive helper method

★★ **R13.2** Outline, but do not implement, a recursive solution for finding the smallest value in an array.

★★ **R13.3** Outline, but do not implement, a recursive solution for sorting an array of numbers. *Hint:* First find the smallest value in the array.

★★ **R13.4** Outline, but do not implement, a recursive solution for generating all subsets of the set $\{1, 2, \ldots, n\}$.

★★★ **R13.5** Exercise P13.12 shows an iterative way of generating all permutations of the sequence $(0, 1, \ldots, n - 1)$. Explain why the algorithm produces the correct result.

★ **R13.6** Write a recursive definition of x^n, where $n \geq 0$, similar to the recursive definition of the Fibonacci numbers. *Hint:* How do you compute x^n from x^{n-1}? How does the recursion terminate?

★★ **R13.7** Improve upon Exercise R13.6 by computing x^n as $(x^{n/2})^2$ if n is even. Why is this approach significantly faster? *Hint:* Compute x^{1023} and x^{1024} both ways.

★ **R13.8** Write a recursive definition of $n! = 1 \times 2 \times \ldots \times n$, similar to the recursive definition of the Fibonacci numbers.

★★ **R13.9** Find out how often the recursive version of `fib` calls itself. Keep a static variable `fibCount` and increment it once in every call of `fib`. What is the relationship between `fib(n)` and `fibCount`?

★★★ **R13.10** How many moves are required in the “Towers of Hanoi” problem of Exercise P13.13 to move n disks? *Hint:* As explained in the exercise,

$$\text{moves}(1) = 1$$
$$\text{moves}(n) = 2 \cdot \text{moves}(n-1) + 1$$

Programming Exercises

★ **P13.1** Write a recursive method `void reverse()` that reverses a sentence. For example:

```
Sentence greeting = new Sentence("Hello!");
greeting.reverse();
System.out.println(greeting.getText());
```

prints the string `"!olleH"`. Implement a recursive solution by removing the first character, reversing a sentence consisting of the remaining text, and combining the two.

★★ **P13.2** Redo Exercise P13.1 with a recursive helper method that reverses a substring of the message text.

★ **P13.3** Implement the `reverse` method of Exercise P13.1 as an iteration.

★★ **P13.4** Use recursion to implement a method `boolean find(String t)` that tests whether a string is contained in a sentence:

```
Sentence s = new Sentence("Mississippi!");
boolean b = s.find("sip"); // Returns true
```

Hint: If the text starts with the string you want to match, then you are done. If not, consider the sentence that you obtain by removing the first character.

★★ **P13.5** Use recursion to implement a method `int indexOf(String t)` that returns the starting position of the first substring of the text that matches `t`. Return –1 if `t` is not a substring of `s`. For example,

```
Sentence s = new Sentence("Mississippi!");
int n = s.indexOf("sip"); // Returns 6
```

Hint: This is a bit trickier than the preceding problem, because you must keep track of how far the match is from the beginning of the sentence. Make that value a parameter of a helper method.

★ **P13.6** Using recursion, find the largest element in an array.

```
public class DataSet
{
   public DataSet(int[] values, int first, int last) { . . . }
   public int getMaximum() { . . . }
   . . .
}
```

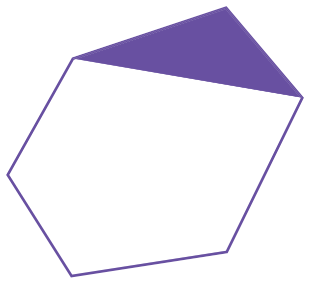
Hint: Find the largest element in the subset containing all but the last element. Then compare that maximum to the value of the last element.

★ **P13.7** Using recursion, compute the sum of all values in an array.

```
public class DataSet
{
   public DataSet(int[] values, int first, int last) { . . . }
   public int getSum() { . . . }
   . . .
}
```

★★ **P13.8** Using recursion, compute the area of a polygon. Cut off a triangle and use the fact that a triangle with corners (x_1, y_1), (x_2, y_2), (x_3, y_3) has area

$$\frac{\left|x_1y_2 + x_2y_3 + x_3y_1 - y_1x_2 - y_2x_3 - y_3x_1\right|}{2}$$



★★★ **P13.9** Implement a `SubstringGenerator` that generates all substrings of a string. For example, the substrings of the string `"rum"` are the seven strings

```
"r", "ru", "rum", "u", "um", "m", ""
```

Hint: First enumerate all substrings that start with the first character. There are n of them if the string has length n. Then enumerate the substrings of the string that you obtain by removing the first character.

★★★ **P13.10** Implement a `SubsetGenerator` that generates all subsets of the characters of a string. For example, the subsets of the characters of the string `"rum"` are the eight strings

```
"rum", "ru", "rm", "r", "um", "u", "m", ""
```

Note that the subsets don't have to be substrings—for example, `"rm"` isn't a substring of `"rum"`.

★★★ **P13.11** In this exercise, you will change the `PermutationGenerator` of Section 13.4 (which computed all permutations at once) to a `PermutationIterator` (which computes them one at a time.)

```
public class PermutationIterator
{
   public PermutationIterator(String s) { . . . }
   public String nextPermutation() { . . . }
   public boolean hasMorePermutations() { . . . }
}
```

Here is how you would print out all permutations of the string `"eat"`:

```
PermutationIterator iter = new PermutationIterator("eat");
while (iter.hasMorePermutations())
{
   System.out.println(iter.nextPermutation());
}
```

Now we need a way to iterate through the permutations recursively. Consider the string `"eat"`. As before, we'll generate all permutations that start with the letter `'e'`, then those that start with `'a'`, and finally those that start with `'t'`. How do we generate the permutations that start with `'e'`? Make another `PermutationIterator` object (called `tailIterator`) that iterates through the permutations of the substring `"at"`. In the `nextPermutation` method, simply ask `tailIterator` what *its* next permutation is, and then add the `'e'` at the front. However, there is one special case. When the tail generator runs out of permutations, all permutations that start with the current letter have been enumerated. Then

- Increment the current position.
- Compute the tail string that contains all letters except for the current one.
- Make a new permutation iterator for the tail string.

You are done when the current position has reached the end of the string.

★★★ **P13.12** The following class generates all permutations of the numbers 0, 1, 2, . . ., $n - 1$, without using recursion.

```
public class NumberPermutationIterator
{
   public NumberPermutationIterator(int n)
   {
         a = new int[n];
         done = false;
         for (int i = 0; i < n; i++) a[i] = i;
      }

      public int[] nextPermutation()
      {
         if (a.length <= 1) { return a; }

         for (int i = a.length - 1; i > 0; i--)
         {
            if (a[i - 1] < a[i])
            {
               int j = a.length - 1;
               while (a[i - 1] > a[j]) j--;
               swap(i - 1, j);
               reverse(i, a.length - 1);
               return a;
            }
         }
         return a;
      }

      public boolean hasMorePermutations()
      {
         if (a.length <= 1) { return false; }
         for (int i = a.length - 1; i > 0; i--)
         {
            if (a[i - 1] < a[i]) { return true; }
         }
         return false;
      }

      public void swap(int i, int j)
      {
         int temp = a[i];
         a[i] = a[j];
         a[j] = temp;
      }

      public void reverse(int i, int j)
      {
         while (i < j) { swap(i, j); i++; j--; }
      }
      private int[] a;
   }
```

The algorithm uses the fact that the set to be permuted consists of distinct numbers. Thus, you cannot use the same algorithm to compute the permutations of the characters in a string. You can, however, use this class to get all permutations of the character positions and then compute a string whose `i`th character is `word.charAt(a[i])`. Use this approach to reimplement the `PermutationIterator` of Exercise P13.11 without recursion.

★★ **P13.13** *Towers of Hanoi.* This is a well-known puzzle. A stack of disks of decreasing size is to be transported from the leftmost peg to the rightmost peg. The middle peg can be used as temporary storage (see Figure 5). One disk can be moved at one time, from

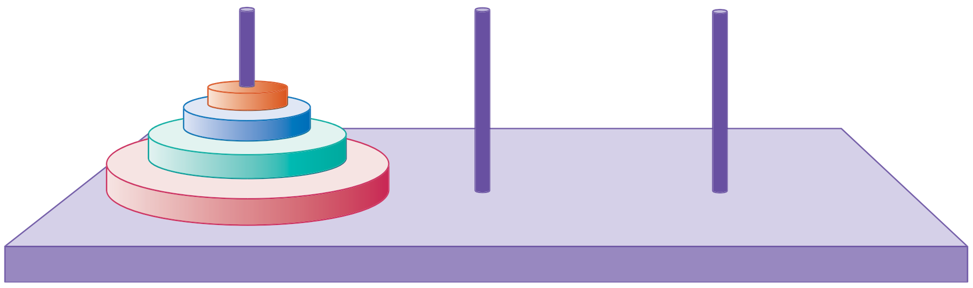


Figure 5 Towers of Hanoi

any peg to any other peg. You can place smaller disks only on top of larger ones, not the other way around.

Write a program that prints the moves necessary to solve the puzzle for *n* disks. (Ask the user for *n* at the beginning of the program.) Print moves in the form

```
Move disk from peg 1 to peg 3
```

Hint: Implement a class `DiskMover`. The constructor takes

- The source peg from which to move the disks (1, 2, or 3)
- The target peg to which to move the disks (1, 2, or 3)
- The number of disks to move

A disk mover that moves a single disk from one peg to another simply has a `nextMove` method that returns a string

Move disk from peg *source* to peg *target*

A disk mover with more than one disk to move must work harder. It needs another `DiskMover` to help it. In the constructor, construct a `DiskMover(source, other, disks - 1)` where `other` is the peg other than `from` and `target`.

The `nextMove` asks that disk mover for its next move until it is done. The effect is to move the first `disks - 1` disks to the other peg. Then the `nextMove` method issues a command to move a disk from the `from` peg to the `to` peg. Finally, it constructs another disk mover `DiskMover(other, target, disks - 1)` that generates the moves that move the disks from the other peg to the target peg.

Hint: It helps to keep track of the state of the disk mover:

- `BEFORE_LARGEST`: The helper mover moves the smaller pile to the other peg.
- `LARGEST`: Move the largest disk from the source to the destination.
- `AFTER_LARGEST`: The helper mover moves the smaller pile from the other peg to the target.
- `DONE`: All moves are done.

Test your program as follows:

```
DiskMover mover = new DiskMover(1, 3, n);
while (mover.hasMoreMoves())
{
   System.out.println(mover.nextMove());
}
```

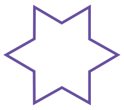
★★★ **P13.14** *Escaping a Maze*. You are currently located inside a maze. The walls of the maze are indicated by asterisks (*).

```
* *******
*     * *
* ***** *
* * *   *
* * *** *
*   *   *
*** * * *
*     * *
******* *
```

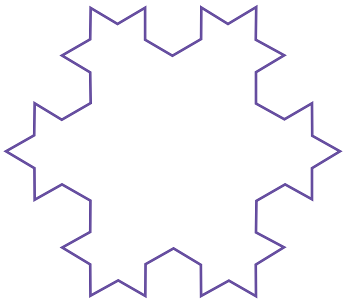
Use the following recursive approach to check whether you can escape from the maze: If you are at an exit, return `true`. Recursively check whether you can escape from one of the empty neighboring locations without visiting the current location. This method merely tests whether there is a path out of the maze. Extra credit if you can print out a path that leads to an exit.

★★★G **P13.15** *The Koch Snowflake.* A snowflake-like shape is recursively defined as follows. Start with an equilateral triangle:

Next, increase the size by a factor of three and replace each straight line with four line segments.



Repeat the process.



Write a program that draws the iterations of this curve. Supply a button that, when clicked, produces the next iteration.

★★ **P13.16** The recursive computation of Fibonacci numbers can be speeded up significantly by keeping track of the values that have already been computed. Provide an implementation of the `fib` method that uses this strategy. Whenever you return a new value, also store it in an auxiliary array. However, before embarking on a computation, consult the array to find whether the result has already been computed. Compare the running time of your improved implementation with that of the original recursive implementation and the loop implementation.

Programming Projects

Project 13.1 Enhance the expression parser of Section 13.5 to handle more sophisticated expressions, such as exponents, and mathematical functions, such as `sqrt` or `sin`.

Project 13.2 Implement a graphical version of the "Towers of Hanoi" program (see Exercise P13.13). Every time the user clicks on a button labeled "Next", draw the next move.

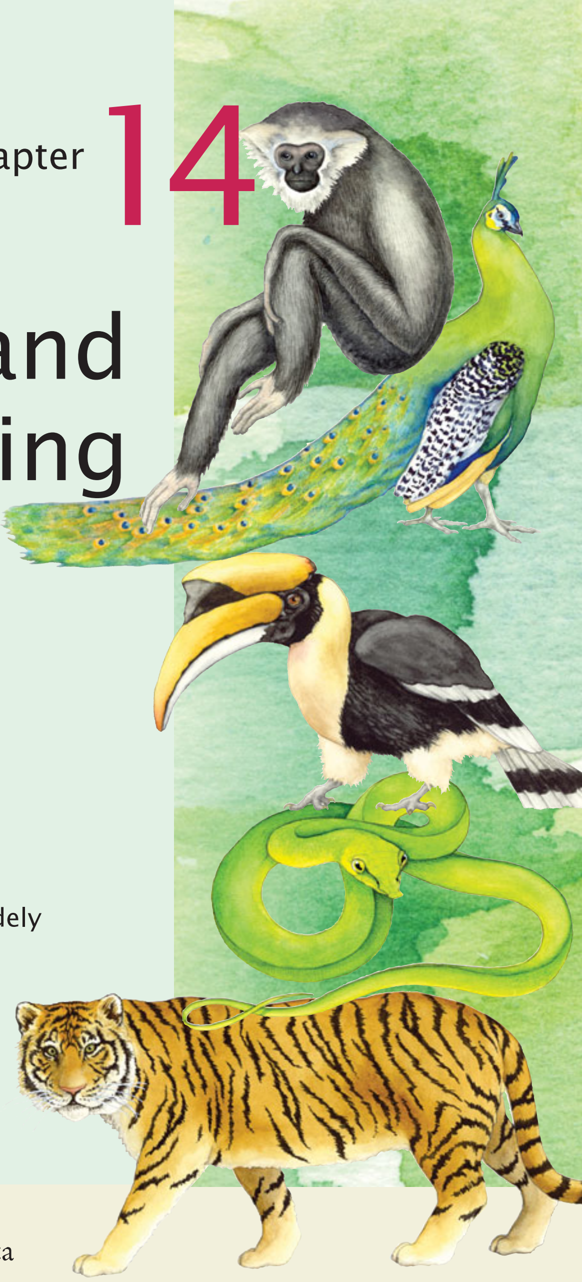
Answers to Self-Check Questions

1. Suppose we omit the statement. When computing the area of a triangle with width 1, we compute the area of the triangle with width `0` as `0`, and then add 1, to arrive at the correct area.
2. You would compute the smaller area recursively, then return
   `smallerArea + width + width - 1.`

   ```
   [][][][]
   [][][][]
   [][][][]
   [][][][]
   ```

   Of course, it would be simpler to compute the area simply as `width * width`. The results are identical because
   $$1+0+2+1+3+2+\cdots+n+n-1=\frac{n(n+1)}{2}+\frac{(n-1)n}{2}=n^2.$$
3. No—the first one could be given a different name such as `substringIsPalindrome`.
4. When `start >= end`, that is, when the investigated string is either empty or has length 1.
5. The loop is slightly faster. Of course, it is even faster to simply compute `width * (width + 1) / 2`.
6. No, the recursive solution is about as efficient as the iterative approach. Both require $n - 1$ multiplications to compute $n!$.
7. They are `b` followed by the six permutations of `eat`, `e` followed by the six permutations of `bat`, `a` followed by the six permutations of `bet`, and `t` followed by the six permutations of `bea`.
8. Simply change `if (word.length() == 0)` to `if (word.length() <= 1)`, because a word with a single letter is also its sole permutation.
9. An iterative solution would have a loop whose body computes the next permutation from the previous ones. But there is no obvious mechanism for getting the next permutation. For example, if you already found permutations `eat`, `eta`, and `aet`, it is not clear how you use that information to get the next permutation. Actually, there is an ingenious mechanism for doing just that, but it is far from obvious—see Exercise P13.12.
10. Factors are combined by multiplicative operators (`*` and `/`), terms are combined by additive operators (`+`, `-`). We need both so that multiplication can bind more strongly than addition.
11. To handle parenthesized expressions, such as `2+3*(4+5)`. The subexpression `4+5` is handled by a recursive call to `getExpressionValue`.
12. The `Integer.parseInt` call in `getFactorValue` throws an exception when it is given the string `")"`.

Chapter 14 Sorting and Searching



CHAPTER GOALS

- To study several sorting and searching algorithms
- To appreciate that algorithms for the same task can differ widely in performance
- To understand the big-Oh notation
- To learn how to estimate and compare the performance of algorithms
- To learn how to measure the running time of a program

Sorting and searching are among the most common tasks in data processing. Of course, the Java library contains methods for carrying out these operations. Nevertheless, studying algorithms for sorting and searching is fruitful because you will learn how to analyze the performance of algorithms and how to choose the best algorithm for a particular task. Sorting and searching are an excellent entry point into the study of algorithm analysis because the tasks themselves are simple to understand. As you will see in this chapter, the most straightforward algorithms do not perform very well, and we can achieve dramatic improvements with more sophisticated algorithms.

CHAPTER CONTENTS

14.1 Selection Sort 526

14.2 Profiling the Selection Sort Algorithm 529

14.3 Analyzing the Performance of the Selection Sort Algorithm 532

SPECIAL TOPIC 14.1: Insertion Sort ⊕

SPECIAL TOPIC 14.2: Oh, Omega, and Theta ⊕

14.4 Merge Sort 534

14.5 Analyzing the Merge Sort Algorithm 537

SPECIAL TOPIC 14.3: The Quicksort Algorithm ⊕

RANDOM FACT 14.1: The First Programmer ⊕

14.6 Searching 540

14.7 Binary Search 542

14.8 Sorting Real Data 545

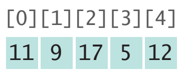
COMMON ERROR 14.1: The compareTo Method Can Return Any Integer, Not Just −1, 0, and 1 546

SPECIAL TOPIC 14.4: The Parameterized Comparable Interface 547

SPECIAL TOPIC 14.5: The Comparator Interface ⊕

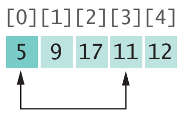
14.1 Selection Sort

In this section, we show you the first of several sorting algorithms. A *sorting algorithm* rearranges the elements of a collection so that they are stored in sorted order. To keep the examples simple, we will discuss how to sort an array of integers before going on to sorting strings or more complex data. Consider the following array a:



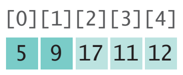
The selection sort algorithm sorts an array by repeatedly finding the smallest element of the unsorted tail region and moving it to the front.

An obvious first step is to find the smallest element. In this case the smallest element is 5, stored in a[3]. We should move the 5 to the beginning of the array. Of course, there is already an element stored in a[0], namely 11. Therefore we cannot simply move a[3] into a[0] without moving the 11 somewhere else. We don't yet know where the 11 should end up, but we know for certain that it should not be in a[0]. We simply get it out of the way by *swapping* it with a[3].

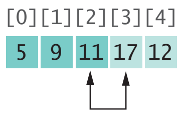


Now the first element is in the correct place. In the foregoing figure, the darker color indicates the portion of the array that is already sorted.

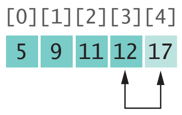
Next we take the minimum of the remaining entries a[1] . . . a[4]. That minimum value, 9, is already in the correct place. We don't need to do anything in this case and can simply extend the sorted area by one to the right:



Repeat the process. The minimum value of the unsorted region is 11, which needs to be swapped with the first value of the unsorted region, 17:



Now the unsorted region is only two elements long, but we keep to the same successful strategy. The minimum value is 12, and we swap it with the first value, 17.



That leaves us with an unprocessed region of length 1, but of course a region of length 1 is always sorted. We are done.

Let's program this algorithm. For this program, as well as the other programs in this chapter, we will use a utility method to generate an array with random entries. We place it into a class `ArrayUtil` so that we don't have to repeat the code in every example. To show the array, we call the static `toString` method of the `Arrays` class in the Java library and print the resulting string.

This algorithm will sort any array of integers. If speed were not an issue, or if there simply were no better sorting method available, we could stop the discussion of sorting right here. As the next section shows, however, this algorithm, while entirely correct, shows disappointing performance when run on a large data set.

Special Topic 14.1 discusses insertion sort, another simple sorting algorithm.

ch14/selsort/SelectionSorter.java

```java
/**
   This class sorts an array, using the selection sort
   algorithm.
*/
public class SelectionSorter
{
   private int[] a;

   /**
      Constructs a selection sorter.
      @param anArray the array to sort
   */
   public SelectionSorter(int[] anArray)
   {
      a = anArray;
   }

   /**
      Sorts the array managed by this selection sorter.
   */
   public void sort()
   {
      for (int i = 0; i < a.length - 1; i++)
      {
         int minPos = minimumPosition(i);
         swap(minPos, i);
      }
   }

   /**
      Finds the smallest element in a tail range of the array.
      @param from the first position in a to compare
      @return the position of the smallest element in the
      range a[from] . . . a[a.length - 1]
   */
   private int minimumPosition(int from)
   {
      int minPos = from;
      for (int i = from + 1; i < a.length; i++)
         if (a[i] < a[minPos]) minPos = i;
      return minPos;
   }

   /**
      Swaps two entries of the array.
      @param i the first position to swap
      @param j the second position to swap
   */
   private void swap(int i, int j)
   {
      int temp = a[i];
      a[i] = a[j];
      a[j] = temp;
   }
}
```

ch14/selsort/SelectionSortDemo.java

```
import java.util.Arrays;

/**
   This program demonstrates the selection sort algorithm by
   sorting an array that is filled with random numbers.
*/
public class SelectionSortDemo
{
   public static void main(String[] args)
   {
      int[] a = ArrayUtil.randomIntArray(20, 100);
      System.out.println(Arrays.toString(a));

      SelectionSorter sorter = new SelectionSorter(a);
      sorter.sort();

      System.out.println(Arrays.toString(a));
   }
}
```

ch14/selsort/ArrayUtil.java

```java
import java.util.Random;

/**
   This class contains utility methods for array manipulation.
*/
public class ArrayUtil
{
   private static Random generator = new Random();

   /**
      Creates an array filled with random values.
      @param length the length of the array
      @param n the number of possible random values
      @return an array filled with length numbers between
      0 and n - 1
   */
   public static int[] randomIntArray(int length, int n)
   {
      int[] a = new int[length];
      for (int i = 0; i < a.length; i++)
         a[i] = generator.nextInt(n);

      return a;
   }
}
```

Typical Output

```
[65, 46, 14, 52, 38, 2, 96, 39, 14, 33, 13, 4, 24, 99, 89, 77, 73, 87, 36, 81]
[2, 4, 13, 14, 14, 24, 33, 36, 38, 39, 46, 52, 65, 73, 77, 81, 87, 89, 96, 99]
```

SELF CHECK

1. Why do we need the `temp` variable in the `swap` method? What would happen if you simply assigned `a[i]` to `a[j]` and `a[j]` to `a[i]`?
2. What steps does the selection sort algorithm go through to sort the sequence 6 5 4 3 2 1?

14.2 Profiling the Selection Sort Algorithm

To measure the performance of a program, you could simply run it and use a stopwatch to measure how long it takes. However, most of our programs run very quickly, and it is not easy to time them accurately in this way. Furthermore, when a program takes a noticeable time to run, a certain amount of that time may simply be used for loading the program from disk into memory and displaying the result (for which we should not penalize it).

In order to measure the running time of an algorithm more accurately, we will create a `StopWatch` class. This class works like a real stopwatch. You can start it, stop it, and read out the elapsed time. The class uses the `System.currentTimeMillis` method, which returns the milliseconds that have elapsed since midnight at the start of January 1, 1970. Of course, you don't care about the absolute number of seconds since this historical moment, but the *difference* of two such counts gives us the number of milliseconds of a time interval.

Here is the code for the StopWatch class:

ch14/selsort/StopWatch.java

```java
/**
   A stopwatch accumulates time when it is running. You can
   repeatedly start and stop the stopwatch. You can use a
   stopwatch to measure the running time of a program.
*/
public class StopWatch
{
   private long elapsedTime;
   private long startTime;
   private boolean isRunning;

   /**
      Constructs a stopwatch that is in the stopped state
      and has no time accumulated.
   */
   public StopWatch()
   {
      reset();
   }

   /**
      Starts the stopwatch. Time starts accumulating now.
   */
   public void start()
   {
      if (isRunning) return;
      isRunning = true;
      startTime = System.currentTimeMillis();
   }

   /**
      Stops the stopwatch. Time stops accumulating and is
      is added to the elapsed time.
   */
   public void stop()
   {
      if (!isRunning) return;
      isRunning = false;
      long endTime = System.currentTimeMillis();
      elapsedTime = elapsedTime + endTime - startTime;
   }

   /**
      Returns the total elapsed time.
      @return the total elapsed time
   */
   public long getElapsedTime()
   {
      if (isRunning)
      {
         long endTime = System.currentTimeMillis();
         return elapsedTime + endTime - startTime;
      }
      else
         return elapsedTime;
   }

   /**
      Stops the watch and resets the elapsed time to 0.
   */
   public void reset()
   {
      elapsedTime = 0;
      isRunning = false;
   }
}
```

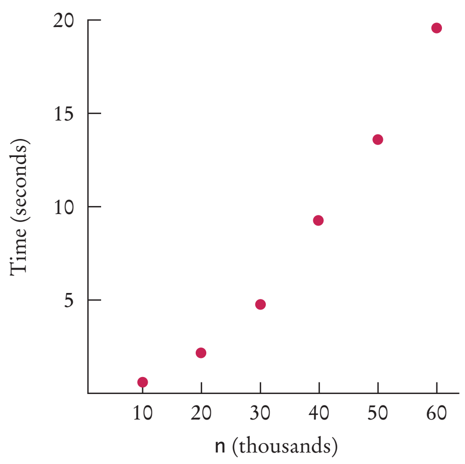
Here is how we will use the stopwatch to measure the performance of the sorting algorithm:

ch14/selsort/SelectionSortTimer.java

```
import java.util.Scanner;

/**
   This program measures how long it takes to sort an
   array of a user-specified size with the selection
   sort algorithm.
*/
public class SelectionSortTimer
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      System.out.print("Enter array size: ");
      int n = in.nextInt();

      // Construct random array

      int[] a = ArrayUtil.randomIntArray(n, 100);
      SelectionSorter sorter = new SelectionSorter(a);

      // Use stopwatch to time selection sort

      StopWatch timer = new StopWatch();

      timer.start();
      sorter.sort();
      timer.stop();

      System.out.println("Elapsed time: "
            + timer.getElapsedTime() + " milliseconds");
   }
}
```

Program Run

```
Enter array size: 100000
Elapsed time: 27880 milliseconds
```



n	Milliseconds
10,000	786
20,000	2,148
30,000	4,796
40,000	9,192
50,000	13,321
60,000	19,299

Figure 1 Time Taken by Selection Sort

To measure the running time of a method, get the current time immediately before and after the method call.

By starting to measure the time just before sorting, and stopping the stopwatch just after, you get the time required for the sorting process, without counting the time for input and output.

The table in Figure 1 shows the results of some sample runs. These measurements were obtained with a Intel processor with a clock speed of 2 GHz, running Java 6 on the Linux operating system. On another computer the actual numbers will look different, but the relationship between the numbers will be the same.

The graph in Figure 1 shows a plot of the measurements. As you can see, doubling the size of the data set more than doubles the time needed to sort it.

SELF CHECK

3. Approximately how many seconds would it take to sort a data set of 80,000 values?
4. Look at the graph in Figure 1. What mathematical shape does it resemble?

14.3 Analyzing the Performance of the Selection Sort Algorithm

Let us count the number of operations that the program must carry out to sort an array with the selection sort algorithm. We don't actually know how many machine operations are generated for each Java instruction, or which of those instructions are more time-consuming than others, but we can make a simplification. We will simply count how often an array element is *visited*. Each visit requires about the same amount of work by other operations, such as incrementing subscripts and comparing values.

Let n be the size of the array. First, we must find the smallest of n numbers. To achieve that, we must visit n array elements. Then we swap the elements, which takes two visits. (You may argue that there is a certain probability that we don't need to swap the values. That is true, and one can refine the computation to reflect that observation. As we will soon see, doing so would not affect the overall conclusion.) In the next step, we need to visit only $n - 1$ elements to find the minimum. In the following step, $n - 2$ elements are visited to find the minimum. The last step visits two elements to find the minimum. Each step requires two visits to swap the elements. Therefore, the total number of visits is

$$\begin{aligned} n + 2 + (n-1) + 2 + \cdots + 2 + 2 &= n + (n-1) + \cdots + 2 + (n-1) \cdot 2 \\ &= 2 + \cdots + (n-1) + n + (n-1) \cdot 2 \\ &= \frac{n(n+1)}{2} - 1 + (n-1) \cdot 2 \end{aligned}$$

because

$$1 + 2 + \cdots + (n-1) + n = \frac{n(n+1)}{2}$$

After multiplying out and collecting terms of n, we find that the number of visits is

$$\tfrac{1}{2}n^2 + \tfrac{5}{2}n - 3$$

We obtain a quadratic equation in n. That explains why the graph of Figure 1 looks approximately like a parabola.

Now simplify the analysis further. When you plug in a large value for n (for example, 1,000 or 2,000), then $\frac{1}{2}n^2$ is 500,000 or 2,000,000. The lower term, $\frac{5}{2}n - 3$, doesn't contribute much at all; it is only 2,497 or 4,997, a drop in the bucket compared to the hundreds of thousands or even millions of comparisons specified by the $\frac{1}{2}n^2$ term. We will just ignore these lower-level terms. Next, we will ignore the constant factor $\frac{1}{2}$. We are not interested in the actual count of visits for a single n. We want to compare the ratios of counts for different values of n. For example, we can say that sorting an array of 2,000 numbers requires four times as many visits as sorting an array of 1,000 numbers:

$$\frac{\left(\frac{1}{2} \cdot 2000^2\right)}{\left(\frac{1}{2} \cdot 1000^2\right)} = 4$$

The factor $\frac{1}{2}$ cancels out in comparisons of this kind. We will simply say, "The number of visits is of order n^2". That way, we can easily see that the number of comparisons increases fourfold when the size of the array doubles: $(2n)^2 = 4n^2$.

To indicate that the number of visits is of order n^2, computer scientists often use *big-Oh notation:* The number of visits is $O(n^2)$. This is a convenient shorthand.

Computer scientists use the big-Oh notation $f(n) = O(g(n))$ to express that the function f grows no faster than the function g.

In general, the expression $f(n) = O(g(n))$ means that f grows no faster than g, or, more formally, that for all n larger than some threshold, the ratio $f(n)/g(n) \le C$ for some constant value C. The function g is usually chosen to be very simple, such as n^2 in our example.

To turn an exact expression such as

$$\tfrac{1}{2}n^2 + \tfrac{5}{2}n - 3$$

into big-Oh notation, simply locate the fastest-growing term, n^2, and ignore its constant coefficient, no matter how large or small it may be.

We observed before that the actual number of machine operations, and the actual amount of time that the computer spends on them, is approximately proportional to the number of element visits. Maybe there are about 10 machine operations (increments, comparisons, memory loads, and stores) for every element visit. The number of machine operations is then approximately $10 \times \frac{1}{2}n^2$. As before, we aren't interested in the coefficient, so we can say that the number of machine operations, and hence the time spent on the sorting, is of the order of n^2 or $O(n^2)$.

Selection sort is an $O(n^2)$ algorithm. Doubling the data set means a fourfold increase in processing time.

The sad fact remains that doubling the size of the array causes a fourfold increase in the time required for sorting it with selection sort. When the size of the array increases by a factor of 100, the sorting time increases by a factor of 10,000. To sort an array of a million entries, (for example, to create a telephone directory) takes 10,000 times as long as sorting 10,000 entries. If 10,000 entries can be sorted in about 1/2 of a second (as in our example), then sorting one million entries requires well over an hour. We will see in the next section how one can dramatically improve the performance of the sorting process by choosing a more sophisticated algorithm.

SELF CHECK

5. If you increase the size of a data set tenfold, how much longer does it take to sort it with the selection sort algorithm?
6. How large does n need to be so that $\frac{1}{2}n^2$ is bigger than $\frac{5}{2}n - 3$?

Special Topic 14.1

Insertion Sort

Special Topic 14.1 describes insertion sort, another simple sorting algorithm that is commonly used for small arrays. Like selection sort, its run time is $O(n^2)$.

Special Topic 14.2

Oh, Omega, and Theta

Special Topic 14.2 defines the big-Theta and big-Omega notations that describe the growth of a function more precisely than the big-Oh notation.

14.4 Merge Sort

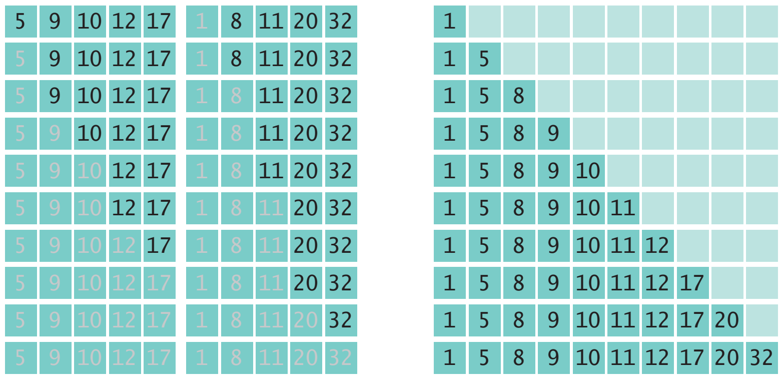
In this section, you will learn about the merge sort algorithm, a much more efficient algorithm than selection sort. The basic idea behind merge sort is very simple.

Suppose we have an array of 10 integers. Let us engage in a bit of wishful thinking and hope that the first half of the array is already perfectly sorted, and the second half is too, like this:

5	9	10	12	17	1	8	11	20	32

✚ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Now it is simple to *merge* the two sorted arrays into one sorted array, by taking a new element from either the first or the second subarray, and choosing the smaller of the elements each time:



In fact, you may have performed this merging before if you and a friend had to sort a pile of papers. You and the friend split the pile in half, each of you sorted your half, and then you merged the results together.

The merge sort algorithm sorts an array by cutting the array in half, recursively sorting each half, and then merging the sorted halves.

That is all well and good, but it doesn't seem to solve the problem for the computer. It still must sort the first and second halves of the array, because it can't very well ask a few buddies to pitch in. As it turns out, though, if the computer keeps dividing the array into smaller and smaller subarrays, sorting each half and merging them back together, it carries out dramatically fewer steps than the selection sort requires.

Let's write a `MergeSorter` class that implements this idea. When the `MergeSorter` sorts an array, it makes two arrays, each half the size of the original, and sorts them recursively. Then it merges the two sorted arrays together:

```
public void sort()
{
   if (a.length <= 1) return;
   int[] first = new int[a.length / 2];
   int[] second = new int[a.length - first.length];
   // Copy the first half of a into first, the second half into second
   . . .
   MergeSorter firstSorter = new MergeSorter(first);
   MergeSorter secondSorter = new MergeSorter(second);
   firstSorter.sort();
   secondSorter.sort();
   merge(first, second);
}
```

The `merge` method is tedious but quite straightforward. You will find it in the code that follows.

ch14/mergesort/MergeSorter.java

```
/**
   This class sorts an array, using the merge sort algorithm.
*/
public class MergeSorter
{
   private int[] a;

   /**
      Constructs a merge sorter.
      @param anArray the array to sort
   */
   public MergeSorter(int[] anArray)
   {
      a = anArray;
   }

   /**
      Sorts the array managed by this merge sorter.
   */
   public void sort()
   {
      if (a.length <= 1) return;
      int[] first = new int[a.length / 2];
      int[] second = new int[a.length - first.length];
      // Copy the first half of a into first, the second half into second
      for (int i = 0; i < first.length; i++) { first[i] = a[i]; }
      for (int i = 0; i < second.length; i++)
      {
         second[i] = a[first.length + i];
      }
      MergeSorter firstSorter = new MergeSorter(first);
      MergeSorter secondSorter = new MergeSorter(second);
      firstSorter.sort();
      secondSorter.sort();
      merge(first, second);
   }

   /**
      Merges two sorted arrays into the array managed by this merge sorter.
      @param first the first sorted array
      @param second the second sorted array
   */
   private void merge(int[] first, int[] second)
   {
      int iFirst = 0;  // Next element to consider in the first array
      int iSecond = 0;  // Next element to consider in the second array
      int j = 0;  // Next open position in a

      // As long as neither iFirst nor iSecond past the end, move
      // the smaller element into a
      while (iFirst < first.length && iSecond < second.length)
      {
         if (first[iFirst] < second[iSecond])
         {
            a[j] = first[iFirst];
            iFirst++;
         }
         else
         {
            a[j] = second[iSecond];
            iSecond++;
         }
         j++;
      }

```

```java
      // Note that only one of the two loops below copies entries
      // Copy any remaining entries of the first array
      while (iFirst < first.length)
      {
         a[j] = first[iFirst];
         iFirst++; j++;
      }
      // Copy any remaining entries of the second half
      while (iSecond < second.length)
      {
         a[j] = second[iSecond];
         iSecond++; j++;
      }
   }
}
```

ch14/mergesort/MergeSortDemo.java

```java
import java.util.Arrays;

/**
   This program demonstrates the merge sort algorithm by
   sorting an array that is filled with random numbers.
*/
public class MergeSortDemo
{
   public static void main(String[] args)
   {
      int[] a = ArrayUtil.randomIntArray(20, 100);
      System.out.println(Arrays.toString(a));

      MergeSorter sorter = new MergeSorter(a);
      sorter.sort();
      System.out.println(Arrays.toString(a));
   }
}
```

Typical Output

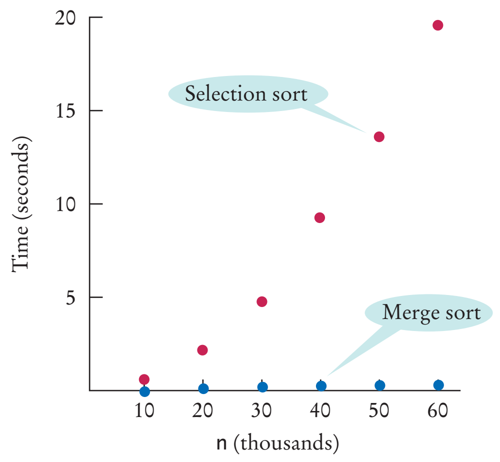
```
[8, 81, 48, 53, 46, 70, 98, 42, 27, 76, 33, 24, 2, 76, 62, 89, 90, 5, 13, 21]
[2, 5, 8, 13, 21, 24, 27, 33, 42, 46, 48, 53, 62, 70, 76, 76, 81, 89, 90, 98]
```

SELF CHECK

7. Why does only one of the two `while` loops at the end of the `merge` method do any work?
8. Manually run the merge sort algorithm on the array 8 7 6 5 4 3 2 1.

14.5 Analyzing the Merge Sort Algorithm

The merge sort algorithm looks a lot more complicated than the selection sort algorithm, and it appears that it may well take much longer to carry out these repeated subdivisions. However, the timing results for merge sort look much better than those for selection sort.



n	Merge Sort (milliseconds)	Selection Sort (milliseconds)
10,000	40	786
20,000	73	2,148
30,000	134	4,796
40,000	170	9,192
50,000	192	13,321
60,000	205	19,299

Figure 2 Merge Sort Timing versus Selection Sort

Figure 2 shows a table and a graph comparing both sets of performance data. As you can see, merge sort is a tremendous improvement. To understand why, let us estimate the number of array element visits that are required to sort an array with the merge sort algorithm. First, let us tackle the merge process that happens after the first and second halves have been sorted.

Each step in the merge process adds one more element to `a`. That element may come from `first` or `second`, and in most cases the elements from the two halves must be compared to see which one to take. We'll count that as 3 visits (one for `a` and one each for `first` and `second`) per element, or $3n$ visits total, where n denotes the length of `a`. Moreover, at the beginning, we had to copy from `a` to `first` and `second`, yielding another $2n$ visits, for a total of $5n$.

If we let $T(n)$ denote the number of visits required to sort a range of n elements through the merge sort process, then we obtain

$$T(n) = T\left(\frac{n}{2}\right) + T\left(\frac{n}{2}\right) + 5n$$

because sorting each half takes $T(n/2)$ visits. Actually, if n is not even, then we have one subarray of size $(n-1)/2$ and one of size $(n+1)/2$. Although it turns out that this detail does not affect the outcome of the computation, we will nevertheless assume for now that n is a power of 2, say $n = 2^m$. That way, all subarrays can be evenly divided into two parts.

Unfortunately, the formula

$$T(n) = 2T\left(\frac{n}{2}\right) + 5n$$

does not clearly tell us the relationship between n and $T(n)$. To understand the relationship, let us evaluate $T(n/2)$, using the same formula:

$$T\left(\frac{n}{2}\right) = 2T\left(\frac{n}{4}\right) + 5\frac{n}{2}$$

Therefore

$$T(n) = 2 \times 2T\left(\frac{n}{4}\right) + 5n + 5n$$

Let us do that again:

$$T\left(\frac{n}{4}\right) = 2T\left(\frac{n}{8}\right) + 5\frac{n}{4}$$

hence

$$T(n) = 2 \times 2 \times 2T\left(\frac{n}{8}\right) + 5n + 5n + 5n$$

This generalizes from 2, 4, 8, to arbitrary powers of 2:

$$T(n) = 2^k T\left(\frac{n}{2^k}\right) + 5nk$$

Recall that we assume that $n = 2^m$; hence, for $k = m$,

$$\begin{aligned} T(n) &= 2^m T\left(\frac{n}{2^m}\right) + 5nm \\ &= nT(1) + 5nm \\ &= n + 5n\log_2(n) \end{aligned}$$

Because $n = 2^m$, we have $m = \log_2(n)$.

To establish the growth order, we drop the lower-order term n and are left with $5n \log_2(n)$. We drop the constant factor 5. It is also customary to drop the base of the logarithm, because all logarithms are related by a constant factor. For example,

$$\log_2(x) = \log_{10}(x)/\log_{10}(2) \approx \log_{10}(x) \times 3.32193$$

Hence we say that merge sort is an $O(n \log(n))$ algorithm.

Merge sort is an $O(n \log(n))$ algorithm. The $n \log(n)$ function grows much more slowly than n^2.

Is the $O(n \log(n))$ merge sort algorithm better than the $O(n^2)$ selection sort algorithm? You bet it is. Recall that it took $100^2 = 10{,}000$ times as long to sort a million records as it took to sort 10,000 records with the $O(n^2)$ algorithm. With the $O(n \log(n))$ algorithm, the ratio is

$$\frac{1{,}000{,}000 \log(1{,}000{,}000)}{10{,}000 \log(10{,}000)} = 100\left(\frac{6}{4}\right) = 150$$

Suppose for the moment that merge sort takes the same time as selection sort to sort an array of 10,000 integers, that is, 3/4 of a second on the test machine. (Actually, it is much faster than that.) Then it would take about 0.75×150 seconds, or under 2 minutes, to sort a million integers. Contrast that with selection sort, which would take over 2 hours for the same task. As you can see, even if it takes you several hours to learn about a better algorithm, that can be time well spent.

In this chapter we have barely begun to scratch the surface of this interesting topic. There are many sorting algorithms, some with even better performance than merge sort, and the analysis of these algorithms can be quite challenging. These important issues are often revisited in later computer science courses.

SELF CHECK

9. Given the timing data for the merge sort algorithm in the table at the beginning of this section, how long would it take to sort an array of 100,000 values?

10. If you double the size of an array, how much longer will the merge sort algorithm take to sort the new array?

Special Topic 14.3

The Quicksort Algorithm

Special Topic 14.3 describes the quicksort algorithm, a commonly used algorithm that has an advantage over merge sort in that no temporary arrays are required to sort and merge the partial results. On average, the quicksort algorithm is an $O(n \log(n))$ algorithm. Because it is simpler, it runs faster than merge sort in most cases. However, its worst-case run-time behavior is $O(n^2)$.

Random Fact 14.1

The First Programmer

Random Fact 14.1 tells the story of Charles Babbage, the builder of a programmable mechanical calculator, and Ada Lovelace, his friend and sponsor. Lovelace is considered by many to be the world's first programmer.

14.6 Searching

Suppose you need to find your friend's telephone number. You look up the friend's name in the telephone book, and naturally you can find it quickly, because the telephone book is sorted alphabetically. Now suppose you have a telephone number and you must know to what party it belongs. You could of course call that number, but suppose nobody picks up on the other end. You could look through the telephone book, a number at a time, until you find the number. That would obviously be a tremendous amount of work, and you would have to be desperate to attempt it.

This thought experiment shows the difference between a search through an unsorted data set and a search through a sorted data set. The following two sections will analyze the difference formally.

A linear search examines all values in an array until it finds a match or reaches the end.

If you want to find a number in a sequence of values that occur in arbitrary order, there is nothing you can do to speed up the search. You must simply look through all elements until you have found a match or until you reach the end. This is called a **linear** or **sequential search**.

A linear search locates a value in an array in $O(n)$ steps.

How long does a linear search take? If we assume that the element v is present in the array a, then the average search visits $n/2$ elements, where n is the length of the array. If it is not present, then all n elements must be inspected to verify the absence. Either way, a linear search is an $O(n)$ algorithm.

Here is a class that performs linear searches through an array a of integers. When searching for the value v, the search method returns the first index of the match, or -1 if v does not occur in a.

Available online in WileyPLUS and at www.wiley.com/college/horstmann.

ch14/linsearch/LinearSearcher.java

```java
/**
   A class for executing linear searches through an array.
*/
public class LinearSearcher
{
   private int[] a;

   /**
      Constructs the LinearSearcher.
      @param anArray an array of integers
   */
   public LinearSearcher(int[] anArray)
   {
      a = anArray;
   }

   /**
      Finds a value in an array, using the linear search
      algorithm.
      @param v the value to search
      @return the index at which the value occurs, or -1
      if it does not occur in the array
   */
   public int search(int v)
   {
      for (int i = 0; i < a.length; i++)
      {
         if (a[i] == v)
            return i;
      }
      return -1;
   }
}
```

ch14/linsearch/LinearSearchDemo.java

```java
import java.util.Arrays;
import java.util.Scanner;

/**
   This program demonstrates the linear search algorithm.
*/
public class LinearSearchDemo
{
   public static void main(String[] args)
   {
      int[] a = ArrayUtil.randomIntArray(20, 100);
      System.out.println(Arrays.toString(a));
      LinearSearcher searcher = new LinearSearcher(a);

      Scanner in = new Scanner(System.in);

      boolean done = false;
      while (!done)
      {
         System.out.print("Enter number to search for, -1 to quit: ");
         int n = in.nextInt();
         if (n == -1)
            done = true;
         else
         {
            int pos = searcher.search(n);
            System.out.println("Found in position " + pos);
         }
      }
   }
}
```

Typical Output

```
[46, 99, 45, 57, 64, 95, 81, 69, 11, 97, 6, 85, 61, 88, 29, 65, 83, 88, 45, 88]
Enter number to search for, -1 to quit: 11
Found in position 8
```

SELF CHECK

11. Suppose you need to look through 1,000,000 records to find a telephone number. How many records do you expect to search before finding the number?

12. Why can't you use a "for each" loop `for (int element : a)` in the `search` method?

14.7 Binary Search

Now let us search for an item in a data sequence that has been previously sorted. Of course, we could still do a linear search, but it turns out we can do much better than that.

Consider the following sorted array a. The data set is:

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]
1	5	8	9	12	17	20	32

We would like to see whether the value 15 is in the data set. Let's narrow our search by finding whether the value is in the first or second half of the array. The last point in the first half of the data set, `a[3]`, is 9, which is smaller than the value we are looking for. Hence, we should look in the second half of the array for a match, that is, in the sequence:

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]
1	5	8	9	12	17	20	32

Now the last value of the first half of this sequence is 17; hence, the value must be located in the sequence:

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]
1	5	8	9	12	17	20	32

The last value of the first half of this very short sequence is 12, which is smaller than the value that we are searching, so we must look in the second half:

[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]
1	5	8	9	12	17	20	32

A binary search locates a value in a sorted array by determining whether the value occurs in the first or second half, then repeating the search in one of the halves.

It is trivial to see that we don't have a match, because 15 ≠ 17. If we wanted to insert 15 into the sequence, we would need to insert it just before `a[5]`.

This search process is called a **binary search**, because we cut the size of the search in half in each step. That cutting in half works only because we know that the sequence of values is sorted.

The following class implements binary searches in a sorted array of integers. The `search` method returns the position of the match if the search succeeds, or `-1` if `v` is not found in `a`.

ch14/binsearch/BinarySearcher.java

```java
/**
   A class for executing binary searches through an array.
*/
public class BinarySearcher
{
   private int[] a;

   /**
      Constructs a BinarySearcher.
      @param anArray a sorted array of integers
   */
   public BinarySearcher(int[] anArray)
   {
      a = anArray;
   }

   /**
      Finds a value in a sorted array, using the binary
      search algorithm.
      @param v the value to search
      @return the index at which the value occurs, or -1
      if it does not occur in the array
   */
   public int search(int v)
   {
      int low = 0;
      int high = a.length - 1;
      while (low <= high)
      {
         int mid = (low + high) / 2;
         int diff = a[mid] - v;

         if (diff == 0) // a[mid] == v
            return mid;
         else if (diff < 0) // a[mid] < v
            low = mid + 1;
         else
            high = mid - 1;
      }
      return -1;
   }
}
```

Now let's determine the number of visits to array elements required to carry out a binary search. We can use the same technique as in the analysis of merge sort.

Because we look at the middle element, which counts as one visit, and then search either the left or the right subarray, we have

$$T(n) = T\left(\frac{n}{2}\right) + 1$$

Using the same equation,

$$T\left(\frac{n}{2}\right) = T\left(\frac{n}{4}\right) + 1$$

By plugging this result into the original equation, we get

$$T(n) = T\left(\frac{n}{4}\right) + 2$$

That generalizes to

$$T(n) = T\left(\frac{n}{2^k}\right) + k$$

As in the analysis of merge sort, we make the simplifying assumption that n is a power of 2, $n = 2^m$, where $m = \log_2(n)$. Then we obtain

$$T(n) = 1 + \log_2(n)$$

Therefore, binary search is an $O(\log(n))$ algorithm.

A binary search locates a value in a sorted array in $O(\log(n))$ steps.

That result makes intuitive sense. Suppose that n is 100. Then after each search, the size of the search range is cut in half, to 50, 25, 12, 6, 3, and 1. After seven comparisons we are done. This agrees with our formula, because $\log_2(100) \approx 6.64386$, and indeed the next larger power of 2 is $2^7 = 128$.

Because a binary search is so much faster than a linear search, is it worthwhile to sort an array first and then use a binary search? It depends. If you search the array only once, then it is more efficient to pay for an $O(n)$ linear search than for an $O(n \log(n))$ sort and an $O(\log(n))$ binary search. But if you will be making many searches in the same array, then sorting it is definitely worthwhile.

The `Arrays` class contains a static `binarySearch` method that implements the binary search algorithm, but with a useful enhancement. If a value is not found in the array, then the returned value is not –1, but $-k - 1$, where k is the position before which the element should be inserted. For example,

```
int[] a = { 1, 4, 9 };
int v = 7;
int pos = Arrays.binarySearch(a, v);
   // Returns -3; v should be inserted before position 2
```

SELF CHECK

13. Suppose you need to look through a sorted array with 1,000,000 elements to find a value. Using the binary search algorithm, how many records do you expect to search before finding the value?

14. Why is it useful that the `Arrays.binarySearch` method indicates the position where a missing element should be inserted?

15. Why does `Arrays.binarySearch` return $-k - 1$ and not $-k$ to indicate that a value is not present and should be inserted before position k?

14.8 Sorting Real Data

The Arrays class implements a sorting method that you should use for your Java programs.

When you write Java programs, you don't have to implement your own sorting algorithms. The Arrays class contains static sort methods to sort arrays of integers and floating-point numbers. For example, you can sort an array of integers simply as

```
int[] a = . . .;
Arrays.sort(a);
```

That sort method uses the quicksort algorithm—see Special Topic 14.3 for more information about that algorithm.

Of course, in application programs, there is rarely a need to search through a collection of integers. However, it is easy to modify these techniques to search through real data.

The sort method of the Arrays class sorts objects of classes that implement the Comparable interface.

The Arrays class also supplies a static sort method for sorting arrays of objects. However, the Arrays class cannot know how to compare arbitrary objects. Suppose, for example, that you have an array of Coin objects. It is not obvious how the coins should be sorted. You could sort them by their names, or by their values. The Arrays.sort method cannot make that decision for you. Instead, it requires that the objects belong to classes that implement the Comparable interface. That interface has a single method:

```
public interface Comparable
{
   int compareTo(Object otherObject);
}
```

The call

```
a.compareTo(b)
```

must return a negative number if a should come before b, 0 if a and b are the same, and a positive number otherwise.

Several classes in the standard Java library, such as the String and Date classes, implement the Comparable interface.

You can implement the Comparable interface for your own classes as well. For example, to sort a collection of coins, the Coin class would need to implement this interface and declare a compareTo method:

```
public class Coin implements Comparable
{
   . . .
   public int compareTo(Object otherObject)
   {
      Coin other = (Coin) otherObject;
      if (value < other.value) return -1;
      if (value == other.value) return 0;
      return 1;
   }
   . . .
}
```

When you implement the compareTo method of the Comparable interface, you must make sure that the method defines a **total ordering** relationship, with the following three properties:

- *Antisymmetric:* If `a.compareTo(b)` ≤ 0, then `b.compareTo(a)` ≥ 0
- *Reflexive:* `a.compareTo(a)` = 0
- *Transitive:* If `a.compareTo(b)` ≤ 0 and `b.compareTo(c)` ≤ 0, then `a.compareTo(c)` ≤ 0

Once your `Coin` class implements the `Comparable` interface, you can simply pass an array of coins to the `Arrays.sort` method:

```
Coin[] coins = new Coin[n];
// Add coins
. . .
Arrays.sort(coins);
```

The `Collections` class contains a `sort` method that can sort array lists.

If the coins are stored in an `ArrayList`, use the `Collections.sort` method instead; it uses the merge sort algorithm:

```
ArrayList<Coin> coins = new ArrayList<Coin>();
// Add coins
. . .
Collections.sort(coins);
```

As a practical matter, you should use the sorting and searching methods in the `Arrays` and `Collections` classes and not those that you write yourself. The library algorithms have been fully debugged and optimized. Thus, the primary purpose of this chapter was not to teach you how to implement practical sorting and searching algorithms. Instead, you have learned something more important, namely that different algorithms can vary widely in performance, and that it is worthwhile to learn more about the design and analysis of algorithms.

SELF CHECK

16. Why can't the `Arrays.sort` method sort an array of `Rectangle` objects?

17. What steps would you need to take to sort an array of `BankAccount` objects by increasing balance?

Common Error 14.1

The `compareTo` Method Can Return Any Integer, Not Just –1, 0, and 1

The call `a.compareTo(b)` is allowed to return *any* negative integer to denote that a should come before `b`, not necessarily the value –1. That is, the test

```
if (a.compareTo(b) == -1) // ERROR!
```

is generally wrong. Instead, you should test

```
if (a.compareTo(b) < 0) // OK
```

Why would a `compareTo` method ever want to return a number other than –1, 0, or 1? Sometimes, it is convenient to just return the difference of two integers. For example, the `compareTo` method of the `String` class compares characters in matching positions:

```
char c1 = charAt(i);
char c2 = other.charAt(i);
```

If the characters are different, then the method simply returns their difference:

```
if (c1 != c2) return c1 - c2;
```

This difference is a negative number if `c1` is less than `c2`, but it is not necessarily the number –1.

Special Topic 14.4

The Parameterized `Comparable` Interface

As of Java version 5, the `Comparable` interface is a parameterized type, similar to the `ArrayList` type:

```
public interface Comparable<T>
{
   int compareTo(T other)
}
```

The type parameter specifies the type of the objects that this class is willing to accept for comparison. Usually, this type is the same as the class type itself. For example, the `Coin` class would implement `Comparable<Coin>`, like this:

```
public class Coin implements Comparable<Coin>
{
   . . .
   public int compareTo(Coin other)
   {
      if (value < other.value) return -1;
      if (value == other.value) return 0;
      return 1;
   }
   . . .
}
```

The type parameter has a significant advantage: You need not use a cast to convert an `Object` parameter into the desired type.

Special Topic 14.5

The `Comparator` Interface

Special Topic 14.5 describes the `Comparator` interface. You want to use a `Comparator` to sort objects of classes that don't implement the `compareTo` method at all, or don't implement the comparison that you want to use.

Summary of Learning Objectives

Describe the selection sort algorithm.

- The selection sort algorithm sorts an array by repeatedly finding the smallest element of the unsorted tail region and moving it to the front.

Measure the running time of a method.

- To measure the running time of a method, get the current time immediately before and after the method call.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Use the big-Oh notation to describe the running time of an algorithm.

- Computer scientists use the big-Oh notation $f(n) = O(g(n))$ to express that the function f grows no faster than the function g.
- Selection sort is an $O(n^2)$ algorithm. Doubling the data set means a fourfold increase in processing time.

Describe the merge sort algorithm.

- The merge sort algorithm sorts an array by cutting the array in half, recursively sorting each half, and then merging the sorted halves.

Contrast the running times of the merge sort and selection sort algorithms.

- Merge sort is an $O(n \log(n))$ algorithm. The $n \log(n)$ function grows much more slowly than n^2.

Describe the linear search algorithm and its running time.

- A linear search examines all values in an array until it finds a match or reaches the end.
- A linear search locates a value in an array in $O(n)$ steps.

Describe the binary search algorithm and its running time.

- A binary search locates a value in a sorted array by determining whether the value occurs in the first or second half, then repeating the search in one of the halves.
- A binary search locates a value in a sorted array in $O(\log(n))$ steps.

Use the Java library methods for sorting data.

- The `Arrays` class implements a sorting method that you should use for your Java programs.
- The `sort` method of the `Arrays` class sorts objects of classes that implement the `Comparable` interface.
- The `Collections` class contains a `sort` method that can sort array lists.

Classes, Objects, and Methods Introduced in this Chapter

```
java.lang.Comparable<T>
   compareTo
java.lang.System
   currentTimeMillis
java.util.Arrays
   binarySearch
   sort
   toString
java.util.Collections
   binarySearch
   sort
java.util.Comparator<T>
   compare
```

Media Resources

- Lab Exercises
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

www.wiley.com/college/horstmann

Review Exercises

★ **R14.1** What is the difference between searching and sorting?

★★ **R14.2** *Checking against off-by-one errors.* When writing the selection sort algorithm of Section 14.1, a programmer must make the usual choices of `<` against `<=`, `a.length` against `a.length - 1`, and `from` against `from + 1`. This is a fertile ground for off-by-one errors. Conduct code walkthroughs of the algorithm with arrays of length 0, 1, 2, and 3 and check carefully that all index values are correct.

★★ **R14.3** For the following expressions, what is the order of the growth of each?

a. $n^2 + 2n + 1$

b. $n^{10} + 9n^9 + 20n^8 + 145n^7$

c. $(n + 1)^4$

d. $(n^2 + n)^2$

e. $n + 0.001n^3$

f. $n^3 - 1000n^2 + 10^9$

g. $n + \log(n)$

h. $n^2 + n\log(n)$

i. $2^n + \mathrm{n}^2$

j. $\dfrac{n^3 + 2n}{n^2 + 0.75}$

★ **R14.4** We determined that the actual number of visits in the selection sort algorithm is

$$T(n) = \frac{1}{2}n^2 + \frac{5}{2}n - 3$$

We characterized this method as having $O(n^2)$ growth. Compute the actual ratios

$$T(2{,}000)/T(1{,}000)$$
$$T(4{,}000)/T(1{,}000)$$
$$T(10{,}000)/T(1{,}000)$$

and compare them with

$$f(2{,}000)/f(1{,}000)$$
$$f(4{,}000)/f(1{,}000)$$
$$f(10{,}000)/f(1{,}000)$$

where $f(n) = n^2$.

★ **R14.5** Suppose algorithm A takes 5 seconds to handle a data set of 1,000 records. If the algorithm A is an $O(n)$ algorithm, how long will it take to handle a data set of 2,000 records? Of 10,000 records?

★★ **R14.6** Suppose an algorithm takes 5 seconds to handle a data set of 1,000 records. Fill in the following table, which shows the approximate growth of the execution times depending on the complexity of the algorithm.

	$O(n)$	$O(n^2)$	$O(n^3)$	$O(n \log(n))$	$O(2^n)$
1,000	5	5	5	5	5
2,000					
3,000		45			
10,000					

For example, because $3{,}000^2/1{,}000^2 = 9$, the algorithm would take 9 times as long, or 45 seconds, to handle a data set of 3,000 records.

★★ **R14.7** Sort the following growth rates from slowest to fastest growth.

$O(n)$ $O(n \log(n))$

$O(n^3)$ $O(2^n)$

$O(n^n)$ $O(\sqrt{n})$

$O(\log(n))$ $O(n\sqrt{n})$

$O(n^2 \log(n))$ $O(n^{\log(n)})$

★ **R14.8** What is the growth rate of the standard algorithm to find the minimum value of an array? Of finding both the minimum and the maximum?

★ **R14.9** What is the growth rate of the following method?

```
public static int count(int[] a, int c)
{
   int count = 0;

   for (int i = 0; i < a.length; i++)
   {
      if (a[i] == c) count++;
   }
   return count;
}
```

★★ **R14.10** Your task is to remove all duplicates from an array. For example, if the array has the values

4 7 11 4 9 5 11 7 3 5

then the array should be changed to

4 7 11 9 5 3

Here is a simple algorithm. Look at `a[i]`. Count how many times it occurs in `a`. If the count is larger than 1, remove it. What is the growth rate of the time required for this algorithm?

★★ **R14.11** Consider the following algorithm to remove all duplicates from an array. Sort the array. For each element in the array, look at its next neighbor to decide whether it is present more than once. If so, remove it. Is this a faster algorithm than the one in Exercise R14.10?

★★★ **R14.12** Develop an $O(n \log (n))$ algorithm for removing duplicates from an array if the resulting array must have the same ordering as the original array.

★★★ **R14.13** Why does insertion sort perform significantly better than selection sort if an array is already sorted?

★★★ **R14.14** Consider the following speedup of the insertion sort algorithm of Special Topic 14.1. For each element, use the enhanced binary search algorithm that yields the insertion position for missing elements. Does this speedup have a significant impact on the efficiency of the algorithm?

Programming Exercises

★ **P14.1** Modify the selection sort algorithm to sort an array of integers in descending order.

★ **P14.2** Modify the selection sort algorithm to sort an array of coins by their value.

★★ **P14.3** Write a program that generates the table of sample runs of the selection sort times automatically. The program should ask for the smallest and largest value of `n` and the number of measurements and then make all sample runs.

★ **P14.4** Modify the merge sort algorithm to sort an array of strings in lexicographic order.

★★★ **P14.5** Write a telephone lookup program. Read a data set of 1,000 names and telephone numbers from a file that contains the numbers in random order. Handle lookups by name and also reverse lookups by phone number. Use a binary search for both lookups.

★★ **P14.6** Implement a program that measures the performance of the insertion sort algorithm described in Special Topic 14.1.

★★★ **P14.7** Write a program that sorts an `ArrayList<Coin>` in decreasing order so that the most valuable coin is at the beginning of the array. Use a `Comparator`.

★★ **P14.8** Consider the binary search algorithm in Section 14.7. If no match is found, the `search` method returns –1. Modify the method so that if `a` is not found, the method returns $-k - 1$, where k is the position before which the element should be inserted. (This is the same behavior as `Arrays.binarySearch`.)

★★ **P14.9** Implement the `sort` method of the merge sort algorithm without recursion, where the length of the array is a power of 2. First merge adjacent regions of size 1, then adjacent regions of size 2, then adjacent regions of size 4, and so on.

★★★ **P14.10** Implement the `sort` method of the merge sort algorithm without recursion, where the length of the array is an arbitrary number. Keep merging adjacent regions whose size is a power of 2, and pay special attention to the last area whose size is less.

★★★ **P14.11** Use insertion sort and the binary search from Exercise P14.8 to sort an array as described in Exercise R14.14. Implement this algorithm and measure its performance.

★ **P14.12** Supply a class `Person` that implements the `Comparable` interface. Compare persons by their names. Ask the user to input 10 names and generate 10 `Person` objects. Using the `compareTo` method, determine the first and last person among them and print them.

★★ **P14.13** Sort an array list of strings by increasing *length*. *Hint:* Supply a `Comparator`.

★★★ **P14.14** Sort an array list of strings by increasing length, and so that strings of the same length are sorted lexicographically. *Hint:* Supply a `Comparator`.

Programming Projects

Project 14.1 Write a program that keeps an appointment book. Make a class `Appointment` that stores a description of the appointment, the appointment day, the starting time, and the ending time. Your program should keep the appointments in a sorted array list. Users can add appointments and print out all appointments for a given day. When a new appointment is added, use binary search to find where it should be inserted in the array list. Do not add it if it conflicts with another appointment.

Project 14.2 Implement a *graphical animation* of sorting and searching algorithms. Fill an array with a set of random numbers between 1 and 100. Draw each array element as a bar, as in Figure 3. Whenever the algorithm changes the array, wait for the user to click the Step button, then call the `repaint` method. The Run button should run the animation until the animation has finished or the user clicks the Step button again.

Animate selection sort, merge sort, and binary search. In the binary search animation, highlight the currently inspected element and the current values of `from` and `to`.

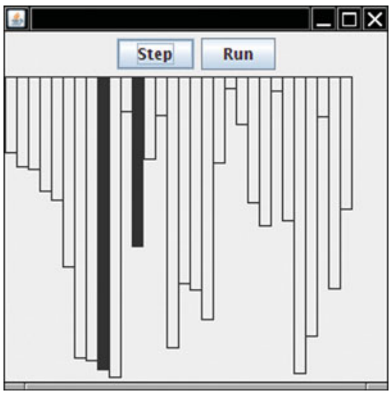


Figure 3
Graphical Animation

Answers to Self-Check Questions

1. Dropping the `temp` variable would not work. Then `a[i]` and `a[j]` would end up being the same value.
2. 1 | 5 4 3 2 6, 1 2 | 4 3 5 6, 1 2 3 4 5 6
3. Four times as long as 40,000 values, or about 50 seconds.
4. A parabola.
5. It takes about 100 times longer.
6. If n is 4, then $\frac{1}{2}n^2$ is 8 and $\frac{5}{2}n - 3$ is 7.
7. When the preceding `while` loop ends, the loop condition must be false, that is, `iFirst >= first.length` or `iSecond >= second.length` (De Morgan's Law).
8. First sort 8 7 6 5. Recursively, first sort 8 7. Recursively, first sort 8. It's sorted. Sort 7. It's sorted. Merge them: 7 8. Do the same with 6 5 to get 5 6. Merge them to 5 6 7 8. Do the same with 4 3 2 1: Sort 4 3 by sorting 4 and 3 and merging them to 3 4. Sort 2 1 by sorting 2 and 1 and merging them to 1 2. Merge 3 4 and 1 2 to 1 2 3 4. Finally, merge 5 6 7 8 and 1 2 3 4 to 1 2 3 4 5 6 7 8.
9. Approximately $100{,}000 \cdot \log(100{,}000) / 50{,}000 \cdot \log(50{,}000) = 2 \cdot 5 / 4.7 = 2.13$ times the time required for 50,000 values. That's $2.13 \cdot 97$ milliseconds or approximately 207 milliseconds.
10. $\dfrac{2n\log(2n)}{n\log(n)} = 2\dfrac{(1+\log(2))}{\log(n)}$ For $n > 2$, that is a value < 3.
11. On average, you'd make 500,000 comparisons.
12. The `search` method returns the index at which the match occurs, not the data stored at that location.
13. You would search about 20. (The binary log of 1,024 is 10.)
14. Then you know where to insert it so that the array stays sorted, and you can keep using binary search.
15. Otherwise, you would not know whether a value is present when the method returns `0`.
16. The `Rectangle` class does not implement the `Comparable` interface.
17. The `BankAccount` class would need to implement the `Comparable` interface. Its `compareTo` method must compare the bank balances.

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Chapter 15

An Introduction to Data Structures

CHAPTER GOALS

- To learn how to use the linked lists provided in the standard library
- To be able to use iterators to traverse linked lists
- To understand the implementation of linked lists
- To distinguish between abstract and concrete data types
- To know the efficiency of fundamental operations of lists and arrays
- To become familiar with the stack and queue data types

Up to this point, we have used arrays as a one-size-fits-all mechanism for collecting objects. However, computer scientists have developed many different data structures that have varying performance tradeoffs. In this chapter, you will learn about the *linked list*, a data structure that allows you to add and remove elements efficiently, without moving any existing elements. You will also learn about the distinction between concrete and abstract data types. An abstract type spells out the fundamental operations that should be supported efficiently, but it leaves the implementation unspecified. The stack and queue types, introduced at the end of this chapter, are examples of abstract types.

CHAPTER CONTENTS

15.1 Using Linked Lists 556

Special Topic 15.1: The Iterable Interface and the "For Each" Loop ⊕

15.2 Implementing Linked Lists 561

Special Topic 15.2: Static Inner Classes ⊕

15.3 Abstract Data Types 572

Random Fact 15.1: Standardization ⊕

15.4 Stacks and Queues 575

Worked Example 15.1: A Reverse Polish Notation Calculator ⊕

Random Fact 15.2: Reverse Polish Notation 578

15.1 Using Linked Lists

A **linked list** is a data structure used for collecting a sequence of objects that allows efficient addition and removal of elements in the middle of the sequence.

To understand the need for such a data structure, imagine a program that maintains a sequence of employee objects, sorted by the last names of the employees. When a new employee is hired, an object needs to be inserted into the sequence. Unless the company happened to hire employees in alphabetical order, the new object probably needs to be inserted somewhere near the middle of the sequence. If we use an array to store the objects, then all objects following the new hire must be moved toward the end.

Conversely, if an employee leaves the company, the object must be removed, and the hole in the sequence needs to be closed up by moving all objects that come after it. Moving a large number of values can involve a substantial amount of processing time. We would like to structure the data in a way that minimizes this cost.

A linked list consists of a number of nodes, each of which has a reference to the next node.

Rather than storing the values in an array, a linked list uses a sequence of *nodes*. Each node stores a value and a reference to the next node in the sequence (see Figure 1). When you insert a new node into a linked list, only the neighboring node references need to be updated. The same is true when you remove a node. What's the catch? Linked lists allow speedy insertion and removal, but element access can be slow.

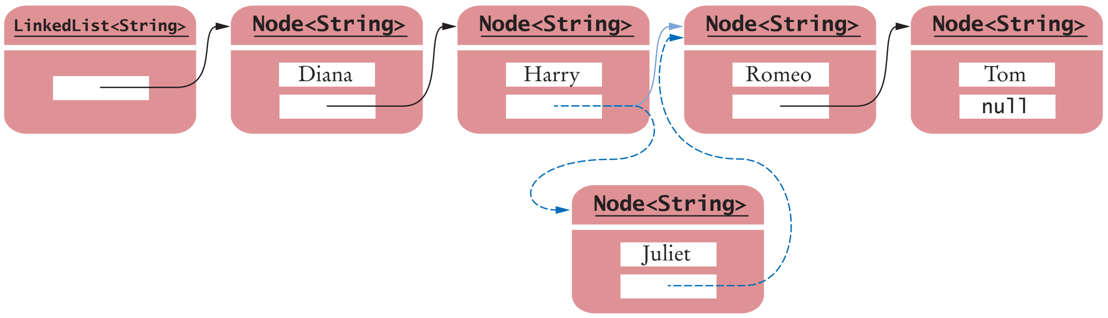


Figure 1 Inserting an Element into a Linked List

Adding and removing elements in the middle of a linked list is efficient.

Visiting the elements of a linked list in sequential order is efficient, but random access is not.

You use a list iterator to access elements inside a linked list.

For example, suppose you want to locate the fifth element. You must first traverse the first four. This is a problem if you need to access the elements in arbitrary order. The term "random access" is used in computer science to describe an access pattern in which elements are accessed in arbitrary (not necessarily random) order. In contrast, sequential access visits the elements in sequence. For example, a binary search requires random access, whereas a linear search requires sequential access.

Of course, if you mostly visit all elements in sequence (for example, to display or print the elements), you don't need to use random access. Use linked lists when you are concerned about the efficiency of inserting or removing elements and you rarely need element access in random order.

The Java library provides a linked list class. In this section you will learn how to use that library class. In the next section you will peek under the hood and see how some of its key methods are implemented.

The `LinkedList` class in the `java.util` package is a **generic class**, just like the `ArrayList` class. That is, you specify the type of the list elements in angle brackets, such as `LinkedList<String>` or `LinkedList<Product>`.

The methods shown in Table 1 give you direct access to the first and the last element in the list.

How do you add and remove elements in the middle of the list? The list will not give you references to the nodes. If you had direct access to them and somehow messed them up, you would break the linked list. As you will see in the next section, when you implement some of the linked list operations yourself, keeping all links between nodes intact is not trivial.

Instead, the Java library supplies a `ListIterator` type. A list **iterator** describes a position anywhere inside the linked list (see Figure 2).

Table 1 `LinkedList` Methods

`LinkedList<String> lst = new LinkedList<String>();`	An empty list.
`lst.addLast("Harry")`	Adds an element to the end of the list. Same as `add`.
`lst.addFirst("Sally")`	Adds an element to the beginning of the list. `lst` is now `[Sally, Harry]`.
`lst.getFirst()`	Gets the element stored at the beginning of the list; here `"Sally"`.
`lst.getLast()`	Gets the element stored at the end of the list; here `"Harry"`.
`String removed = lst.removeFirst();`	Removes the first element of the list and returns it. `removed` is `"Sally"` and `lst` is `[Harry]`. Use `removeLast` to remove the last element.
`ListIterator<String> iter = lst.listIterator()`	Provides an iterator for visiting all list elements (see Table 2 on page 560).

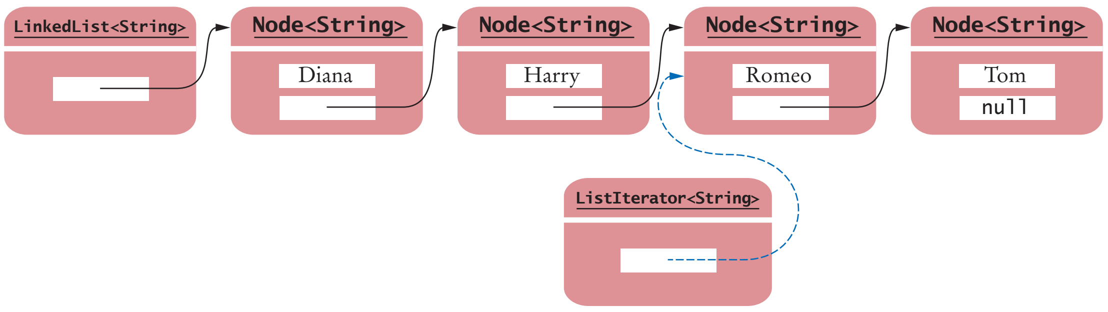


Figure 2 A List Iterator

Conceptually, you should think of the iterator as pointing between two elements, just as the cursor in a word processor points between two characters (see Figure 3). In the conceptual view, think of each element as being like a letter in a word processor, and think of the iterator as being like the blinking cursor between letters.

You obtain a list iterator with the `listIterator` method of the `LinkedList` class:

```
LinkedList<String> employeeNames = . . .;
ListIterator<String> iterator = employeeNames.listIterator();
```

Note that the iterator class is also a generic type. A `ListIterator<String>` iterates through a list of strings; a `ListIterator<Product>` visits the elements in a `LinkedList<Product>`.

Initially, the iterator points before the first element. You can move the iterator position with the `next` method:

```
iterator.next();
```

The `next` method throws a `NoSuchElementException` if you are already past the end of the list. You should always call the method `hasNext` before calling `next`—it returns `true` if there is a next element.

```
if (iterator.hasNext())
   iterator.next();
```

The `next` method returns the element that the iterator is passing. When you use a `ListIterator<String>`, the return type of the `next` method is `String`. In general, the return type of the `next` method matches the type parameter of the list.

You traverse all elements in a linked list of strings with the following loop:

```
while (iterator.hasNext())
{
   String name = iterator.next();
   Do something with name
}
```

As a shorthand, if your loop simply visits all elements of the linked list, you can use the "for each" loop:

```
for (String name : employeeNames)
{
   Do something with name
}
```

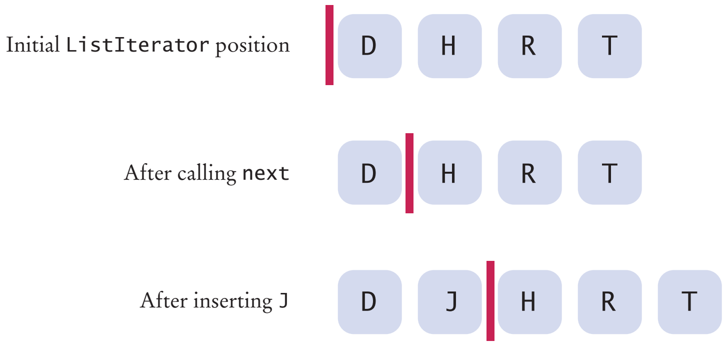


Figure 3 A Conceptual View of the List Iterator

Then you don't have to worry about iterators at all. Behind the scenes, the `for` loop uses an iterator to visit all list elements (see Special Topic 15.1).

The nodes of the `LinkedList` class store two links: one to the next element and one to the previous one. Such a list is called a **doubly linked list**. You can use the `previous` and `hasPrevious` methods of the `ListIterator` interface to move the iterator position backwards.

The `add` method adds an object after the iterator, then moves the iterator position past the new element.

```
iterator.add("Juliet");
```

You can visualize insertion to be like typing text in a word processor. Each character is inserted after the cursor, and then the cursor moves past the inserted character (see Figure 3). Most people never pay much attention to this—you may want to try it out and watch carefully how your word processor inserts characters.

The `remove` method removes the object that was returned by the last call to `next` or `previous`. For example, the following loop removes all names that fulfill a certain condition:

ANIMATION
List Iterators

```
while (iterator.hasNext())
{
   String name = iterator.next();
   if (name fulfills condition)
      iterator.remove();
}
```

You have to be careful when using the `remove` method. It can be called only once after calling `next` or `previous`. The following is an error:

```
iterator.next();
iterator.next();
iterator.remove();
iterator.remove(); // Error: You cannot call remove twice.
```

You cannot call `remove` immediately after a call to `add`:

```
iter.add("Fred");
iter.remove(); // Error: Can only call remove after calling next or previous
```

If you call the `remove` method improperly, it throws an `IllegalStateException`.

Table 2 summarizes the methods of the `ListIterator` interface.

Table 2 Methods of the ListIterator Interface

`String s = iter.next();`	Assume that `iter` points to the beginning of the list `[Sally]` before calling `next`. After the call, `s` is `"Sally"` and the iterator points to the end.
`iter.hasNext()`	Returns `false` because the iterator is at the end of the collection.

`if (iter.hasPrevious())`
`{`
`   s = iter.previous();`
`}`
	`hasPrevious` returns `true` because the iterator is not at the beginning of the list.

`iter.add("Diana");`	Adds an element before the iterator position. The list is now `[Diana, Sally]`.

`iter.next();`
`iter.remove();`
	`remove` removes the last element returned by `next` or `previous`.
	The list is again `[Diana]`.

Here is a sample program that inserts strings into a list and then iterates through the list, adding and removing elements. Finally, the entire list is printed. The comments indicate the iterator position.

ch15/uselist/ListTester.java

```java
import java.util.LinkedList;
import java.util.ListIterator;

/**
   A program that tests the LinkedList class.
*/
public class ListTester
{
   public static void main(String[] args)
   {
      LinkedList<String> staff = new LinkedList<String>();
      staff.addLast("Diana");
      staff.addLast("Harry");
      staff.addLast("Romeo");
      staff.addLast("Tom");

      // | in the comments indicates the iterator position

      ListIterator<String> iterator = staff.listIterator(); // |DHRT
      iterator.next(); // D|HRT
      iterator.next(); // DH|RT

      // Add more elements after second element

      iterator.add("Juliet"); // DHJ|RT
      iterator.add("Nina"); // DHJN|RT

      iterator.next(); // DHJNR|T

      // Remove last traversed element

      iterator.remove(); // DHJN|T

      // Print all elements

      for (String name : staff)
         System.out.print(name + " ");
      System.out.println();
      System.out.println("Expected: Diana Harry Juliet Nina Tom");
   }
}
```

Program Run

```
Diana Harry Juliet Nina Tom
Expected: Diana Harry Juliet Nina Tom
```

SELF CHECK

1. Do linked lists take more storage space than arrays of the same size?
2. Why don't we need iterators with arrays?

Special Topic 15.1

The `Iterable` Interface and the "For Each" Loop

Special Topic 15.1 discusses the `Iterable` interface. The "for each" loop can be applied to any object that implements the `Iterable` interface.

15.2 Implementing Linked Lists

In the last section you saw how to use the linked list class supplied by the Java library. In this section, we will look at the implementation of a simplified version of this class. This shows you how the list operations manipulate the links as the list is modified.

To keep this sample code simple, we will not implement all methods of the linked list class. We will implement only a singly linked list, and the list class will supply direct access only to the first list element, not the last one. Our list will not use a type parameter. We will simply store raw `Object` values and insert casts when retrieving them. The result will be a fully functional list class that shows how the links are updated in the `add` and `remove` operations and how the iterator traverses the list.

A `Node` object stores an object and a reference to the next node. Because the methods of both the linked list class and the iterator class have frequent access to the `Node` instance variables, we do not make the instance variables of the `Node` class private. Instead, we make `Node` a private inner class of the `LinkedList` class. Because none of the `LinkedList` methods returns a `Node` object, it is safe to leave the instance variables public.

```
public class LinkedList
{
   . . .
   class Node
   {
```

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

```
      public Object data;
      public Node next;
   }
}
```

A linked list object holds a reference to the first node, and each node holds a reference to the next node.

Our `LinkedList` class holds a reference `first` to the first node (or `null`, if the list is completely empty).

```
public class LinkedList
{
   private Node first;
   . . .
   public LinkedList()
   {
      first = null;
   }

   public Object getFirst()
   {
      if (first == null)
         throw new NoSuchElementException();
      return first.data;
   }
}
```

Now let us turn to the `addFirst` method (see Figure 4). When a new node is added to the list, it becomes the head of the list, and the node that was the old list head becomes its next node:

```
public class LinkedList
{
   . . .
   public void addFirst(Object element)
   {
      Node newNode = new Node(); 1
      newNode.data = element;
      newNode.next = first; 2
      first = newNode; 3
   }
   . . .
}
```

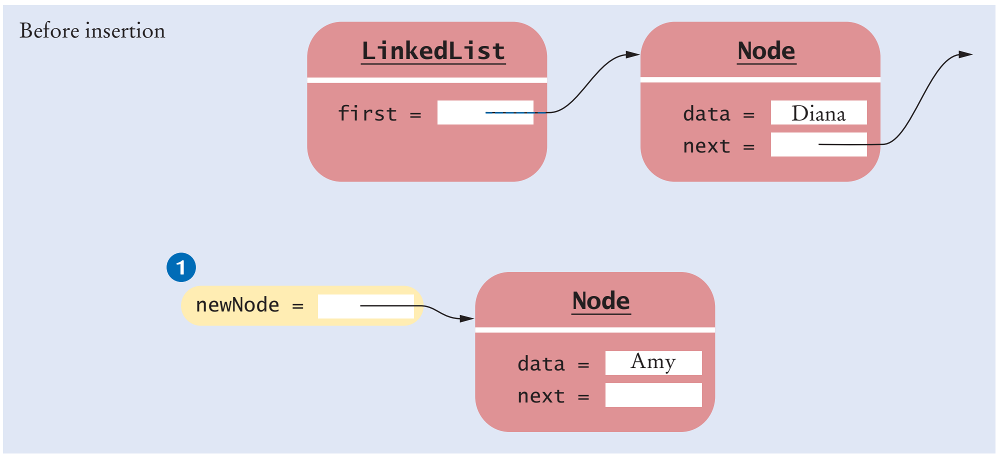


Figure 4 Adding a Node to the Head of a Linked List

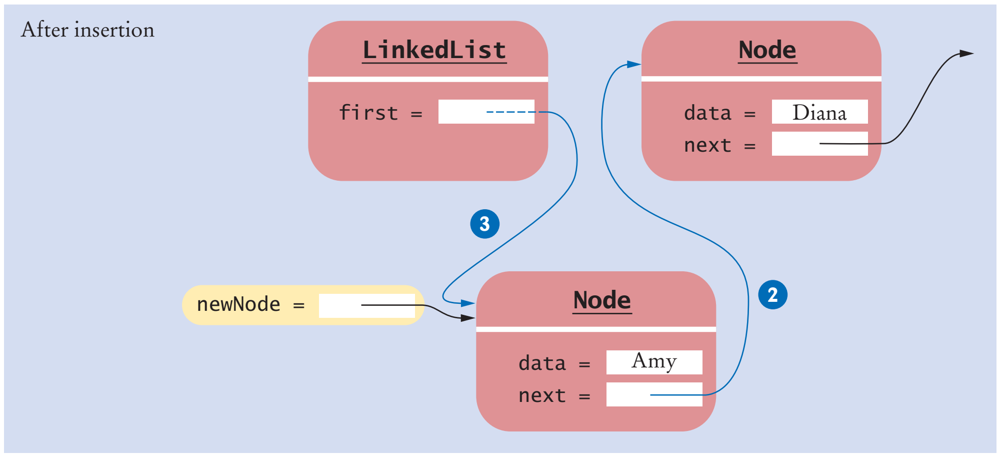


Figure 4 (continued) Adding a Node to the Head of a Linked List

Removing the first element of the list works as follows. The data of the first node are saved and later returned as the method result. The successor of the first node becomes the first node of the shorter list (see Figure 5). Then there are no further references to the old node, and the garbage collector will eventually recycle it.

```
public class LinkedList
{
   . . .
   public Object removeFirst()
   {
      if (first == null) throw new NoSuchElementException();
      Object element = first.data;
      first = first.next; 1
      return element;
   }
   . . .
}
```

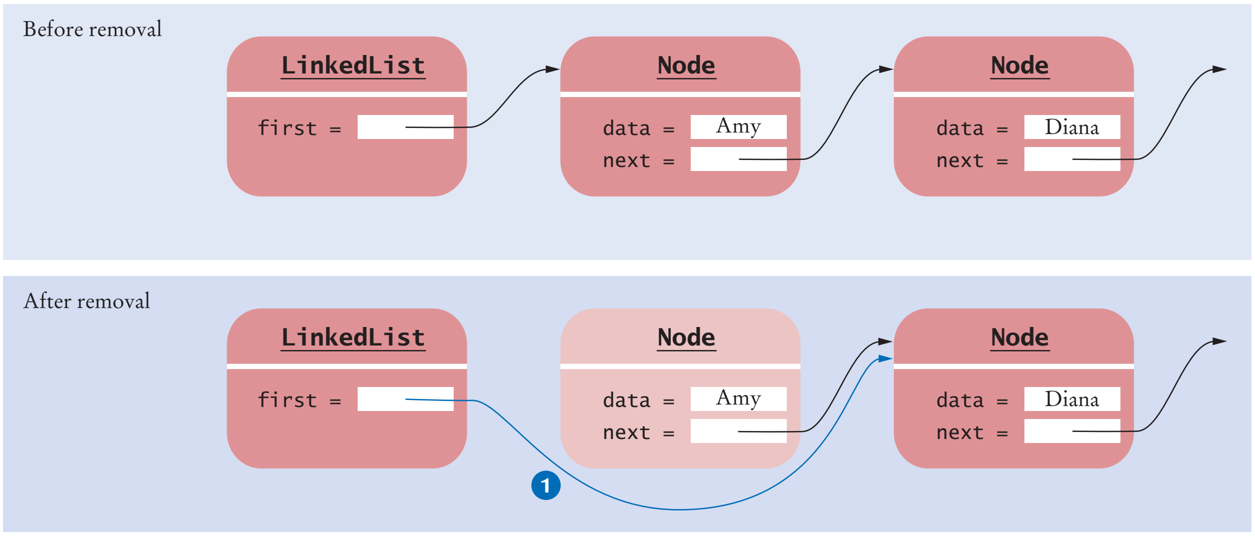


Figure 5 Removing the First Node from a Linked List

Next, we need to implement the iterator class. The `ListIterator` interface in the standard library declares nine methods. We omit four of them (the methods that move the iterator backwards and the methods that report an integer index of the iterator).

Our `LinkedList` class declares a private inner class `LinkedListIterator`, which implements our simplified `ListIterator` interface. Because `LinkedListIterator` is an inner class, it has access to the private features of the `LinkedList` class—in particular, the instance variable `first` and the private `Node` class.

Note that clients of the `LinkedList` class don't actually know the name of the iterator class. They only know it is a class that implements the `ListIterator` interface.

```
public class LinkedList
{
   . . .
   public ListIterator listIterator()
   {
      return new LinkedListIterator();
   }

   class LinkedListIterator implements ListIterator
   {
      private Node position;
      private Node previous;
      . . .
      public LinkedListIterator()
      {
         position = null;
         previous = null;
      }
   }
   . . .
}
```

A list iterator object has a reference to the last visited node.

Each iterator object has a reference, `position`, to the last visited node. We also store a reference to the last node before that, `previous`. We will need that reference to adjust the links properly in the `remove` method.

The `next` method is simple. The `position` reference is advanced to `position.next`, and the old position is remembered in `previous`. There is a special case, however—if the iterator points before the first element of the list, then the old `position` is `null`, and `position` must be set to `first`.

```
class LinkedListIterator implements ListIterator
{
   . . .
   public Object next()
   {
      if (!hasNext())
         throw new NoSuchElementException();
      previous = position; // Remember for remove

      if (position == null)
         position = first;
      else
         position = position.next;

      return position.data;
   }
   . . .
}
```

The `next` method is supposed to be called only when the iterator is not yet at the end of the list, so we declare the `hasNext` method accordingly. The iterator is at the end if the list is empty (that is, `first == null`) or if there is no element after the current position (`position.next == null`).

```
class LinkedListIterator implements ListIterator
{
   . . .
   public boolean hasNext()
   {
      if (position == null)
         return first != null;
      else
         return position.next != null;
   }
   . . .
}
```

The `set` method changes the data stored in the previously visited element. Its implementation is straightforward because our linked lists can be traversed in only one direction. The linked list implementation of the standard library must keep track of whether the last iterator movement was forward or backward. For that reason, the standard library forbids a call to the `set` method following an `add` or `remove` method. That restriction is unnecessary in our implementation, and we do not enforce it.

```
public void set(Object element)
{
   if (position == null)
      throw new NoSuchElementException();
   position.data = element;
}
```

Implementing operations that modify a linked list is challenging—you need to make sure that you update all node references correctly.

Removing the last visited node is more involved. If the element to be removed is the first element, we just call `removeFirst`. Otherwise, an element in the middle of the list must be removed, and the node preceding it needs to have its `next` reference updated to skip the removed element (see Figure 6). If the `previous` reference equals `position`, then this call to `remove` does not immediately follow a call to `next`, and we throw an `IllegalStateException`.

According to the declaration of the `remove` method, it is illegal to call `remove` twice in a row. Therefore, the `remove` method sets the `position` reference to `previous`.

```
class LinkedListIterator implements ListIterator
{
   . . .
   public void remove()
   {
      if (previous == position)
         throw new IllegalStateException();
      if (position == first)
      {
         removeFirst();
      }
      else
      {
         previous.next = position.next;   1
      }
      position = previous;   2
   }
   . . .
}
```

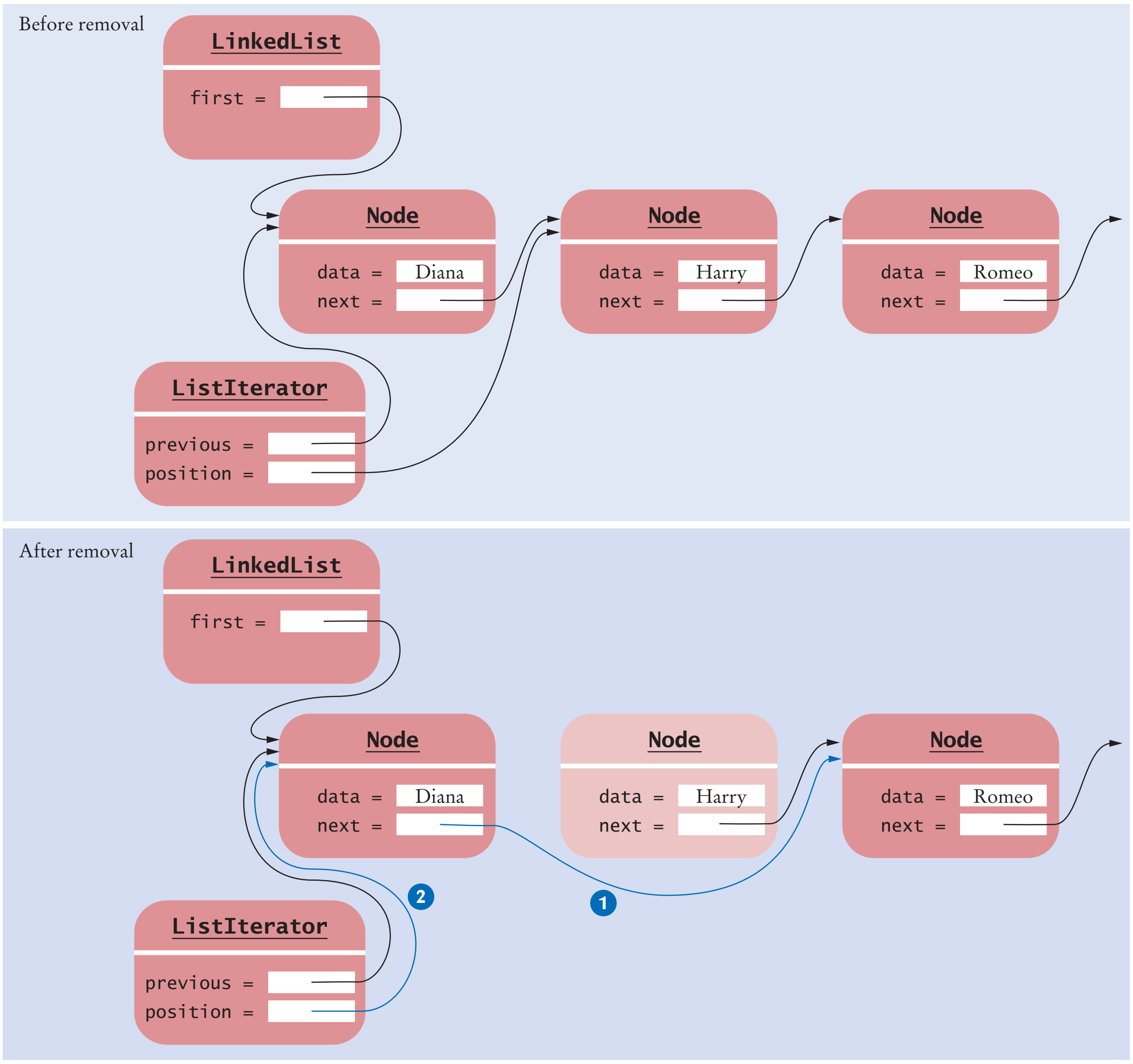


Figure 6 Removing a Node from the Middle of a Linked List

Finally, the most complex operation is the addition of a node. You insert the new node after the node last visited by the iterator (see Figure 7).

```
class LinkedListIterator implements ListIterator
{
   . . .
   public void add(Object element)
   {
      if (position == null)
      {
         addFirst(element);
         position = first;
      }
```

```
            else
            {
               Node newNode = new Node();
               newNode.data = element;
               newNode.next = position.next; ❶
               position.next = newNode; ❷
               position = newNode; ❸
            }
            previous = position; ❹
         }
         . . .
      }
```

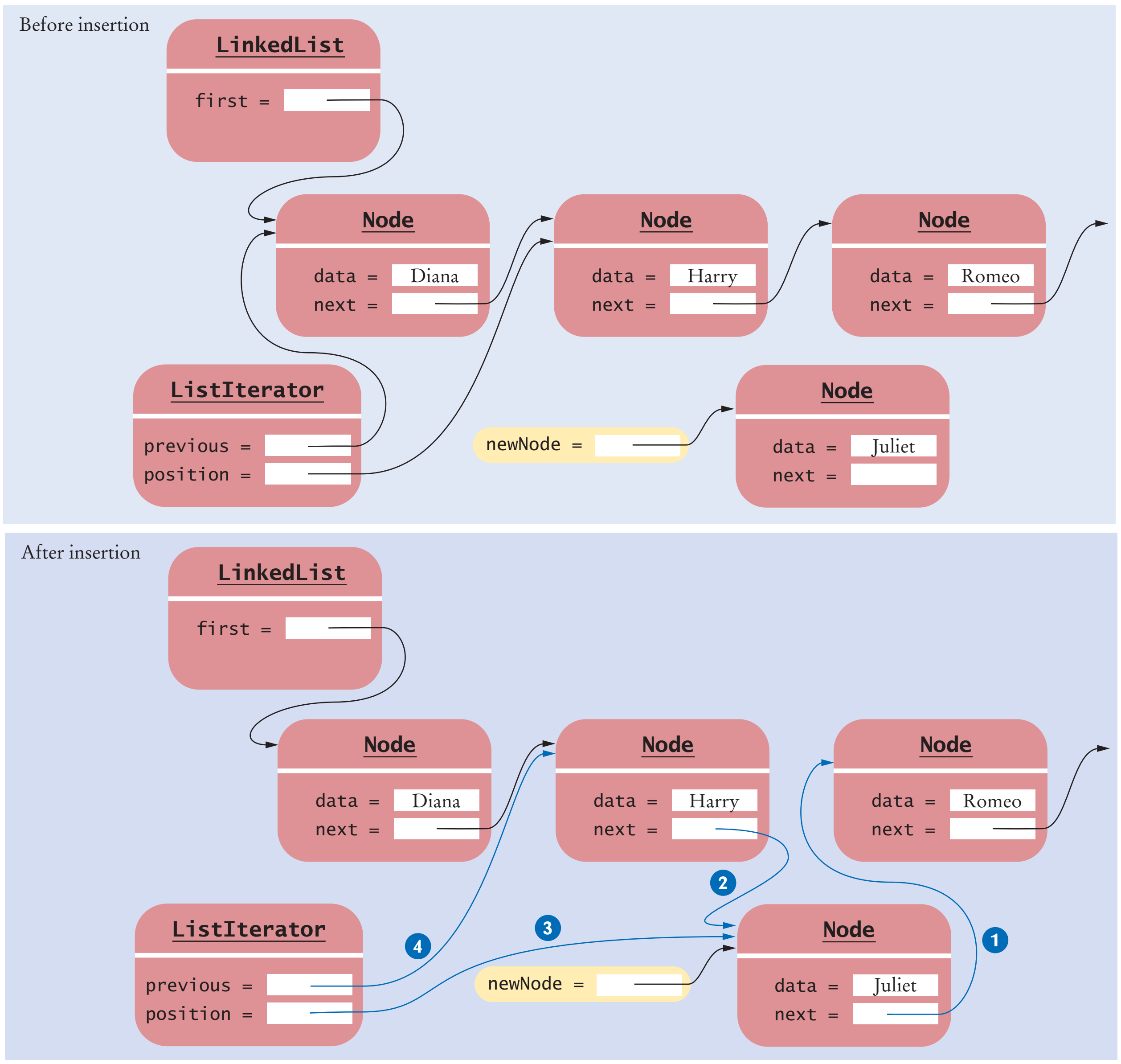


Figure 7 Adding a Node to the Middle of a Linked List

At the end of this section is the complete implementation of our `LinkedList` class.

You now know how to use the `LinkedList` class in the Java library, and you have had a peek "under the hood" to see how linked lists are implemented.

ch15/impllist/LinkedList.java

```java
import java.util.NoSuchElementException;

/**
   A linked list is a sequence of nodes with efficient
   element insertion and removal. This class
   contains a subset of the methods of the standard
   java.util.LinkedList class.
*/
public class LinkedList
{
   private Node first;

   /**
      Constructs an empty linked list.
   */
   public LinkedList()
   {
      first = null;
   }

   /**
      Returns the first element in the linked list.
      @return the first element in the linked list
   */
   public Object getFirst()
   {
      if (first == null)
         throw new NoSuchElementException();
      return first.data;
   }

   /**
      Removes the first element in the linked list.
      @return the removed element
   */
   public Object removeFirst()
   {
      if (first == null)
         throw new NoSuchElementException();
      Object element = first.data;
      first = first.next;
      return element;
   }

   /**
      Adds an element to the front of the linked list.
      @param element the element to add
   */
   public void addFirst(Object element)
   {
      Node newNode = new Node();
      newNode.data = element;
      newNode.next = first;
      first = newNode;
   }

   /**
      Returns an iterator for iterating through this list.
      @return an iterator for iterating through this list
   */
   public ListIterator listIterator()
   {
      return new LinkedListIterator();
   }

   class Node
   {
      public Object data;
      public Node next;
   }

   class LinkedListIterator implements ListIterator
   {
      private Node position;
      private Node previous;

      /**
         Constructs an iterator that points to the front
         of the linked list.
      */
      public LinkedListIterator()
      {
         position = null;
         previous = null;
      }

      /**
         Moves the iterator past the next element.
         @return the traversed element
      */
      public Object next()
      {
         if (!hasNext())
            throw new NoSuchElementException();
         previous = position; // Remember for remove

         if (position == null)
            position = first;
         else
            position = position.next;

         return position.data;
      }

      /**
         Tests if there is an element after the iterator position.
         @return true if there is an element after the iterator position
      */
      public boolean hasNext()
      {
         if (position == null)
            return first != null;
         else
            return position.next != null;
      }

      /**
         Adds an element before the iterator position
         and moves the iterator past the inserted element.
         @param element the element to add
      */
      public void add(Object element)
      {
         if (position == null)
         {
            addFirst(element);
            position = first;
         }
         else
         {
            Node newNode = new Node();
            newNode.data = element;
            newNode.next = position.next;
            position.next = newNode;
            position = newNode;
         }
         previous = position;
      }

      /**
         Removes the last traversed element. This method may
         only be called after a call to the next() method.
      */
      public void remove()
      {
         if (previous == position)
            throw new IllegalStateException();

         if (position == first)
         {
            removeFirst();
         }
         else
         {
            previous.next = position.next;
         }
         position = previous;
      }

      /**
         Sets the last traversed element to a different value.
         @param element the element to set
      */
      public void set(Object element)
      {
         if (position == null)
            throw new NoSuchElementException();
         position.data = element;
      }
   }
}
```

ch15/impllist/ListIterator.java

```java
/**
   A list iterator allows access to a position in a linked list.
   This interface contains a subset of the methods of the
   standard java.util.ListIterator interface. The methods for
   backward traversal are not included.
*/
public interface ListIterator
{
   /**
      Moves the iterator past the next element.
      @return the traversed element
   */
   Object next();

   /**
      Tests if there is an element after the iterator position.
      @return true if there is an element after the iterator position
   */
   boolean hasNext();

   /**
      Adds an element before the iterator position
      and moves the iterator past the inserted element.
      @param element the element to add
   */
   void add(Object element);

   /**
      Removes the last traversed element. This method may
      only be called after a call to the next() method.
   */
   void remove();

   /**
      Sets the last traversed element to a different value.
      @param element the element to set
   */
   void set(Object element);
}
```

SELF CHECK

3. Trace through the `addFirst` method when adding an element to an empty list.
4. Conceptually, an iterator points between elements (see Figure 3). Does the `position` reference point to the element to the left or to the element to the right?
5. Why does the `add` method have two separate cases?

Special Topic 15.2

Static Inner Classes

Special Topic 15.2 shows how you can make the inner `Node` class slightly more efficient by declaring it as a static inner class.

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

15.3 Abstract Data Types

An abstract data type defines the fundamental operations on the data but does not specify an implementation.

There are two ways of looking at a linked list. One way is to think of the concrete implementation of such a list as a sequence of node objects with links between them (see Figure 8).

On the other hand, you can think of the *abstract* concept that underlies the linked list. In the abstract, a linked list is an ordered sequence of data items that can be traversed with an iterator (see Figure 9).

Similarly, there are two ways of looking at an array list. Of course, an array list has a concrete implementation: a partially filled array of object references (see Figure 10). But you don't usually think about the concrete implementation when using an array list. You take the abstract point of view. An array list is an ordered sequence of data items, each of which can be accessed by an integer index (see Figure 11).

The concrete implementations of a linked list and an array list are quite different. The abstractions, on the other hand, seem to be similar at first glance. To see the difference, consider the public interfaces stripped down to their minimal essentials.

An array list allows *random access* to all elements. You specify an integer index, and you can get or set the corresponding element.

```
public class ArrayList
{
   . . .
   public Object get(int index) { . . . }
   public void set(int index, Object element) { . . . }
   . . .
}
```

With a linked list, on the other hand, element access is a bit more complex. A linked list allows *sequential access*. You need to ask the linked list for an iterator. Using that iterator, you can easily traverse the list elements one at a time. But if you want

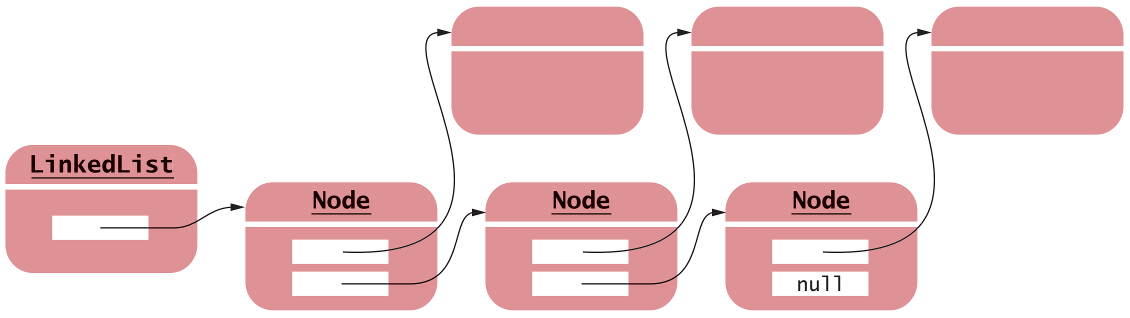


Figure 8 A Concrete View of a Linked List

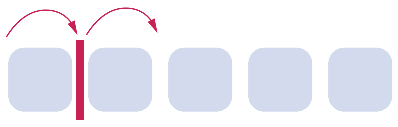


Figure 9 An Abstract View of a List

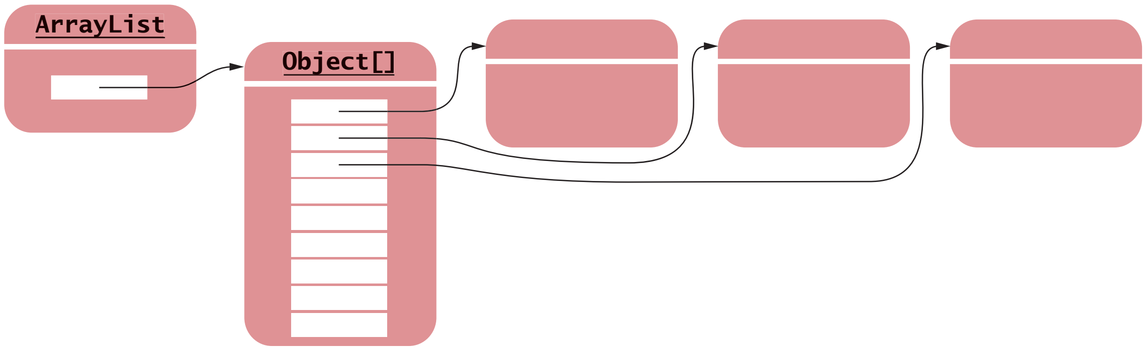


Figure 10 A Concrete View of an Array List

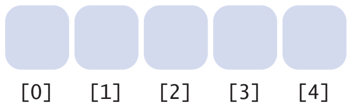


Figure 11 An Abstract View of an Array

to go to a particular element, say the 100th one, you first have to skip all elements before it.

```
public class LinkedList
{
   . . .
   public ListIterator listIterator() { . . . }
   . . .
}

public interface ListIterator
{
   Object next();
   boolean hasNext();
   void add(Object element);
   void remove();
   void set(Object element);
   . . .
}
```

Here we show only the *fundamental* operations on array lists and linked lists. Other operations can be composed from these fundamental operations. For example, you can add or remove an element in an array list by moving all elements beyond the insertion or removal index, calling `get` and `set` multiple times.

Of course, the `ArrayList` class has methods to add and remove elements in the middle, even if they are slow. Conversely, the `LinkedList` class has `get` and `set` methods that let you access any element in the linked list, albeit very inefficiently, by performing repeated sequential accesses.

In fact, the term `ArrayList` signifies that its implementors wanted to combine the interfaces of an array and a list. Somewhat confusingly, both the `ArrayList` and the `LinkedList` class implement an interface called `List` that declares operations both for random access and for sequential access.

That terminology is not in common use outside the Java library. Instead, let us adopt a more traditional terminology. We will call the abstract types *array* and *list*.

Table 3 Efficiency of Operations for the Abstract Array and List Types

Operation	Abstract Array	Abstract List
Random access	$O(1)$	$O(n)$
Linear traversal step	$O(1)$	$O(1)$
Add/remove an element	$O(n)$	$O(1)$

The Java library provides concrete implementations `ArrayList` and `LinkedList` for these abstract types. Other concrete implementations are possible in other libraries. In fact, Java arrays are another implementation of the abstract array type.

To understand an abstract data type completely, you need to know not just its fundamental operations but also their relative efficiency.

An abstract list is an ordered sequence of items that can be traversed sequentially and that allows for $O(1)$ insertion and removal of elements at any position.

In an abstract list, an element can be added or removed in constant time (assuming that the iterator is already in the right position). A fixed number of node references need to be modified to add or remove a node, regardless of the size of the list. Using the big-Oh notation, an operation that requires a bounded amount of time, regardless of the total number of elements in the structure, is denoted as $O(1)$. Random access in an abstract array also takes $O(1)$ time.

An abstract array is an ordered sequence of items with $O(1)$ random access via an integer index.

Adding or removing an arbitrary element in an abstract array of size n takes $O(n)$ time, because on average $n/2$ elements need to be moved. Random access in an abstract list takes $O(n)$ time because on average $n/2$ elements need to be skipped.

Table 3 shows this information for abstract arrays and lists.

Why consider abstract types at all? If you implement a particular algorithm, you can tell what operations you need to carry out on the data structures that your algorithm manipulates. You can then determine the abstract type that supports those operations efficiently, without being distracted by implementation details.

For example, suppose you have a sorted collection of items and you want to locate items using the binary search algorithm (see Section 14.7). That algorithm makes a random access to the middle of the collection, followed by other random accesses. Thus, fast random access is essential for the algorithm to work correctly. Once you know that an abstract array supports fast random access and an abstract list does not, you then look for concrete implementations of the abstract array type. You won't be fooled into using a `LinkedList`, even though the `LinkedList` class actually provides `get` and `set` methods.

In the next section, you will see additional examples of abstract data types.

SELF CHECK

6. What is the advantage of viewing a type abstractly?
7. How would you sketch an abstract view of a doubly linked list? A concrete view?
8. How much slower is the binary search algorithm for an abstract list compared to the linear search algorithm?

Random Fact 15.1

Standardization

Random Fact 15.1 discusses the benefits of standardization in computer science, and tells how standards are created.

15.4 Stacks and Queues

In this section we will consider two common abstract data types that allow insertion and removal of items at the ends only, not in the middle. A **stack** lets you insert and remove elements at only one end, traditionally called the *top* of the stack. To visualize a stack, think of a stack of books (see Figure 12).

A stack is a collection of items with “last in, first out” retrieval.

New items can be added to the top of the stack. Items are removed at the top of the stack as well. Therefore, they are removed in the order that is opposite from the order in which they have been added, called *last in, first out* or *LIFO* order. For example, if you add items `A`, `B`, and `C` and then remove them, you obtain `C`, `B`, and `A`. Traditionally, the addition and removal operations are called `push` and `pop`.

A queue is a collection of items with “first in, first out” retrieval.

A **queue** is similar to a stack, except that you add items to one end of the queue (the *tail*) and remove them from the other end of the queue (the *head*). To visualize a queue, simply think of people lining up (see Figure 13). People join the tail of the queue and wait until they have reached the head of the queue. Queues store items in a *first in, first out* or *FIFO* fashion. Items are removed in the same order in which they have been added.

There are many uses of queues and stacks in computer science. The Java graphical user interface system keeps an event queue of all events, such as mouse and keyboard events. The events are inserted into the queue whenever the operating system notifies the application of the event. Events are removed and passed to event listeners in the order in which they were inserted. Another example is a print queue. A printer may be accessed by several applications, perhaps running on different computers. If each of the applications tried to access the printer at the same time, the printout would be garbled. Instead, each application places all bytes that need to be sent to the printer into a file and inserts that file into the print queue. When the printer is done printing one file, it retrieves the next one from the queue. Therefore,

Figure 12
A Stack of Books

⊕ Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Figure 13 A Queue

print jobs are printed using the “first in, first out” rule, which is a fair arrangement for users of the shared printer.

Stacks are used when a “last in, first out” rule is required. For example, consider an algorithm that attempts to find a path through a maze. When the algorithm encounters an intersection, it pushes the location on the stack, and then it explores the first branch. If that branch is a dead end, it returns to the location at the top of the stack and explores the next untried branch. If all branches are dead ends, it pops the location off the stack, revealing a previously encountered intersection. Another important example is the **run-time stack** that a processor or virtual machine keeps to organize the variables of nested methods. Whenever a new method is called, its parameters and local variables are pushed onto a stack. When the method exits, they are popped off again. This stack makes recursive method calls possible.

There is a `Stack` class in the Java library that implements the abstract stack type and the `push` and `pop` operations.

The `Queue` interface in the standard Java library has methods `add` to add an element to the tail of the queue, `remove` to remove the head of the queue, and `peek` to get the head element of the queue without removing it.

The standard library provides a number of queue classes for programs in which multiple activities, called threads, run in parallel. These queues are useful for sharing work between threads. We do not discuss those classes in this book. The `LinkedList` class also implements the `Queue` interface, and you can use it when a queue is required:

```
Queue<String> q = new LinkedList<String>();
```

Table 4 shows how to use the stack and queue methods in Java.

The `Stack` class in the Java library uses an array list to implement a stack. Exercise P15.15 shows how to use a linked list instead.

Table 4 Working with Queues and Stacks

`Queue<Integer> q = new LinkedList<Integer>();`	The `LinkedList` class implements the `Queue` interface.
`q.add(1); q.add(2); q.add(3);`	Adds to the tail of the queue; `q` is now `[1, 2, 3]`.
`int head = q.remove();`	Removes the head of the queue; `head` is set to 1 and `q` is `[2, 3]`.
`head = q.peek();`	Gets the head of the queue without removing it; `head` is set to 2.
`Stack<Integer> s = new Stack<Integer>();`	Constructs an empty stack.
`s.push(1); s.push(2); s.push(3);`	Adds to the top of the stack; `s` is now `[1, 2, 3]`.
`int top = s.pop();`	Removes the top of the stack; `top` is set to 3 and `s` is now `[1, 2]`.
`head = s.peek();`	Gets the top of the stack without removing it; `head` is set to 2.

You would definitely not want to use an array list to implement a queue. Removing the first element of an array list is inefficient—all other elements must be moved toward the beginning. A queue can be efficiently implemented as a linked list. Moreover, Exercise P15.16 shows you how to implement a queue efficiently as a "circular" array, in which all elements stay at the position at which they were inserted, but the index values that denote the head and tail of the queue change when elements are added and removed.

In this chapter, you have seen the two most fundamental abstract data types, arrays and lists, and their concrete implementations. You also learned about the stack and queue types. In the next chapter, you will see additional data types that require more sophisticated implementation techniques.

SELF CHECK

9. Draw a sketch of the abstract queue type, similar to Figures 9 and 11.

10. Why wouldn't you want to use a stack to manage print jobs?

Worked Example 15.1

A Reverse Polish Notation Calculator

Worked Example 15.1 shows how to use a stack for implementing a "Reverse Polish Notation" calculator.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Random Fact 15.2

Reverse Polish Notation

In the 1920s, the Polish mathematician Jan Łukasiewicz realized that it is possible to dispense with parentheses in arithmetic expressions, provided that you write the operators *before* their arguments, for example, `+ 3 4` instead of `3 + 4`. Thirty years later, Australian computer scientist Charles Hamblin noted that an even better scheme would be to have the operators *follow* the operands. This was termed **reverse Polish notation** or RPN.

Reverse Polish notation might look strange to you, but that is just an accident of history. Had earlier mathematicians realized its advantages, today's schoolchildren might be using it and not worry about precedence rules and parentheses.

Standard Notation	Reverse Polish Notation
3 + 4	3 4 +
3 + 4 × 5	3 4 5 × +
3 × (4 + 5)	3 4 5 + ×
(3 + 4) × (5 + 6)	3 4 + 5 6 + ×
3 + 4 + 5	3 4 + 5 +

In 1972, Hewlett-Packard introduced the HP 35 calculator that used reverse Polish notation. The calculator had no keys labeled with parentheses or an equals symbol. There is just a key labeled ENTER to push a number onto a stack. For that reason, Hewlett-Packard's marketing department used to refer to their product as "the calculators that have no equal".

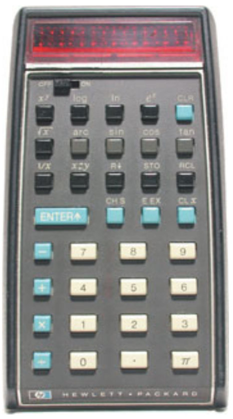


Figure 14
The Calculator with No Equal

Over time, calculator vendors have adapted to the standard algebraic notation rather than forcing its users to learn a new notation. However, those users who have made the effort to learn reverse Polish notation tend to be fanatic proponents, and to this day, some Hewlett-Packard calculator models still support it.

Summary of Learning Objectives

Describe the linked list data structure and the use of list iterators.

- A linked list consists of a number of nodes, each of which has a reference to the next node.
- Adding and removing elements in the middle of a linked list is efficient.
- Visiting the elements of a linked list in sequential order is efficient, but random access is not.
- You use a list iterator to access elements inside a linked list.

Explain how linked lists are implemented.

- A linked list object holds a reference to the first node, and each node holds a reference to the next node.
- A list iterator object has a reference to the last visited node.
- Implementing operations that modify a linked list is challenging— you need to make sure that you update all node references correctly.

Describe the notion of abstract data types and the behavior of the abstract list and array types.

- An abstract data type defines the fundamental operations on the data but does not specify an implementation.
- An abstract list is an ordered sequence of items that can be traversed sequentially and that allows for $O(1)$ insertion and removal of elements at any position.
- An abstract array is an ordered sequence of items with $O(1)$ random access via an integer index.
- A stack is a collection of items with "last in, first out" retrieval.
- A queue is a collection of items with "first in, first out" retrieval.

Classes, Objects, and Methods Introduced in this Chapter

```
java.util.Collection<E>
   add
   contains
   iterator
   remove
   size
java.util.Iterator<E>
   hasNext
   next
   remove
java.util.LinkedList<E>
   addFirst
   addLast
   getFirst
   getLast
   removeFirst
   removeLast
java.util.List<E>
   listIterator
java.util.ListIterator<E>
   add
   hasPrevious
   previous
   set
```

Media Resources

www.wiley.com/ college/ horstmann

- ***Worked Example*** A Reverse Polish Notation Calculator
- Lab Exercises
- ***Animation*** List Iterators
- Practice Quiz
- Code Completion Exercises

Review Exercises

★ **R15.1** Explain what the following code prints. Draw pictures of the linked list after each step. Just draw the forward links, as in Figure 1.

```
LinkedList<String> staff = new LinkedList<String>();
staff.addFirst("Harry");
staff.addFirst("Diana");
staff.addFirst("Tom");
System.out.println(staff.removeFirst());
System.out.println(staff.removeFirst());
System.out.println(staff.removeFirst());
```

★ **R15.2** Explain what the following code prints. Draw pictures of the linked list after each step. Just draw the forward links, as in Figure 1.

```
LinkedList<String> staff = new LinkedList<String>();
staff.addFirst("Harry");
staff.addFirst("Diana");
staff.addFirst("Tom");
System.out.println(staff.removeLast());
System.out.println(staff.removeFirst());
System.out.println(staff.removeLast());
```

★ **R15.3** Explain what the following code prints. Draw pictures of the linked list after each step. Just draw the forward links, as in Figure 1.

```
LinkedList<String> staff = new LinkedList<String>();
staff.addFirst("Harry");
staff.addLast("Diana");
staff.addFirst("Tom");
System.out.println(staff.removeLast());
System.out.println(staff.removeFirst());
System.out.println(staff.removeLast());
```

★ **R15.4** Explain what the following code prints. Draw pictures of the linked list and the iterator position after each step.

```
LinkedList<String> staff = new LinkedList<String>();
ListIterator<String> iterator = staff.listIterator();
iterator.add("Tom");
iterator.add("Diana");
iterator.add("Harry");
iterator = staff.listIterator();
if (iterator.next().equals("Tom"))
   iterator.remove();
while (iterator.hasNext())
   System.out.println(iterator.next());
```

★ **R15.5** Explain what the following code prints. Draw pictures of the linked list and the iterator position after each step.

```
LinkedList<String> staff = new LinkedList<String>();
ListIterator<String> iterator = staff.listIterator();
iterator.add("Tom");
iterator.add("Diana");
iterator.add("Harry");
iterator = staff.listIterator();
iterator.next();
iterator.next();
iterator.add("Romeo");
iterator.next();
iterator.add("Juliet");
iterator = staff.listIterator();
iterator.next();
iterator.remove();
while (iterator.hasNext())
   System.out.println(iterator.next());
```

★★ **R15.6** The linked list class in the Java library supports operations `addLast` and `removeLast`. To carry out these operations efficiently, the `LinkedList` class has an added reference `last` to the last node in the linked list. Draw a “before/after” diagram of the changes of the links in a linked list under the `addLast` and `removeLast` methods.

★★ **R15.7** The linked list class in the Java library supports bidirectional iterators. To go backward efficiently, each `Node` has an added reference, `previous`, to the predecessor node in the linked list. Draw a “before/after” diagram of the changes of the links in a linked list under the `addFirst` and `removeFirst` methods that shows how the `previous` links need to be updated.

★★ **R15.8** What advantages do lists have over arrays? What disadvantages do they have?

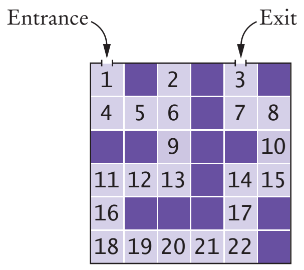
★★ **R15.9** Suppose you needed to organize a collection of telephone numbers for a company division. There are currently about 6,000 employees, and you know that the phone switch can handle at most 10,000 phone numbers. You expect several hundred lookups against the collection every day. Would you use an array or a list to store the information?

★★ **R15.10** Suppose you needed to keep a collection of appointments. Would you use a list or an array of `Appointment` objects?

★ **R15.11** Suppose you write a program that models a card deck. Cards are taken from the top of the deck and given out to players. As cards are returned to the deck, they are placed on the bottom of the deck. Would you store the cards in a stack or a queue?

★ **R15.12** Suppose the strings `"A"` . . . `"Z"` are pushed onto a stack. Then they are popped off the stack and pushed onto a second stack. Finally, they are all popped off the second stack and printed. In which order are the strings printed?

★ **R15.13** Consider the following algorithm for traversing a maze such as this one:



Make the cell at the entrance the current cell. Take the following actions, then repeat:

- If the current cell is adjacent to the exit, stop.
- Mark the current cell as visited.

- Add all unvisited neighbors to the north, east, south, and west to a queue.
- Remove the next element from the queue and make it the current cell.

In which order will the cells of the sample maze be visited?

★ **R15.14** Repeat Exercise R15.13, using a stack instead of a queue.

Programming Exercises

★★ **P15.1** Using only the public interface of the linked list class, write a method

```
public static void downsize(LinkedList<String> staff)
```

that removes every other employee from a linked list.

★★ **P15.2** Using only the public interface of the linked list class, write a method

```
public static void reverse(LinkedList<String> staff)
```

that reverses the entries in a linked list.

★★★ **P15.3** Add a method `reverse` to our implementation of the `LinkedList` class that reverses the links in a list. Implement this method by directly rerouting the links, not by using an iterator.

★ **P15.4** Add a method `size` to our implementation of the `LinkedList` class that computes the number of elements in the list, by following links and counting the elements until the end of the list is reached.

★ **P15.5** Add an instance variable `currentSize` to our implementation of the `LinkedList` class. Modify the `add` and `remove` methods of both the linked list and the list iterator to update the `currentSize` variable so that it always contains the correct size. Change the `size` method of the preceding exercise so that it simply returns the value of this instance variable.

★★ **P15.6** The linked list class of the standard library has an `add` method that allows efficient insertion at the end of the list. Implement this method for the `LinkedList` class in Section 15.2. Add an instance variable to the linked list class that points to the last node in the list. Make sure the other mutator methods update that variable.

★★★ **P15.7** Repeat Exercise P15.6, but use a different implementation strategy. Remove the reference to the first node in the `LinkedList` class, and make the `next` reference of the last node point to the first node, so that all nodes form a cycle. Such an implementation is called a *circular linked list*.

★★★ **P15.8** Reimplement the `LinkedList` class of Section 15.2 so that the `Node` and `LinkedListIterator` classes are not inner classes.

★★★ **P15.9** Add an instance variable `previous` to the `Node` class in Section 15.2, and supply `previous` and `hasPrevious` methods in the iterator.

★★ **P15.10** The LISP language, created in 1960, implements linked lists in a very elegant way. You will explore a Java analog in this set of exercises. The key observation is that the *tail* of an abstract list—that is, the list with its head node removed—is also a list. The tail of that list is again a list, and so on, until you reach the empty list. Here is a Java interface for such as list:

```
public interface LispList
{
   boolean isEmpty();
   Object head();
   LispList tail();
   . . .
}
```

There are two kinds of lists, empty lists and nonempty lists:

```
public class EmptyList extends LispList { ... }
public class NonEmptyList extends LispList { ... }
```

These classes are quite trivial. The `EmptyList` class has no instance variables. Its `head` and `tail` methods simply throw an `UnsupportedOperationException`, and its `isEmpty` method returns `true`. The `NonEmptyList` class has instance variables for the head and tail.

Here is one way of making a lisp list with three elements:

```
LispList list = new NonEmptyList("A", new NonEmptyList("B",
   new NonEmptyList("C", new EmptyList())));
```

This is a bit tedious, and it is a good idea to supply a convenience method `cons` that calls the constructor, as well as a static variable `NIL` that is an instance of an empty list. Then our list construction becomes

```
LispList list = NIL.cons("C").cons("B").cons("A");
```

Note that you need to build up the list starting from the (empty) tail.

To see the elegance of this approach, consider the implementation of a `toString` method that produces a string containing all list elements. The method must be implemented by both subclasses:

```
public class EmptyList
{
   ...
   public String toString() { return ""; }
}

public class NonEmptyList
{
   ...
   public String toString() { return head() + " " + tail().toString(); }
}
```

Note that no `if` statement is required. A list is either empty or nonempty, and the correct `toString` method is invoked due to polymorphism.

In this exercise, complete the `LispList` interface and the `EmptyList` and `NonEmptyList` classes. Write a test program that constructs a list and prints it.

★ **P15.11** Add a method `length` to the `LispList` interface of Exercise P15.10 that returns the length of the list. Implement the method in the `EmptyList` and `NonEmptyList` classes.

★★ **P15.12** Add a method

```
LispList merge(LispList other)
```

to the `LispList` interface of Exercise P15.10 that returns the length of the list. Implement the method in the `EmptyList` and `NonEmptyList` classes. When merging two lists, alternate between the elements, then add the remainder of the longer list. For example, merging the lists with elements `1 2 3 4` and `5 6` yields `1 5 2 6 3 4`.

★ **P15.13** Add a method

```
boolean contains(Object obj)
```

to the `LispList` interface of Exercise P15.10 that returns true if the list contains an element that equals `obj`.

★★★ **P15.14** The standard Java library implements a `Stack` class, but in this exercise you are asked to provide your own implementation. Do not implement type parameters. Use an `Object[]` array to hold the stack elements. When the array fills up, allocate an array of twice the size and copy the values to the larger array.

★ **P15.15** Implement a `Stack` class by using a linked list to store the elements. Do not implement type parameters.

★★ **P15.16** Implement a queue as a *circular array* as follows: Use two index variables `head` and `tail` that contain the index of the next element to be removed and the next element to be added. After an element is removed or added, the index is incremented (see Figure 15).

After a while, the `tail` element will reach the top of the array. Then it "wraps around" and starts again at `0`—see Figure 16. For that reason, the array is called "circular".

```
public class CircularArrayQueue
{
   private int head;
   private int tail;
   private int theSize;
   private Object[] elements;

   public CircularArrayQueue(int capacity) { . . . }
   public void add(Object x) { . . . }
   public Object remove() { . . . }
   public int size() { . . . }
}
```

This implementation supplies a *bounded* queue—it can eventually fill up. See the next exercise on how to remove that limitation.

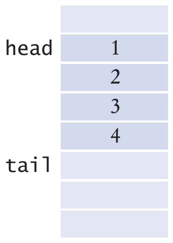


Figure 15
Adding and Removing Queue Elements

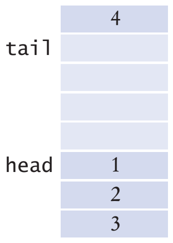


Figure 16
A Queue That Wraps Around the End of the Array

★★★ **P15.17** The queue in Exercise P15.16 can fill up if more elements are added than the array can hold. Improve the implementation as follows. When the array fills up, allocate a larger array, copy the values to the larger array, and assign it to the `elements` instance variable. *Hint:* You can't just copy the elements into the same position of the new array. Move the head element to position 0 instead.

★★ **P15.18** Modify the insertion sort algorithm of Special Topic 14.1 to sort a linked list.

★★ **P15.19** Modify the Invoice class of Chapter 12 so that it implements the `Iterable<LineItem>` interface. Then demonstrate how an `Invoice` object can be used in a "for each" loop.

★ **P15.20** In a paint program, a "flood fill" fills all empty pixels of a drawing with a given color, stopping when it reaches occupied pixels. In this exercise, you will implement a simple variation of this algorithm, flood-filling a 10×10 array of integers that are initially 0. Prompt for the starting row and column. Push the (row, column) pair on a stack. (You will need to provide a simple `Pair` class.)

Then repeat the following operations until the stack is empty.

- Pop off the (row, column) pair from the top of the stack.
- If it has not yet been filled, fill it now. (Fill in numbers 1, 2, 3, and so on, to show the order in which the square is filled.)
- Push the coordinates of any unfilled neighbors in the north, east, south, or west direction on the stack.

When you are done, print the entire array.

★ **P15.21** Repeat Exercise P15.20, but use a queue instead.

★★ **P15.22** Use a stack to enumerate all permutations of a string. Suppose you want to find all permutations of the string `meat`. Push the string `+meat` on the stack. Now repeat the following operations until the stack is empty.

- Pop off the top of the stack.
- If that string ends in a `+` (such as `tame+`), remove the `+` and print the string
- Otherwise, remove each letter in turn from the right of the `+`, insert it just before the `+`, and push the resulting string on the stack. For example, after popping `e+mta`, you push `em+ta`, `et+ma`, and `ea+mt`.

★★ **P15.23** Repeat Exercise P15.22, but use a queue instead.

★★G **P15.24** Write a program to display a linked list graphically. Draw each element of the list as a box, and indicate the links with line segments. Draw an iterator as in Figure 3. Supply buttons to move the iterator and to add and remove elements.

Programming Projects

Project 15.1 Implement a class `Polynomial` that describes a polynomial such as

$$p(x) = 5x^{10} + 9x^{7} - x - 10$$

Store a polynomial as a linked list of terms. A term contains the coefficient and the power of x. For example, you would store $p(x)$ as

$$(5, 10), (9, 7), (-1, 1), (-10, 0)$$

Supply methods to add, multiply, and print polynomials, and to compute the derivative of a polynomial.

Project 15.2 Make the list implementation of this chapter as powerful as the implementation of the Java library. (Do not implement type parameters, though.)

- Provide bidirectional iteration.
- Make `Node` a static inner class.
- Implement the standard `List` and `ListIterator` interfaces and provide the missing methods. (*Tip:* You may find it easier to extend `AbstractList` instead of implementing all `List` methods from scratch.)

Project 15.3 Implement the following algorithm for the evaluation of arithmetic expressions.

Each operator has a *precedence*. The `+` and `-` operators have the lowest precedence, `*` and `/` have a higher (and equal) precedence, and `^` (which denotes "raising to a power" in this exercise) has the highest. For example,

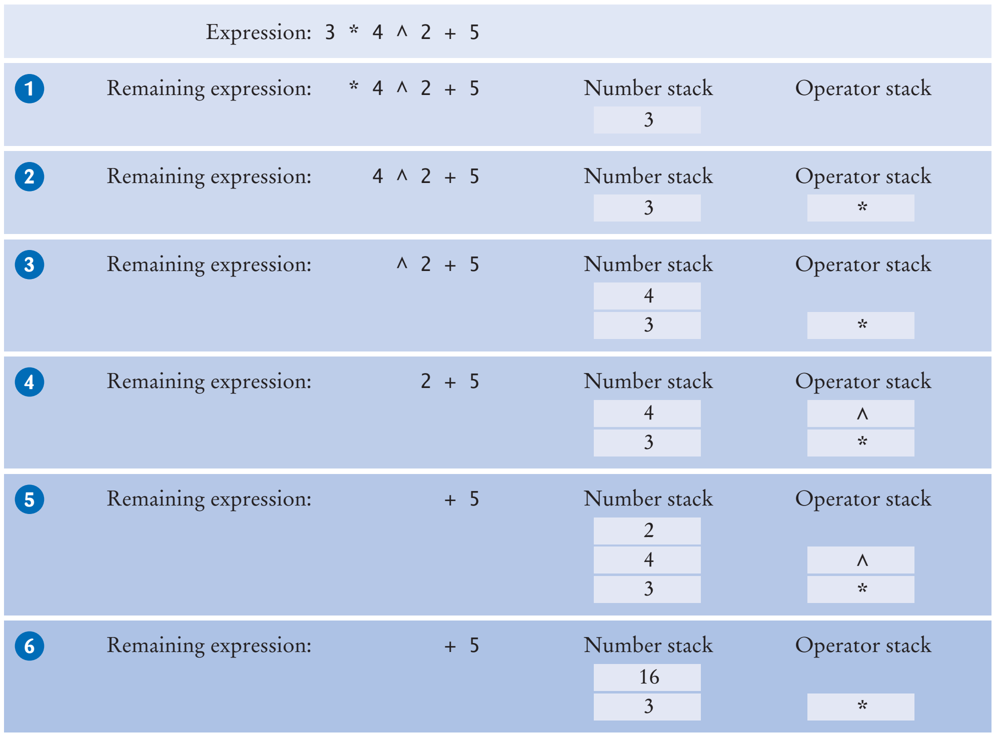
```
3 * 4 ^ 2 + 5
```

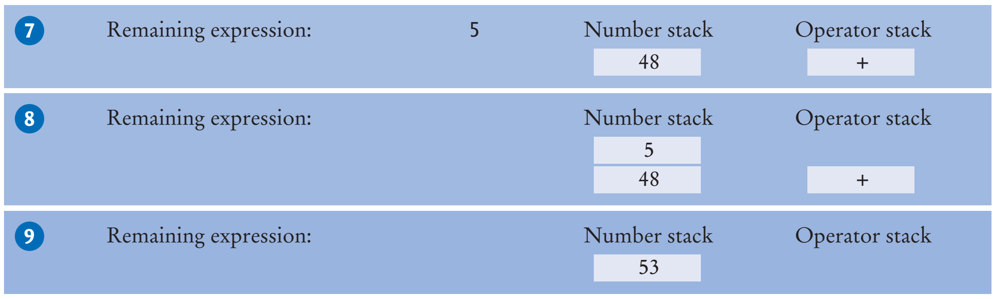
should mean the same as

```
(3 * (4 ^ 2)) + 5
```

with a value of 53.

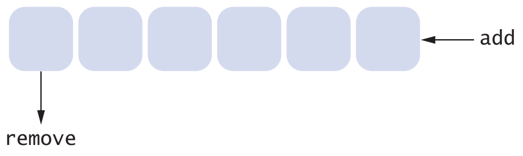
In your algorithm, use two stacks. One stack holds numbers, the other holds operators. When you encounter a number, push it on the number stack. When you encounter an operator, push it on the operator stack if it has higher precedence than the operator on the top of the stack. Otherwise, pop an operator off the operator stack, pop two numbers off the number stack, and push the result of the computation on the number stack. Repeat until the top of the operator stack has lower precedence. At the end of the expression, clear the stack in the same way. For example, here is how the expression `3 * 4 ^ 2 + 5` is evaluated:


Expression: 3 * 4 ^ 2 + 5
1 Remaining expression: * 4 ^ 2 + 5
Number stack
3
Operator stack
2 Remaining expression: 4 ^ 2 + 5
Number stack
3
Operator stack
*
3 Remaining expression: ^ 2 + 5
Number stack
4
3
Operator stack
*
4 Remaining expression: 2 + 5
Number stack
4
3
Operator stack
^
*
5 Remaining expression: + 5
Number stack
2
4
3
Operator stack
^
*
6 Remaining expression: + 5
Number stack
16
3
Operator stack
*



You should enhance this algorithm to deal with parentheses. Also, make sure that subtractions and divisions are carried out in the correct order. For example, `12 - 5 - 3` should yield 4.

Answers to Self-Check Questions

1. Yes, for two reasons. You need to store the node references, and each node is a separate object. (There is a fixed overhead to store each object in the virtual machine.)
2. An integer index can be used to access any array location.
3. When the list is empty, `first` is `null`. A new `Node` is allocated. Its `data` instance variable is set to the newly inserted object. It's `next` instance variable is set to `null` because `first` is `null`. The `first` instance variable is set to the new node. The result is a linked list of length 1.
4. It points to the element to the left. You can see that by tracing out the first call to `next`. It leaves `position` to point to the first node.
5. If `position` is `null`, we must be at the head of the list, and inserting an element requires updating the `first` reference. If we are in the middle of the list, the `first` reference should not be changed.
6. You can focus on the essential characteristics of the data type without being distracted by implementation details.
7. The abstract view would be like Figure 9, but with arrows in both directions. The concrete view would be like Figure 8, but with references to the previous node added to each node.
8. To locate the middle element takes n / 2 steps. To locate the middle of the subinterval to the left or right takes another n / 4 steps. The next lookup takes n / 8 steps. Thus, we expect almost n steps to locate an element. At this point, you are better off just making a linear search that, on average, takes n / 2 steps.
9. 

10. Stacks use a "last in, first out" discipline. If you are the first one to submit a print job and lots of people add print jobs before the printer has a chance to deal with your job, they get their printouts first, and you have to wait until all other jobs are completed.

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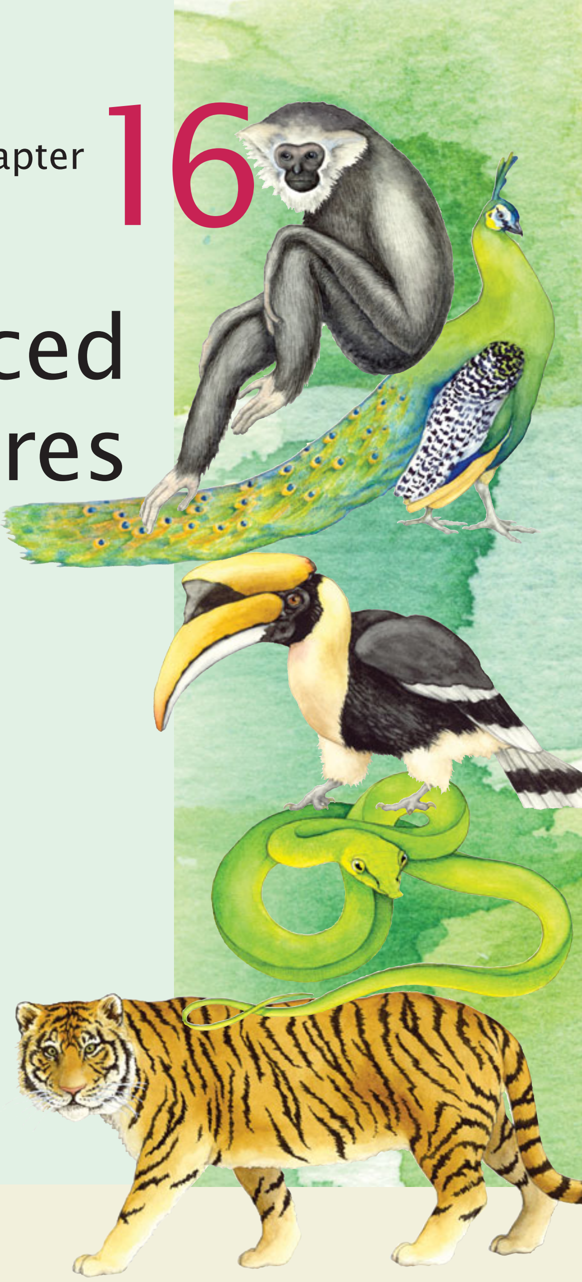
Chapter 16

Advanced Data Structures



CHAPTER GOALS

- To learn about the set and map data types
- To understand the implementation of hash tables
- To be able to program hash functions
- To learn about binary trees
- To become familiar with the heap data structure
- To learn how to implement the priority queue data type
- To understand how to use heaps for sorting

In this chapter we study data structures that are more complex than arrays or lists. These data structures take control of organizing their elements, rather than keeping them in a fixed position. In return, they can offer better performance for adding, removing, and finding elements.

You will learn about the abstract set and map data types and the implementations that the standard library offers for these abstract types. You will see how two completely different implementations—hash tables and trees—can be used to implement these abstract types efficiently.

CHAPTER CONTENTS

16.1 Sets 666
Quality Tip 16.1: Use Interface References to Manipulate Data Structures 670
16.2 Maps 670
Special Topic 16.1: Enhancements to Collection Classes in Java 7 672
How To 16.1: Choosing a Container 673
Worked Example 16.1: Word Frequency ⊕
16.3 Hash Tables 674
16.4 Computing Hash Codes 681
Common Error 16.1: Forgetting to Provide hashCode 685
16.5 Binary Search Trees 686
16.6 Binary Tree Traversal 696
16.7 Priority Queues 698
16.8 Heaps 699
16.9 The Heapsort Algorithm 709
Random Fact 16.1: Software Piracy 714

16.1 Sets

In the preceding chapter you encountered two important data structures: arrays and lists. Both have one characteristic in common: These data structures keep the elements in the same order in which you inserted them. However, in many applications, you don't really care about the order of the elements in a collection. For example, a server may keep a collection of objects representing available printers (see Figure 1). The order of the objects doesn't really matter.

A set is an unordered collection of distinct elements. Elements can be added, located, and removed.

In mathematics, such an unordered collection is called a **set**. You have probably learned some set theory in a course in mathematics, and you may know that sets are a fundamental mathematical notion.

But what does that mean for data structures? If the data structure is no longer responsible for remembering the order of element insertion, can it give us better performance for some of its operations? It turns out that it can indeed, as you will see later in this chapter.

Let's list the fundamental operations on a set:

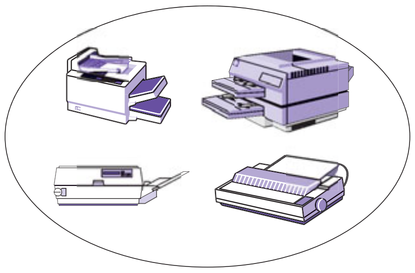
- Adding an element
- Removing an element
- Locating an element (Does the set contain a given object?)
- Listing all elements (not necessarily in the order in which they were added)

Sets don't have duplicates. Adding a duplicate of an element that is already present is silently ignored.

In mathematics, a set rejects duplicates. If an object is already in the set, an attempt to add it again is ignored. That's useful in many programming situations as well. For example, if we keep a set of available printers, each printer should occur at most once in the set. Thus, we will interpret the `add` and `remove` operations of sets just as we do in mathematics: Adding an element has no effect if the element is already in the set, and attempting to remove an element that isn't in the set is silently ignored.

Of course, we could use a linked list or array list to implement a set. But adding, removing, and containment testing would be $O(n)$ operations, because they all have to do a linear search through the list. (Adding requires a search through the list to make sure that we don't add a duplicate.) As you will see later in this chapter, there are data structures that can handle these operations much more quickly.

Figure 1
A Set of Printers



The HashSet and TreeSet classes both implement the Set interface.

In fact, there are two different data structures for this purpose, called *hash tables* and *trees*. The standard Java library provides set implementations based on both data structures, called HashSet and TreeSet. Both of these data structures implement the Set interface (see Figure 2).

When you want to use a set in your program, you must choose between these implementations. In order to use a HashSet, the elements must provide a hashCode method. We discuss this method in Sections 16.3 and 16.4. Many classes in the standard library implement these methods, for example String, Integer, Point, Rectangle, Color, and all the collection classes. Therefore, you can form a HashSet<String>, HashSet<Rectangle>, or even a HashSet<HashSet<Integer>>.

The TreeSet class uses a different strategy for arranging its elements. Elements are kept in sorted order. In order to use a TreeSet, the element type should implement the Comparable interface (see Section 15.8). The String and Integer classes fulfill this requirement, but many other classes do not. You can also construct a TreeSet with a Comparator (see Special Topic 15.5).

As a rule of thumb, use a hash set unless you want to visit the set elements in sorted order.

Now let's look at using a set of strings. First, construct the set, either as

```
Set<String> names = new HashSet<String>();
```

or

```
Set<String> names = new TreeSet<String>();
```

Note that we store the reference to the HashSet<String> or TreeSet<String> object in a Set<String> variable. After you construct the collection object, the implementation no longer matters; only the interface is important.

Adding and removing set elements is straightforward:

```
names.add("Romeo");
names.remove("Juliet");
```

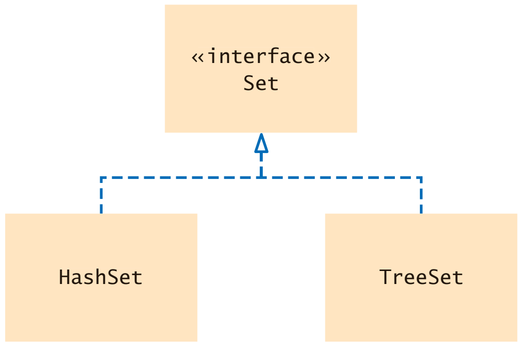


Figure 2
Set Classes and Interfaces in the Standard Library

The `contains` method tests whether an element is contained in the set:

```
if (names.contains("Juliet")) . . .
```

To visit all elements in a set, use an iterator.

Finally, to list all elements in the set, get an iterator. As with list iterators, you use the `next` and `hasNext` methods to step through the set.

```
Iterator<String> iter = names.iterator();
while (iter.hasNext())
{
   String name = iter.next();
   Do something with name
}
```

Or, as with arrays and lists, you can use the "for each" loop instead of explicitly using an iterator:

```
for (String name : names)
{
   Do something with name
}
```

A set iterator visits elements in seemingly random order (`HashSet`) or sorted order (`TreeSet`).

Note that the elements are *not* visited in the order in which you inserted them. When you use a hash set, the elements are visited in a seemingly random order—see Section 16.5 for the reason. With a tree set, elements are visited in sorted order.

You cannot add an element to a set at an iterator position.

There is an important difference between the `Iterator` that you obtain from a set and the `ListIterator` that a list yields. The `ListIterator` has an `add` method to add an element at the list iterator position. The `Iterator` interface has no such method. It makes no sense to add an element at a particular position in a set, because the set can order the elements any way it likes. Thus, you always add elements directly to a set, never to an iterator of the set.

However, you can remove a set element at an iterator position, just as you do with list iterators.

Also, the `Iterator` interface has no `previous` method to go backwards through the elements. Because the elements are not ordered, it is not meaningful to distinguish between "going forward" and "going backward". The following test program shows a practical application of sets. We read in all words from a dictionary file that contains correctly spelled words and place them into a set. We then read all words from a document into a second set—here, the book "Alice in Wonderland". Finally, we print all words from that set that are not in the dictionary set. These are the potential misspellings. (As you can see from the output, we used an American dictionary, and words with British spelling, such as *clamour*, are flagged as potential errors.)

ch16/spellcheck/SpellCheck.java

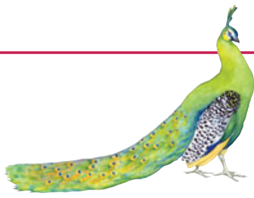
```
import java.util.HashSet;
import java.util.Scanner;
import java.util.Set;
import java.io.File;
import java.io.FileNotFoundException;

/**
   This program checks which words in a file are not present in a dictionary.
*/
public class SpellCheck
{
   public static void main(String[] args)
      throws FileNotFoundException
14     {
15        // Read the dictionary and the document
16
17        Set<String> dictionaryWords = readWords("words");
18        Set<String> documentWords = readWords("alice30.txt");
19
20        // Print all words that are in the document but not the dictionary
21
22        for (String word : documentWords)
23        {
24           if (!dictionaryWords.contains(word))
25           {
26              System.out.println(word);
27           }
28        }
29     }
30
31     /**
32        Reads all words from a file.
33        @param filename the name of the file
34        @return a set with all lowercased words in the file. Here, a
35        word is a sequence of upper- and lowercase letters.
36     */
37     public static Set<String> readWords(String filename)
38        throws FileNotFoundException
39     {
40        Set<String> words = new HashSet<String>();
41        Scanner in = new Scanner(new File(filename));
42        // Use any characters other than a-z or A-Z as delimiters
43        in.useDelimiter("[^a-zA-Z]+");
44        while (in.hasNext())
45        {
46           words.add(in.next().toLowerCase());
47        }
48        return words;
49     }
50  }
```

Program Run

```
neighbouring
croqueted
pennyworth
dutchess
comfits
xii
dinn
clamour
. . .
```

SELF CHECK

1. Arrays and lists remember the order in which you added elements; sets do not. Why would you want to use a set instead of an array or list?
2. Why are set iterators different from list iterators?
3. Suppose you changed line 18 of the `SpellCheck` program to use a `TreeSet` instead of a `HashSet`. How would the output change?
4. When would you choose a tree set over a hash set?



Quality Tip 16.1

Use Interface References to Manipulate Data Structures

It is considered good style to store a reference to a `HashSet` or `TreeSet` in a variable of type `Set`.

```
Set<String> names = new HashSet<String>();
```

This way, you have to change only one line if you decide to use a `TreeSet` instead.

Also, methods that operate on sets should specify parameters of type `Set`:

```
public static void print(Set<String> s)
```

Then the method can be used for all set implementations.

In theory, we should make the same recommendation for linked lists, namely to save `LinkedList` references in variables of type `List`. However, in the Java library, the `List` interface is common to both the `ArrayList` and the `LinkedList` class. In particular, it has `get` and `set` methods for random access, even though these methods are very inefficient for linked lists. You can't write efficient code if you don't know whether random access is efficient or not. This is plainly a serious design error in the standard library, and I cannot recommend using the `List` interface for that reason. (To see just how embarrassing that error is, have a look at the source code for the `binarySearch` method of the `Collections` class. That method takes a `List` parameter, but binary search makes no sense for a linked list. The code then clumsily tries to discover whether the list is a linked list, and then switches to a linear search!)

The `Set` interface and the `Map` interface, which you will see in the next section, are well-designed, and you should use them.

16.2 Maps

A map keeps associations between key and value objects.

A map is a data type that keeps associations between *keys* and *values.* Figure 3 gives a typical example: a map that associates names with colors. This map might describe the favorite colors of various people.

Mathematically speaking, a map is a function from one set, the *key set*, to another set, the *value set*. Every key in the map has a unique value, but a value may be associated with several keys.

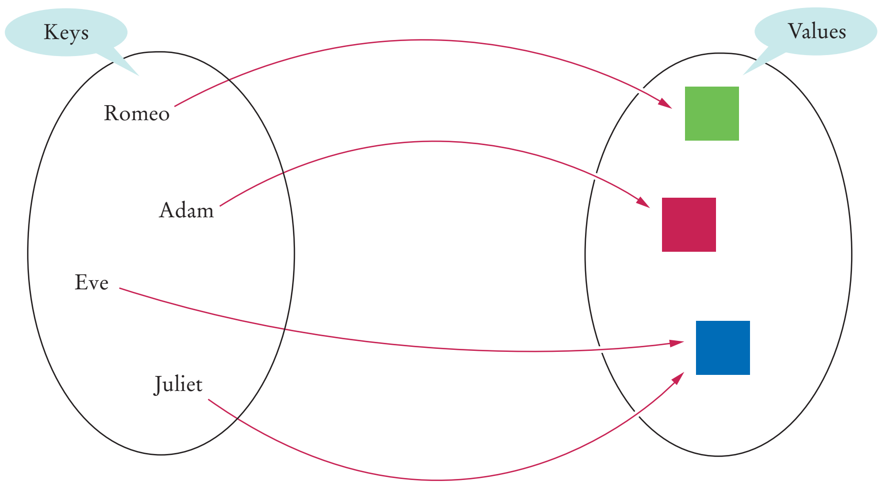


Figure 3 A Map

The HashMap and TreeMap classes both implement the Map interface.

Just as there are two kinds of set implementations, the Java library has two implementations for maps: HashMap and TreeMap. Both of them implement the Map interface (see Figure 4). As with sets, you need to decide which of the two to use. As a rule of thumb, use a hash map unless you want to visit the keys in sorted order.

After constructing a HashMap or TreeMap, you should store the reference to the map object in a Map reference:

```
Map<String, Color> favoriteColors = new HashMap<String, Color>();
```

or

```
Map<String, Color> favoriteColors = new TreeMap<String, Color>();
```

Use the put method to add an association:

```
favoriteColors.put("Juliet", Color.RED);
```

You can change the value of an existing association, simply by calling put again:

```
favoriteColors.put("Juliet", Color.BLUE);
```

The get method returns the value associated with a key.

```
Color julietsFavoriteColor = favoriteColors.get("Juliet");
```

If you ask for a key that isn't associated with any values, then the get method returns null.

To remove a key and its associated value, use the remove method:

```
favoriteColors.remove("Juliet");
```

To find all keys and values in a map, iterate through the key set and find the values that correspond to the keys.

Sometimes you want to enumerate all keys in a map. The keySet method yields the set of keys. You can then ask the key set for an iterator and get all keys. From each key, you can find the associated value with the get method. Thus, the following instructions print all key/value pairs in a map m:

```
Set<String> keySet = m.keySet();
for (String key : keySet)
{
   Color value = m.get(key);
   System.out.println(key + " : " + value);
}
```

When you use a hash map, the keys are visited in a seemingly random order. With a tree map, keys are visited in sorted order. The following sample program shows a map in action.

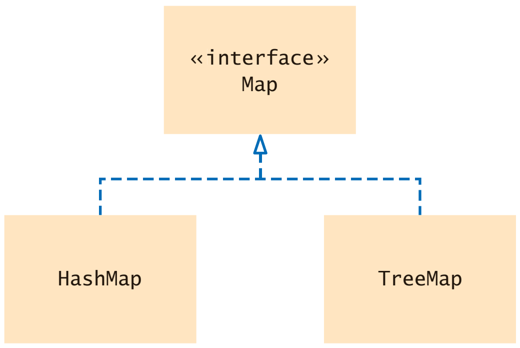


Figure 4
Map Classes and Interfaces in the Standard Library

ch16/map/MapDemo.java

```java
import java.awt.Color;
import java.util.HashMap;
import java.util.Map;
import java.util.Set;

/**
   This program demonstrates a map that maps names to colors.
*/
public class MapDemo
{
   public static void main(String[] args)
   {
      Map<String, Color> favoriteColors = new HashMap<String, Color>();
      favoriteColors.put("Juliet", Color.BLUE);
      favoriteColors.put("Romeo", Color.GREEN);
      favoriteColors.put("Adam", Color.RED);
      favoriteColors.put("Eve", Color.BLUE);

      // Print all keys and values in the map

      Set<String> keySet = favoriteColors.keySet();
      for (String key : keySet)
      {
         Color value = favoriteColors.get(key);
         System.out.println(key + " : " + value);
      }
   }
}
```

Program Run

```
Romeo : java.awt.Color[r=0,g=255,b=0]
Eve : java.awt.Color[r=0,g=0,b=255]
Adam : java.awt.Color[r=255,g=0,b=0]
Juliet : java.awt.Color[r=0,g=0,b=255]
```

SELF CHECK

5. What is the difference between a set and a map?
6. Why is the collection of the keys of a map a set?

Special Topic 16.1

Enhancements to Collection Classes in Java 7

Java 7 provides several syntactical conveniences for working with collection classes.

Type parameters in constructors can be inferred from variable types. You no longer have to repeat them in the variable declaration and the constructor. For example,

```
Set<String> names = new HashSet<>(); // Constructs a HashSet<String>
Map<String, Integer> scores = new TreeMap<>(); // Constructs a TreeMap<String, Integer>
```

You can obtain *collection literals* of type `List`, `Set`, and `Map`, with the following syntax:

```
["Tom", "Diana", "Harry"];
{ 2, 3, 5, 7, 11 };
{ "Juliet" : Color.BLUE, "Romeo" : Color.GREEN, "Eve" : Color.BLUE };
```

These objects are immutable: you cannot change the contents of the list, set, or map literal. The objects are instances of classes that implements the `List`, `Set`, and `Map` interfaces, but you don't know what those classes are.

You can pass collection or map literals to methods, for example

```
names.addAll(["Tom", "Diana", "Harry"]);
```

If you want to store a literal in a variable, you must use the interface type for the variable declaration:

```
List<String> friends = ["Tom", "Diana", "Harry"];
```

Alternatively, you can initialize a collection with a literal:

```
ArrayList<String> friends = new ArrayList<>(["Tom", "Diana", "Harry"]);
```

This works because all Java collection and map classes have constructors that copy entries from another collection or map.

Finally, you can use the `[]` operator instead of the `get`, `set`, or `put` methods. For example,

```
String name = names[0];
names[0] = "Fred";
scores["Fred"] = 13;
int score = scores["Fred"];
```

How To 16.1 Choosing a Container

Suppose you need to store objects in a container. You have now seen a number of different data structures. This How To reviews how to pick an appropriate container for your application.

Step 1 Determine how you access the values.

You store values in a container so that you can later retrieve them. How do you want to access individual values? You have several choices.

- Values are accessed by an integer position. Use an `ArrayList`. Go to Step 2, then stop.
- Values are accessed by a key that is not a part of the object. Use a map.
- It doesn't matter. Values are always accessed "in bulk", by traversing the collection and doing something with each value.

Step 2 Determine the element types of key/value types.

For a list or set, determine the type of the elements that you want to store. For example, if you collect a set of books, then the element type is `Book`.

Similarly, for a map, determine the types of the keys and the associated values. If you want to look up books by ID, you can use a `Map<Integer, Book>` or `Map<String, Book>`, depending on your ID type.

Step 3 Determine whether element or key order matters.

When you visit elements from a container or keys from a map, do you care about the order in which they are visited? You have several choices.

- Elements or keys must be sorted. Use a `TreeSet` or `TreeMap`. Go to Step 6.
- Elements must be in the same order in which they were inserted. Your choice is now narrowed down to a `LinkedList` or `ArrayList`.
- It doesn't matter. As long as you get to visit all elements, you don't care in which order. If you chose a map in Step 1, use a `HashMap` and go to Step 5.

Step 4 For a collection, determine which operations must be fast.

You have several choices.

- Finding elements must be fast. Use a `HashSet` and go to Step 5.
- Adding and removing elements at the beginning or middle must be fast. Use a `LinkedList`.
- It doesn't matter. You only insert at the end, or collect so few elements that you aren't concerned about speed. Then use an `ArrayList`.

Step 5 For hash sets and maps, decide whether you need to implement the `equals` and `hashCode` methods.

If your elements or keys belong to a class that someone else provided, check whether the class implements `hashCode` and `equals` methods. If so, you are all set. This is the case for most classes in the standard Java library, such as `String`, `Integer`, `Rectangle`, and so on.

If not, decide whether you can compare the elements by identity. Are all elements distinct in your program? That is, can it never happen that you have two different elements with the same instance variables? In that case, you need not do anything—the `hashCode` and `equals` methods of the `Object` class are appropriate.

If you need to implement your own `equals` and `hashCode` methods, turn to Section 16.4.

Step 6 If you use a tree, decide whether to supply a comparator.

Look at the class of the set elements or map keys. Does that class implement the `Comparable` interface? If so, is the sort order given by the `compareTo` method the one you want? If yes, then you don't need to do anything further. This is the case for many classes in the standard library, in particular for `String` and `Integer`.

If no, then your element class must implement the `Comparable` interface, or you must provide a class that implements the `Comparator` interface. See Section 14.8 for the details.

Worked Example 16.1

Word Frequency

In this Worked Example, we read a text file and print a list of all words in the file in alphabetical order, together with a count that indicates how often each word occurred in the file

16.3 Hash Tables

In this section, you will see how the technique of **hashing** can be used to find elements in a data structure quickly, without making a linear search through all elements. Hashing gives rise to the **hash table**, which can be used to implement sets and maps.

A hash function computes an integer value from an object.

A **hash function** is a function that computes an integer value, the **hash code**, from an object, in such a way that different objects are likely to yield different hash codes. The `Object` class has a `hashCode` method that other classes need to override. The call

```
int h = x.hashCode();
```

computes the hash code of the object `x`.

Available online in WileyPLUS and at `www.wiley.com/college/horstmann`.

Table 1 Sample Strings and Their Hash Codes

String	Hash Code	String	Hash Code
"Adam"	2035631	"Joe"	74656
"Eve"	70068	"Juliet"	–2065036585
"Harry"	69496448	"Katherine"	2079199209
"Jim"	74478	"Sue"	83491

Table 1 shows some examples of strings and their hash codes. You will see in Section 16.4 how these values are obtained.

A good hash function minimizes *collisions*—identical hash codes for different objects.

It is possible for two or more distinct objects to have the same hash code; this is called a *collision*. For example, the strings "VII" and "Ugh" happen to have the same hash code. These collisions are very rare for strings (see Exercise P16.6).

Section 16.5 explains how you should override the hashCode method for other classes.

A hash code is used as an array index into a hash table. In the simplest implementation of a hash table, you could make an array and insert each object at the location of its hash code (see Figure 5).

If there are no collisions, it is a very simple matter to find out whether an object is already present in the set or not. Compute its hash code and check whether the array position with that hash code is already occupied. This doesn't require a search through the entire array!

Of course, it is not feasible to allocate an array that is large enough to hold all possible integer index positions. Therefore, we must pick an array of some reasonable size and then reduce the hash code to fall inside the array:

```
int h = x.hashCode();
if (h < 0) h = -h;
position = h % buckets.length;
```

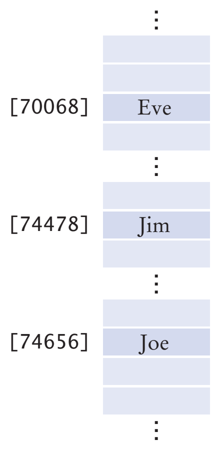


Figure 5
A Simplistic Implementation of a Hash Table

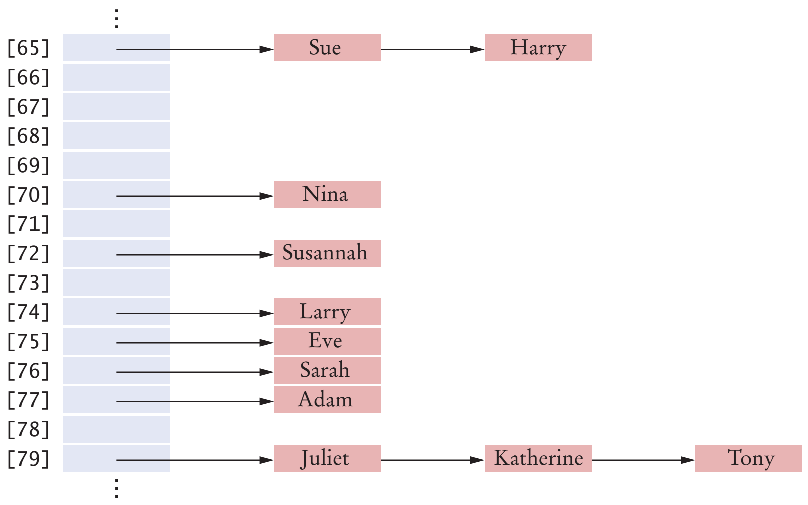


Figure 6 A Hash Table with Buckets to Store Elements with the Same Hash Code

After reducing the hash code modulo a smaller array size, it becomes even more likely that several objects will collide. In order to handle collisions, we will store all colliding elements in a "bucket", a linked list of elements with the same position value (see Figure 6).

A hash table can be implemented as an array of *buckets*—sequences of nodes that hold elements with the same hash code.

Here is the algorithm for finding an object `x` in a hash table.

1. Compute the hash code and reduce it modulo the table size. This gives an index `h` into the hash table.
2. Iterate through the elements of the bucket at position `h`. For each element of the bucket, check whether it is equal to `x`.
3. If a match is found among the elements of that bucket, then `x` is in the set. Otherwise, it is not.

Adding an element is a straightforward extension of the algorithm for finding an object. First compute the hash code to locate the bucket in which the element should be inserted. Try finding the object in that bucket. If it is already present, do nothing. Otherwise, insert it.

Removing an element is equally simple. First compute the hash code to locate the bucket in which the element should be inserted. Try finding the object in that bucket. If it is present, remove it. Otherwise, do nothing.

If there are no or only a few collisions, then adding, locating, and removing hash table elements takes constant or $O(1)$ time.

In the best case, in which there are no collisions, all buckets either are empty or have a single element. Then adding, finding, and removing elements takes constant or $O(1)$ time.

More generally, for this algorithm to be effective, the bucket sizes must be small. (In the worst case, where all elements end up in the same bucket, a hash table degenerates into a linked list!)

In order to reduce the chances for collisions, you should make a hash table somewhat larger than the number of elements that you expect to insert. An excess capacity of about 30 percent is typically recommended. According to some researchers, the hash table size should be chosen to be a prime number to minimize the number of collisions.

At the end of this section you will find the code for a simple implementation of a hash set. That implementation takes advantage of the `AbstractSet` class, which already implements most of the methods of the `Set` interface.

In this implementation you must specify the size of the hash table. In the standard library, you don't need to supply a table size. If the hash table gets too full, a new table of twice the size is created, and all elements are inserted into the new table.

ch16/hashtable/HashSet.java

```java
import java.util.AbstractSet;
import java.util.Iterator;
import java.util.NoSuchElementException;

/**
   A hash set stores an unordered collection of objects, using
   a hash table.
*/
public class HashSet extends AbstractSet
{
   private Node[] buckets;
   private int size;

   /**
      Constructs a hash table.
      @param bucketsLength the length of the buckets array
   */
   public HashSet(int bucketsLength)
   {
      buckets = new Node[bucketsLength];
      size = 0;
   }

   /**
      Tests for set membership.
      @param x an object
      @return true if x is an element of this set
   */
   public boolean contains(Object x)
   {
      int h = x.hashCode();
      if (h < 0) h = -h;
      h = h % buckets.length;

      Node current = buckets[h];
      while (current != null)
      {
         if (current.data.equals(x)) return true;
         current = current.next;
      }
      return false;
   }

   /**
      Adds an element to this set.
      @param x an object
      @return true if x is a new object, false if x was
      already in the set
   */
   public boolean add(Object x)
   {
      int h = x.hashCode();
      if (h < 0) h = -h;
      h = h % buckets.length;

      Node current = buckets[h];
      while (current != null)
      {
         if (current.data.equals(x))
            return false; // Already in the set
         current = current.next;
      }
      Node newNode = new Node();
      newNode.data = x;
      newNode.next = buckets[h];
      buckets[h] = newNode;
      size++;
      return true;
   }

   /**
      Removes an object from this set.
      @param x an object
      @return true if x was removed from this set, false
      if x was not an element of this set
   */
   public boolean remove(Object x)
   {
      int h = x.hashCode();
      if (h < 0) h = -h;
      h = h % buckets.length;

      Node current = buckets[h];
      Node previous = null;
      while (current != null)
      {
         if (current.data.equals(x))
         {
            if (previous == null) buckets[h] = current.next;
            else previous.next = current.next;
            size--;
            return true;
         }
         previous = current;
         current = current.next;
      }
      return false;
   }

   /**
      Returns an iterator that traverses the elements of this set.
      @return a hash set iterator
   */
   public Iterator iterator()
   {
      return new HashSetIterator();
   }

   /**
      Gets the number of elements in this set.
      @return the number of elements
   */
   public int size()
   {
      return size;
   }

   class Node
   {
      public Object data;
      public Node next;
   }

   class HashSetIterator implements Iterator
   {
      private int bucket;
      private Node current;
      private int previousBucket;
      private Node previous;

      /**
         Constructs a hash set iterator that points to the
         first element of the hash set.
      */
      public HashSetIterator()
      {
         current = null;
         bucket = -1;
         previous = null;
         previousBucket = -1;
      }

      public boolean hasNext()
      {
         if (current != null && current.next != null)
            return true;
         for (int b = bucket + 1; b < buckets.length; b++)
            if (buckets[b] != null) return true;
         return false;
      }

      public Object next()
      {
         previous = current;
         previousBucket = bucket;
         if (current == null || current.next == null)
         {
            // Move to next bucket
            bucket++;

            while (bucket < buckets.length
                  && buckets[bucket] == null)
               bucket++;
            if (bucket < buckets.length)
               current = buckets[bucket];
            else
               throw new NoSuchElementException();
         }
         else // Move to next element in bucket
            current = current.next;
         return current.data;
      }

      public void remove()
      {
         if (previous != null && previous.next == current)
            previous.next = current.next;
         else if (previousBucket < bucket)
            buckets[bucket] = current.next;
         else
            throw new IllegalStateException();
         current = previous;
         bucket = previousBucket;
      }
   }
}
```

ch16/hashtable/HashSetDemo.java

```
import java.util.Iterator;
import java.util.Set;

/**
   This program demonstrates the hash set class.
*/
public class HashSetDemo
{
   public static void main(String[] args)
   {
      Set names = new HashSet(101); // 101 is a prime

      names.add("Harry");
      names.add("Sue");
      names.add("Nina");
      names.add("Susannah");
      names.add("Larry");
      names.add("Eve");
      names.add("Sarah");
      names.add("Adam");
      names.add("Tony");
      names.add("Katherine");
      names.add("Juliet");
      names.add("Romeo");
      names.remove("Romeo");
      names.remove("George");

      Iterator iter = names.iterator();
      while (iter.hasNext())
         System.out.println(iter.next());
   }
}
```

Program Run

```
Harry
Sue
Nina
Susannah
Larry
Eve
Sarah
Adam
Juliet
Katherine
Tony
```

SELF CHECK

7. If a hash function returns `0` for all values, will the `HashSet` work correctly?
8. What does the `hasNext` method of the `HashSetIterator` do when it has reached the end of a bucket?

16.4 Computing Hash Codes

A hash function computes an integer hash code from an object, so that different objects are likely to have different hash codes. Let us first look at how you can compute a hash code from a string. Clearly, you need to combine the character values of the string to yield some integer. You could, for example, add up the character values:

```
int h = 0;
for (int i = 0; i < s.length(); i++)
   h = h + s.charAt(i);
```

However, that would not be a good idea. It doesn't scramble the character values enough. Strings that are permutations of another (such as `"eat"` and `"tea"`) all have the same hash code.

Here is the method the standard library uses to compute the hash code for a string.

```
final int HASH_MULTIPLIER = 31;
int h = 0;
for (int i = 0; i < s.length(); i++)
   h = HASH_MULTIPLIER * h + s.charAt(i);
```

For example, the hash code of "eat" is

```
31 * (31 * 'e' + 'a') + 't' = 100184
```

The hash code of "tea" is quite different, namely

```
31 * (31 * 't' + 'e') + 'a' = 114704
```

(Use the Unicode table from Appendix A to look up the character values: 'a' is 97, 'e' is 101, and 't' is 116.)

When implementing the hashCode method, combine the hash codes for the instance variables.

For your own classes, you should make up a hash code that combines the hash codes of the instance variables in a similar way. For example, let us implement a hashCode method for the Coin class. There are two instance variables: the coin name and the coin value. First, compute their hash code. You know how to compute the hash code of a string. To compute the hash code of a floating-point number, first wrap the floating-point number into a Double object, and then compute its hash code.

```
class Coin
{
   public int hashCode()
   {
      int h1 = name.hashCode();
      int h2 = new Double(value).hashCode();
      . . .
   }
}
```

Then combine the two hash codes.

```
final int HASH_MULTIPLIER = 29;
int h = HASH_MULTIPLIER * h1 + h2;
return h;
```

Use a prime number as the hash multiplier—it scrambles the values better.

If you have more than two instance variables, then combine their hash codes as follows:

```
int h = HASH_MULTIPLIER * h1 + h2;
h = HASH_MULTIPLIER * h + h3;
h = HASH_MULTIPLIER * h + h4;
. . .
return h;
```

If one of the instance variables is an integer, just use the integer value as its hash code.

Your hashCode method must be compatible with the equals method.

When you add objects of your class into a hash table, you need to double-check that the hashCode method is *compatible* with the equals method of your class. Two objects that are equal must yield the same hash code:

- If x.equals(y), then x.hashCode() == y.hashCode()

After all, if x and y are equal to each other, then you don't want to insert both of them into a set—sets don't store duplicates. But if their hash codes are different, x and y may end up in different buckets, and the add method would never notice that they are actually duplicates.

Of course, the converse of the compatibility condition is generally not true. It is possible for two objects to have the same hash code without being equal.

For the Coin class, the compatibility condition holds. We define two coins to be equal to each other if their names and values are equal. In that case, their hash codes will also be equal, because the hash code is computed from the hash codes of the `name` and `value` instance variables.

You get into trouble if your class provides an `equals` method but not a `hashCode` method. Suppose we forget to provide a `hashCode` method for the `Coin` class. Then it inherits the hash code method from the `Object` superclass. That method computes a hash code from the *memory location* of the object. The effect is that any two objects are very likely to have a different hash code.

```
Coin coin1 = new Coin(0.25, "quarter");
Coin coin2 = new Coin(0.25, "quarter");
```

Now `coin1.hashCode()` is derived from the memory location of `coin1`, and `coin2.hashCode()` is derived from the memory location of `coin2`. Even though `coin1.equals(coin2)` is `true`, their hash codes differ.

If a class provides neither `equals` nor `hashCode`, then objects are compared by identity.

However, if you provide *neither* `equals` *nor* `hashCode`, then there is no problem. The `equals` method of the `Object` class considers two objects equal only if their memory location is the same. That is, the `Object` class has compatible `equals` and `hashCode` methods. Of course, then the notion of equality is very restricted: Only identical objects are considered equal. That is not necessarily a bad notion of equality: If you want to collect a set of coins in a purse, you may not want to lump coins of equal value together.

Whenever you use a hash set, you need to make sure that an appropriate hash function exists for the type of the objects that you add to the set. Check the `equals` method of your class. It tells you when two objects are considered equal. There are two possibilities. Either `equals` has been provided or it has not been provided. If `equals` has not been provided, only identical objects are considered equal. In that case, don't provide `hashCode` either. However, if the `equals` method has been provided, look at its implementation. Typically, two objects are considered equal if some or all of the instance variables are equal. Sometimes, not all instance variables are used in the comparison. Two `Student` objects may be considered equal if their `studentID` variables are equal. Implement the `hashCode` method to combine the hash codes of the instance variables that are compared in the `equals` method.

In a hash map, only the keys are hashed.

When you use a `HashMap`, only the keys are hashed. They need compatible `hashCode` and `equals` methods. The values are never hashed or compared. The reason is simple—the map only needs to find, add, and remove keys quickly.

ch16/hashcode/Coin.java

```
/**
   A coin with a monetary value.
*/
public class Coin
{
   private double value;
   private String name;

   /**
      Constructs a coin.
      @param aValue the monetary value of the coin
      @param aName the name of the coin
   */
   public Coin(double aValue, String aName)
   {
```

```java
      value = aValue;
      name = aName;
   }

   /**
      Gets the coin value.
      @return the value
   */
   public double getValue()
   {
      return value;
   }

   /**
      Gets the coin name.
      @return the name
   */
   public String getName()
   {
      return name;
   }

   public boolean equals(Object otherObject)
   {
      if (otherObject == null) return false;
      if (getClass() != otherObject.getClass()) return false;
      Coin other = (Coin) otherObject;
      return value == other.value && name.equals(other.name);
   }

   public int hashCode()
   {
      int h1 = name.hashCode();
      int h2 = new Double(value).hashCode();
      final int HASH_MULTIPLIER = 29;
      int h = HASH_MULTIPLIER * h1 + h2;
      return h;
   }

   public String toString()
   {
      return "Coin[value=" + value + ",name=" + name + "]";
   }
}
```

ch16/hashcode/CoinHashCodePrinter.java

```java
import java.util.HashSet;
import java.util.Set;

/**
   A program that prints hash codes of coins.
*/
public class CoinHashCodePrinter
{
   public static void main(String[] args)
   {
      Coin coin1 = new Coin(0.25, "quarter");
      Coin coin2 = new Coin(0.25, "quarter");
      Coin coin3 = new Coin(0.05, "nickel");

      System.out.println("hash code of coin1=" + coin1.hashCode());
      System.out.println("hash code of coin2=" + coin2.hashCode());
      System.out.println("hash code of coin3=" + coin3.hashCode());

      Set<Coin> coins = new HashSet<Coin>();
      coins.add(coin1);
      coins.add(coin2);
      coins.add(coin3);

      for (Coin c : coins)
         System.out.println(c);
   }
}
```

Program Run

```
hash code of coin1=-1513525892
hash code of coin2=-1513525892
hash code of coin3=-1768365211
Coin[value=0.25,name=quarter]
Coin[value=0.05,name=nickel]
```

SELF CHECK

9. What is the hash code of the string `"to"`?
10. What is the hash code of `new Integer(13)`?

Common Error 16.1

Forgetting to Provide `hashCode`

When putting elements into a hash table, make sure that the `hashCode` method is provided. (The only exception is that you don't need to provide `hashCode` if `equals` isn't provided either. In that case, distinct objects of your class are considered different, even if they have matching contents.)

If you forget to implement the `hashCode` method, then you inherit the `hashCode` method of the `Object` class. That method computes a hash code of the memory location of the object. For example, suppose that you do *not* provide the `hashCode` method of the `Coin` class. Then the following code is likely to fail:

```
Set<Coin> coins = new HashSet<Coin>();
coins.add(new Coin(0.25, "quarter"));
// The following comparison will probably fail if hashCode not provided
if (coins.contains(new Coin(0.25, "quarter"))
   System.out.println("The set contains a quarter.");
```

The two `Coin` objects are constructed at different memory locations, so the `hashCode` method of the `Object` class will probably compute different hash codes for them. (As always with hash codes, there is a small chance that the hash codes happen to collide.) Then the `contains` method will inspect the wrong bucket and never find the matching coin.

The remedy is to provide a `hashCode` method in the `Coin` class.

16.5 Binary Search Trees

A set implementation is allowed to rearrange its elements in any way it chooses so that it can find elements quickly. Suppose a set implementation *sorts* its entries. Then it can use **binary search** to locate elements quickly. Binary search takes $O(\log(n))$ steps, where n is the size of the set. For example, binary search in an array of 1,000 elements is able to locate an element in at most 10 steps by cutting the size of the search interval in half in each step.

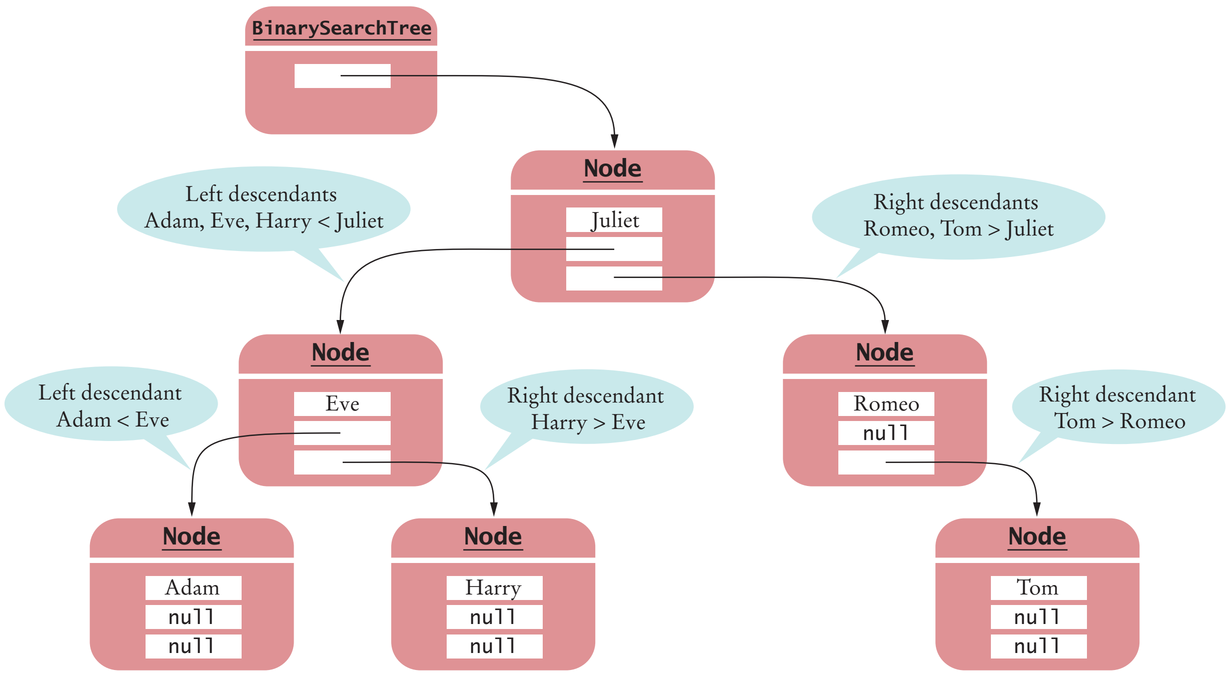
If we use an array to store the elements of a set, inserting or removing an element is an $O(n)$ operation. In this section, you will see how tree-shaped data structures can keep elements in sorted order with more efficient insertion and removal.

A binary tree consists of nodes, each of which has at most two child nodes.

A linked list is a one-dimensional data structure. In a linked list, a node has only one successor. You can imagine that all nodes are arranged in line. In contrast, a **tree** is made of nodes that have references to multiple nodes, called the child nodes. Because the child nodes can also have children, the data structure has a tree-like appearance. It is traditional to draw the tree upside down, like a family tree or hierarchy chart (see Figure 7). In keeping with the tree image, the node at the top is called the *root node*, and the nodes without children are called *leaf nodes*. In a **binary tree**, every node has at most two children (called the *left* and *right children*); hence the name *binary*.

Finally, a **binary search tree** is constructed to have this important property:

- The data values of *all* descendants to the left of *any* node are less than the data value stored in that node, and *all* descendants to the right have greater data values.



BinarySearchTree
Node
Juliet
Left descendants Adam, Eve, Harry < Juliet
Right descendants Romeo, Tom > Juliet
Node
Eve
Node
Romeo
null
Left descendant Adam < Eve
Right descendant Harry > Eve
Right descendant Tom > Romeo
Node
Adam
null
null
Node
Harry
null
null
Node
Tom
null
null

Figure 7 A Binary Search Tree

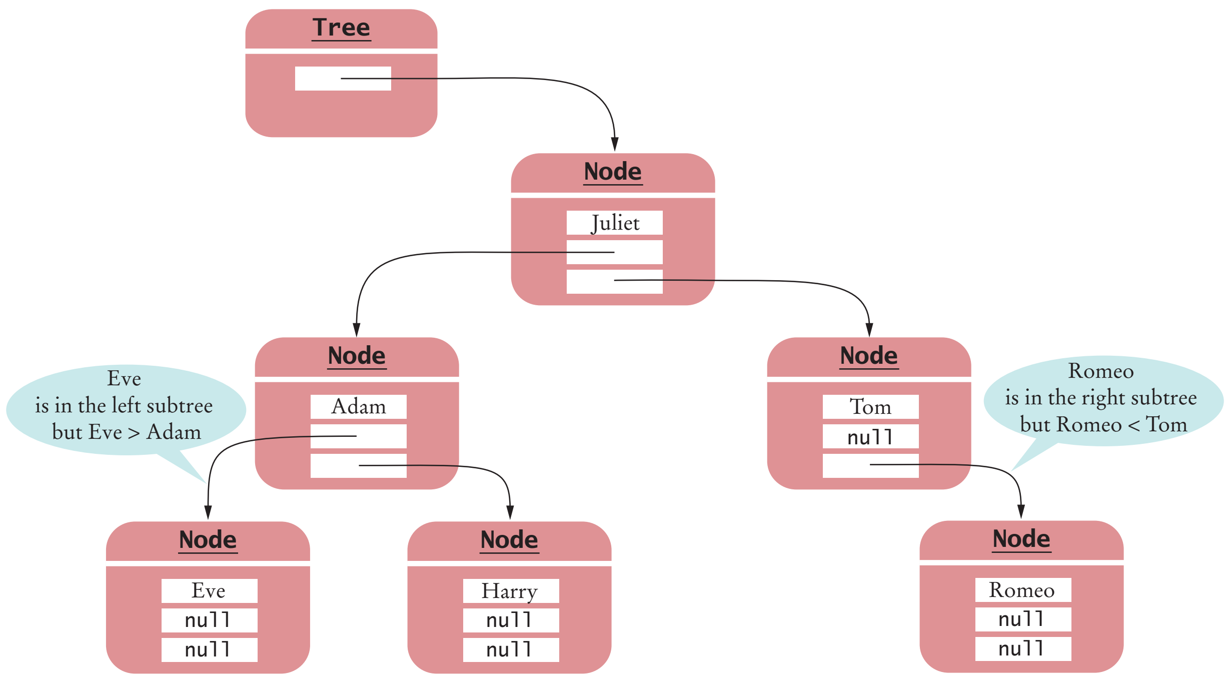


Figure 8 A Binary Tree That Is Not a Binary Search Tree

All nodes in a binary search tree fulfill the property that the descendants to the left have smaller data values than the node data value, and the descendants to the right have larger data values.

The tree in Figure 7 has this property. To verify the binary search property, you must check each node. Consider the node “Juliet”. All descendants to the left have data before “Juliet”. All descendants on the right have data after “Juliet”. Move on to “Eve”. There is a single descendant to the left, with data “Adam” before “Eve”, and a single descendant to the right, with data “Harry” after “Eve”. Check the remaining nodes in the same way.

Figure 8 shows a binary tree that is not a binary search tree. Look carefully—the root node passes the test, but its two children do not.

Let us implement these tree classes. Just as you needed classes for lists and their nodes, you need one class for the tree, containing a reference to the *root node*, and a separate class for the nodes. Each node contains two references (to the left and right child nodes) and an instance variable `data`. At the fringes of the tree, one or two of the child references can be `null`. The `data` variable has type `Comparable`, not `Object`, because you must be able to compare the values in a binary search tree in order to place them into the correct position.

```
public class BinarySearchTree
{
   private Node root;

   public BinarySearchTree() { . . . }
   public void add(Comparable obj) { . . . }
   . . .
   class Node
   {
      public Comparable data;
      public Node left;
      public Node right;
```

```
        public void addNode(Node newNode) { . . . }
        . . .
    }
}
```

To insert a value into a binary search tree, keep comparing the value with the node data and follow the nodes to the left or right, until reaching a `null` node.

To insert data into the tree, use the following algorithm:

- If you encounter a non-`null` node reference, look at its `data` value. If the `data` value of that node is larger than the one you want to insert, continue the process with the left child. If the existing `data` value is smaller, continue the process with the right child.
- If you encounter a `null` node reference, replace it with the new node.

For example, consider the tree in Figure 9. It is the result of the following statements:

```
BinarySearchTree tree = new BinarySearchTree();
tree.add("Juliet"); 1
tree.add("Tom");      2
tree.add("Diana");  3
tree.add("Harry");    4
```

We want to insert a new element `Romeo` into it.

```
tree.add("Romeo"); 5
```

Start with the root node, `Juliet`. `Romeo` comes after `Juliet`, so you move to the right subtree. You encounter the node `Tom`. `Romeo` comes before `Tom`, so you move to the left subtree. But there is no left subtree. Hence, you insert a new `Romeo` node as the left child of `Tom` (see Figure 10).

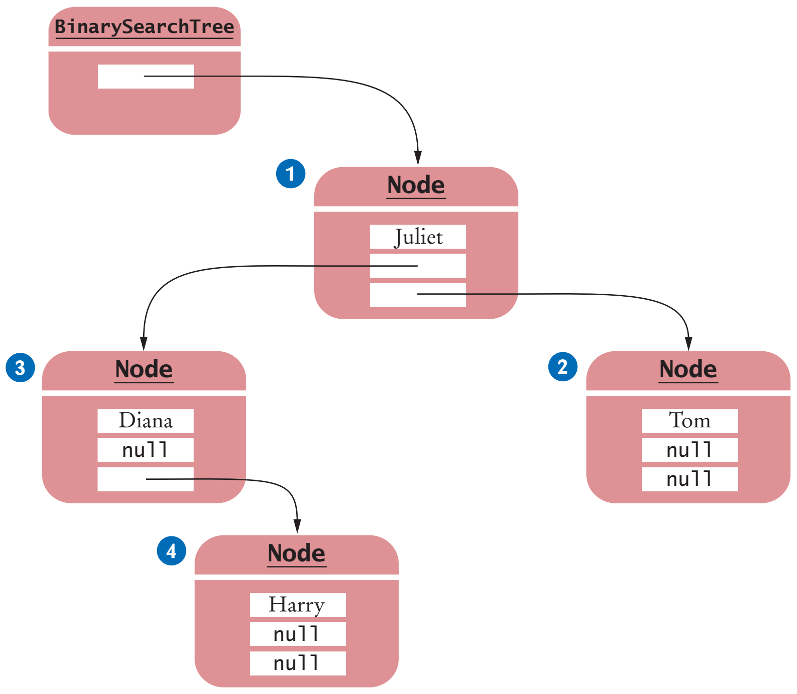
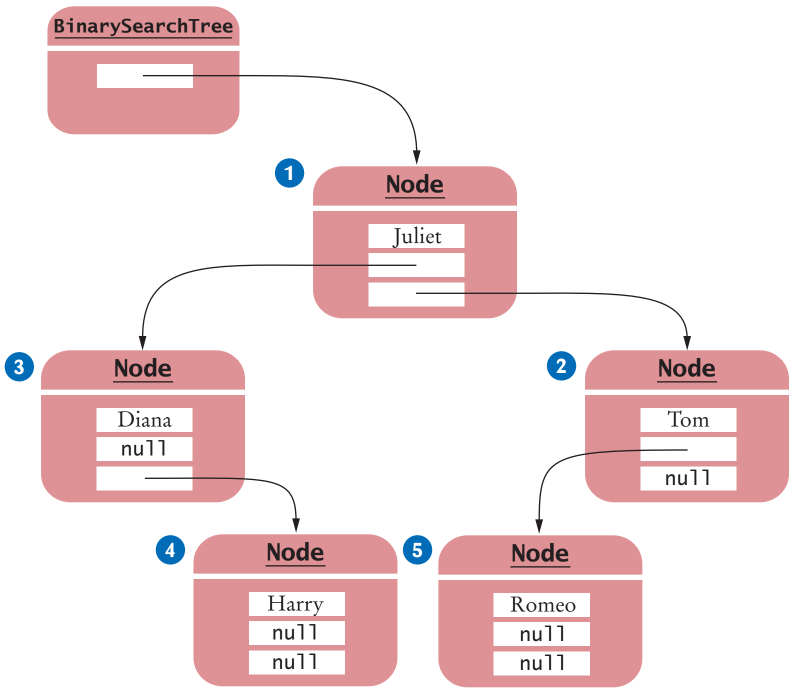


Figure 9
Binary Search Tree After Four Insertions

Figure 10
Binary Search Tree
After Five Insertions



You should convince yourself that the resulting tree is still a binary search tree. When `Romeo` is inserted, it must end up as a right descendant of `Juliet`—that is what the binary search tree condition means for the root node `Juliet`. The root node doesn't care where in the right subtree the new node ends up. Moving along to `Tom`, the right child of `Juliet`, all it cares about is that the new node `Romeo` ends up somewhere on its left. There is nothing to its left, so `Romeo` becomes the new left child, and the resulting tree is again a binary search tree.

Here is the code for the `add` method of the `BinarySearchTree` class:

```
public void add(Comparable obj)
{
   Node newNode = new Node();
   newNode.data = obj;
   newNode.left = null;
   newNode.right = null;
   if (root == null) root = newNode;
   else root.addNode(newNode);
}
```

If the tree is empty, simply set its root to the new node. Otherwise, you know that the new node must be inserted somewhere within the nodes, and you can ask the root node to perform the insertion. That node object calls the `addNode` method of the `Node` class, which checks whether the new object is less than the object stored in the node. If so, the element is inserted in the left subtree; if not, it is inserted in the right subtree:

```
class Node
{
   . . .
   public void addNode(Node newNode)
   {
         int comp = newNode.data.compareTo(data);
         if (comp < 0)
         {
            if (left == null) left = newNode;
            else left.addNode(newNode);
         }
         else if (comp > 0)
         {
            if (right == null) right = newNode;
            else right.addNode(newNode);
         }
      }
      . . .
   }
```

Let's trace the calls to `addNode` when inserting `Romeo` into the tree in Figure 9. The first call to `addNode` is

```
root.addNode(newNode)
```

Because `root` points to `Juliet`, you compare `Juliet` with `Romeo` and find that you must call

```
root.right.addNode(newNode)
```

The node `root.right` is `Tom`. Compare the data values again (`Tom` vs. `Romeo`) and find that you must now move to the left. Since `root.right.left` is `null`, set `root.right.left` to `newNode`, and the insertion is complete (see Figure 10).

Unlike a linked list or an array, and like a hash table, a binary tree has no *insert positions.* You cannot select the position where you would like to insert an element into a binary search tree. The data structure is *self-organizing;* that is, each element finds its own place.

We will now discuss the removal algorithm. Our task is to remove a node from the tree. Of course, we must first *find* the node to be removed. That is a simple matter, due to the characteristic property of a binary search tree. Compare the data value to be removed with the data value that is stored in the root node. If it is smaller, keep looking in the left subtree. Otherwise, keep looking in the right subtree.

Let us now assume that we have located the node that needs to be removed. First, let us consider an easy case, when that node has only one child (see Figure 11).

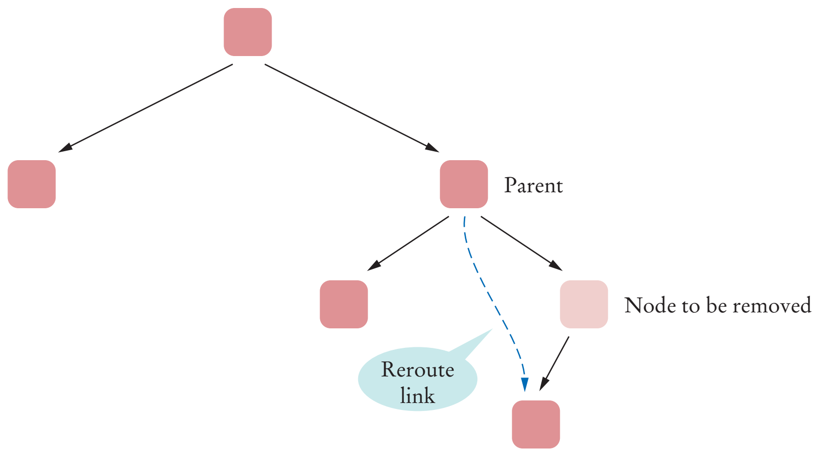


Figure 11 Removing a Node with One Child

When removing a node with only one child from a binary search tree, the child replaces the node to be removed.

To remove the node, simply modify the parent link that points to the node so that it points to the child instead.

If the node to be removed has no children at all, then the parent link is simply set to `null`.

When removing a node with two children from a binary search tree, replace it with the smallest node of the right subtree.

The case in which the node to be removed has two children is more challenging. Rather than removing the node, it is easier to replace its data value with the next larger value in the tree. That replacement preserves the binary search tree property. (Alternatively, you could use the largest element of the left subtree—see Exercise P16.21).

To locate the next larger value, go to the right subtree and find its smallest data value. Keep following the left child links. Once you reach a node that has no left child, you have found the node containing the smallest data value of the subtree. Now remove that node—it is easily removed because it has at most one child to the right. Then store its data value in the original node that was slated for removal. Figure 12 shows the details. You will find the complete code at the end of this section.

At the end of this section, you will find the source code for the `BinarySearchTree` class. It contains the `add` and `remove` methods that we just described, as well as a `find` method that tests whether a value is present in a binary search tree, and a `print` method that we will analyze in the following section.

In a balanced tree, all paths from the root to the leaves have about the same length.

Now that you have seen the implementation of this data structure, you may well wonder whether it is any good. Like nodes in a list, nodes are allocated one at a time. No existing elements need to be moved when a new element is inserted or removed; that is an advantage. How fast insertion and removal are, however, depends on the shape of the tree. These operations are fast if the tree is *balanced* (see Figure 13).

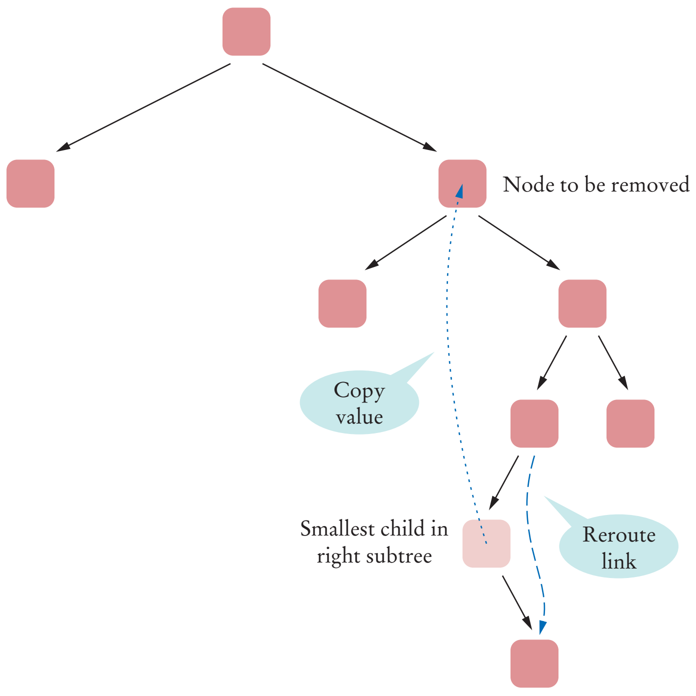


Figure 12 Removing a Node with Two Children

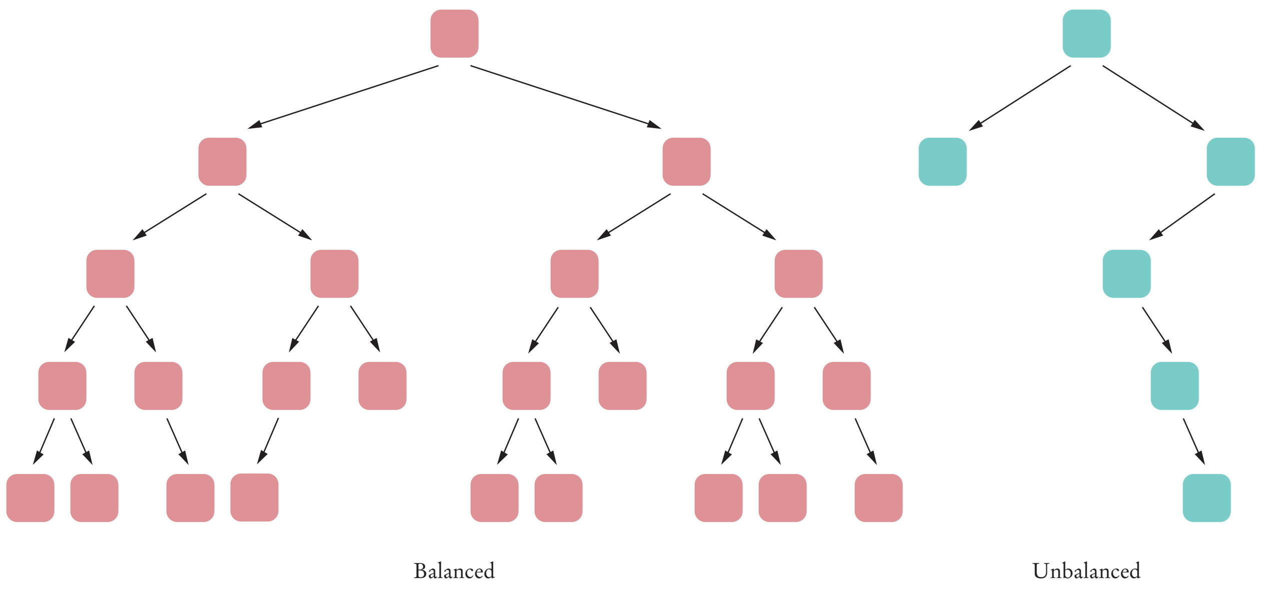


Figure 13 Balanced and Unbalanced Trees

Adding, finding, and removing an element in a tree set is proportional to the height of the tree.

In a balanced tree, all paths from the root to one of the leaf nodes (that is, nodes without children) have approximately the same length. The number of nodes in the longest of these paths is called the *height* of the tree. The trees in Figure 13 have height 5.

Because the operations of finding, adding, and removing an element process the nodes along a path from the root to a leaf, their execution time is proportional to the height of the tree, and not to the total number of nodes in the tree.

A tree of height h can have up to $n = 2^h - 1$ nodes. For example, a completely filled tree of height 4 has $1 + 2 + 4 + 8 = 15 = 2^4 - 1$ nodes. In other words, $h = \log_2 (n + 1)$ for a completely filled tree. For a balanced tree, we still have $h \approx \log_2 n$. For example, the height of a tree with 1,000 nodes is approximately 10 (because $1024 = 2^{10}$). A tree with 1,000,000 nodes has height approximately 20. In such a tree, you can find any element in about 20 steps. That is a lot faster than traversing the 1,000,000 elements of a list.

If a binary search tree is balanced, then adding, locating, or removing an element takes $O(\log(n))$ time.

On the other hand, if the tree happens to be *unbalanced*, then binary tree operations can be slow—in the worst case, as slow as insertion into a linked list.

If new elements are fairly random, the resulting tree is likely to be well balanced. However, if the incoming elements happen to be in sorted order already, then the resulting tree is completely unbalanced. Each new element is inserted at the end, and the entire tree must be traversed every time to find that end!

Binary search trees work well for random data, but if you suspect that the data in your application might be sorted or have long runs of sorted data, you should not use a binary search tree. There are more sophisticated tree structures whose methods keep trees balanced at all times. In these tree structures, one can guarantee that finding, adding, and removing elements takes $O(\log(n))$ time. The standard Java library uses *red-black trees*, a special form of balanced binary trees, to implement sets and maps.

ch16/tree/BinarySearchTree.java

```
/**
   This class implements a binary search tree whose
   nodes hold objects that implement the Comparable
   interface.
*/
public class BinarySearchTree
{
   private Node root;

   /**
      Constructs an empty tree.
   */
   public BinarySearchTree()
   {
      root = null;
   }

   /**
      Inserts a new node into the tree.
      @param obj the object to insert
   */
   public void add(Comparable obj)
   {
      Node newNode = new Node();
      newNode.data = obj;
      newNode.left = null;
      newNode.right = null;
      if (root == null) root = newNode;
      else root.addNode(newNode);
   }

   /**
      Tries to find an object in the tree.
      @param obj the object to find
      @return true if the object is contained in the tree
   */
   public boolean find(Comparable obj)
   {
      Node current = root;
      while (current != null)
      {
         int d = current.data.compareTo(obj);
         if (d == 0) return true;
         else if (d > 0) current = current.left;
         else current = current.right;
      }
      return false;
   }

   /**
      Tries to remove an object from the tree. Does nothing
      if the object is not contained in the tree.
      @param obj the object to remove
   */
   public void remove(Comparable obj)
   {
      // Find node to be removed

      Node toBeRemoved = root;
      Node parent = null;
      boolean found = false;
      while (!found && toBeRemoved != null)
      {
         int d = toBeRemoved.data.compareTo(obj);
         if (d == 0) found = true;
         else
         {
            parent = toBeRemoved;
            if (d > 0) toBeRemoved = toBeRemoved.left;
            else toBeRemoved = toBeRemoved.right;
         }
      }

      if (!found) return;

      // toBeRemoved contains obj

      // If one of the children is empty, use the other

      if (toBeRemoved.left == null || toBeRemoved.right == null)
      {
         Node newChild;
         if (toBeRemoved.left == null)
            newChild = toBeRemoved.right;
         else
            newChild = toBeRemoved.left;

         if (parent == null) // Found in root
            root = newChild;
         else if (parent.left == toBeRemoved)
            parent.left = newChild;
         else
            parent.right = newChild;
         return;
      }

      // Neither subtree is empty

      // Find smallest element of the right subtree

      Node smallestParent = toBeRemoved;
      Node smallest = toBeRemoved.right;
      while (smallest.left != null)
      {
         smallestParent = smallest;
         smallest = smallest.left;
      }

      // smallest contains smallest child in right subtree

      // Move contents, unlink child

      toBeRemoved.data = smallest.data;
      if (smallestParent == toBeRemoved)
         smallestParent.right = smallest.right;
      else
         smallestParent.left = smallest.right;
```

```
   }

   /**
      Prints the contents of the tree in sorted order.
   */
   public void print()
   {
      if (root != null)
         root.printNodes();
      System.out.println();
   }

   /**
      A node of a tree stores a data item and references
      to the child nodes to the left and to the right.
   */
   class Node
   {
      public Comparable data;
      public Node left;
      public Node right;

      /**
         Inserts a new node as a descendant of this node.
         @param newNode the node to insert
      */
      public void addNode(Node newNode)
      {
         int comp = newNode.data.compareTo(data);
         if (comp < 0)
         {
            if (left == null) left = newNode;
            else left.addNode(newNode);
         }
         if (comp > 0)
         {
            if (right == null) right = newNode;
            else right.addNode(newNode);
         }
      }

      /**
         Prints this node and all of its descendants
         in sorted order.
      */
      public void printNodes()
      {
         if (left != null)
            left.printNodes();
         System.out.print(data + " ");
         if (right != null)
            right.printNodes();
      }
   }
}
```

SELF CHECK

11. What is the difference between a tree, a binary tree, and a balanced binary tree?

12. Give an example of a string that, when inserted into the tree of Figure 10, becomes a right child of `Romeo`.

16.6 Binary Tree Traversal

Now that the data are inserted in the tree, what can you do with them? It turns out to be surprisingly simple to print all elements in sorted order. You *know* that all data in the left subtree of any node must come before the node and before all data in the right subtree. That is, the following algorithm will print the elements in sorted order:

1. Print the left subtree.
2. Print the data.
3. Print the right subtree.

Let's try this out with the tree in Figure 10 on page 689. The algorithm tells us to

1. Print the left subtree of `Juliet`; that is, `Diana` and descendants.
2. Print `Juliet`.
3. Print the right subtree of `Juliet`; that is, `Tom` and descendants.

How do you print the subtree starting at `Diana`?

1. Print the left subtree of `Diana`. There is nothing to print.
2. Print `Diana`.
3. Print the right subtree of `Diana`, that is, `Harry`.

That is, the left subtree of `Juliet` is printed as

```
Diana Harry
```

The right subtree of `Juliet` is the subtree starting at `Tom`. How is it printed? Again, using the same algorithm:

1. Print the left subtree of `Tom`, that is, `Romeo`.
2. Print `Tom`.
3. Print the right subtree of `Tom`. There is nothing to print.

Thus, the right subtree of `Juliet` is printed as

```
Romeo Tom
```

Now put it all together: the left subtree, `Juliet`, and the right subtree:

```
Diana Harry Juliet Romeo Tom
```

The tree is printed in sorted order.

Now we can implement the `print` method. You need a worker method `printNodes` of the `Node` class:

```
class Node
{
   . . .
   public void printNodes()
   {
      if (left != null)
         left.printNodes();
      System.out.print(data + " ");

      if (right != null)
         right.printNodes();
   }
   . . .
}
```

To print the entire tree, start this recursive printing process at the root, with the following method of the `BinarySearchTree` class.

```
public class BinarySearchTree
{
   . . .
   public void print()
   {
      if (root != null)
         root.printNodes();
      System.out.println();
   }
   . . .
}
```

To visit all elements in a tree, visit the root and recursively visit the subtrees. We distinguish between preorder, inorder, and postorder traversal.

This visitation scheme is called *inorder traversal* (visit the left subtree, the root, the right subtree). There are two other common traversal schemes, called *preorder traversal* and *postorder traversal*.

In preorder traversal,

- Visit the root,
- Visit the left subtree,
- Visit the right subtree.

In postorder traversal,

- Visit the left subtree,
- Visit the right subtree,
- Visit the root.

These two visitation schemes will not print the tree in sorted order. However, they are important in other applications of binary trees. Here is an example.

In Chapter 13, we presented an algorithm for parsing arithmetic expressions such as

```
(3 + 4) * 5
3 + 4 * 5
```

It is customary to draw these expressions in tree form—see Figure 14. If all operators have two arguments, then the resulting tree is a binary tree. Its leaves store numbers, and its interior nodes store operators.

Note that the expression trees describe the order in which the operators are applied.

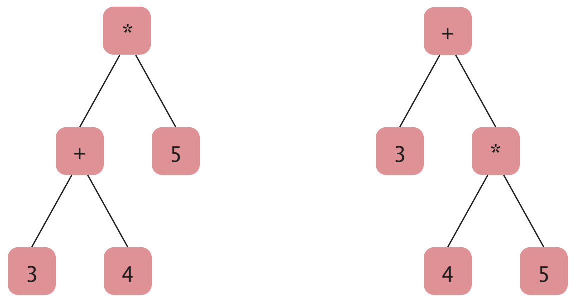


Figure 14 Expression Trees

This order becomes visible when applying the postorder traversal of the expression tree. The first tree yields

```
3 4 + 5 *
```

Postorder traversal of an expression tree yields the instructions for evaluating the expression on a stack-based calculator.

whereas the second tree yields

```
3 4 5 * +
```

You can interpret these sequences as expressions in "reverse Polish notation" (see Special Topic 15.1), or equivalently, instructions for a stack-based calculator (see Worked Example 15.1).

SELF CHECK

13. What are the inorder traversals of the two trees in Figure 14?

14. Are the trees in Figure 14 binary search trees?

16.7 Priority Queues

In Section 15.4, you encountered two common abstract data types: stacks and queues. Another important abstract data type, the **priority queue**, collects elements, each of which has a *priority*. A typical example of a priority queue is a collection of work requests, some of which may be more urgent than others. Unlike a regular queue, the priority queue does not maintain a first-in, first-out discipline. Instead, elements are retrieved according to their priority. In other words, new items can be inserted in any order. But whenever an item is removed, that item has highest priority.

When removing an element from a priority queue, the element with the highest priority is retrieved.

It is customary to give low values to high priorities, with priority 1 denoting the highest priority. The priority queue extracts the *minimum* element from the queue.

For example, consider this sample code:

```
PriorityQueue<WorkOrder> q = new PriorityQueue<WorkOrder>();
q.add(new WorkOrder(3, "Shampoo carpets"));
q.add(new WorkOrder(1, "Fix overflowing sink"));
q.add(new WorkOrder(2, "Order cleaning supplies"));
```

When calling `q.remove()` for the first time, the work order with priority 1 is removed. The next call to `q.remove()` removes the work order whose priority is highest among those remaining in the queue—in our example, the work order with priority 2.

The standard Java library supplies a `PriorityQueue` class that is ready for you to use. Later in this chapter, you will learn how to supply your own implementation.

Keep in mind that the priority queue is an *abstract* data type. You do not know how a priority queue organizes its elements. There are several concrete data structures that can be used to implement priority queues.

Of course, one implementation comes to mind immediately. Just store the elements in a linked list, adding new elements to the head of the list. The `remove` method then traverses the linked list and removes the element with the highest priority. In this implementation, adding elements is quick, but removing them is slow.

Another implementation strategy is to keep the elements in sorted order, for example in a binary search tree. Then it is an easy matter to locate and remove the largest element. However, another data structure, called a heap, is even more suitable for implementing priority queues.

16.8 Heaps

A heap is an almost completely filled tree in which the values of all nodes are at most as large as those of their descendants.

A **heap** (or, for greater clarity, *min-heap*) is a binary tree with two special properties.

1. A heap is *almost completely filled:* all nodes are filled in, except the last level may have some nodes missing toward the right (see Figure 15).
2. The tree fulfills the *heap property:* all nodes store values that are at most as large as the values stored in their descendants (see Figure 16).

It is easy to see that the heap property ensures that the smallest element is stored in the root.

A heap is superficially similar to a binary search tree, but there are two important differences.

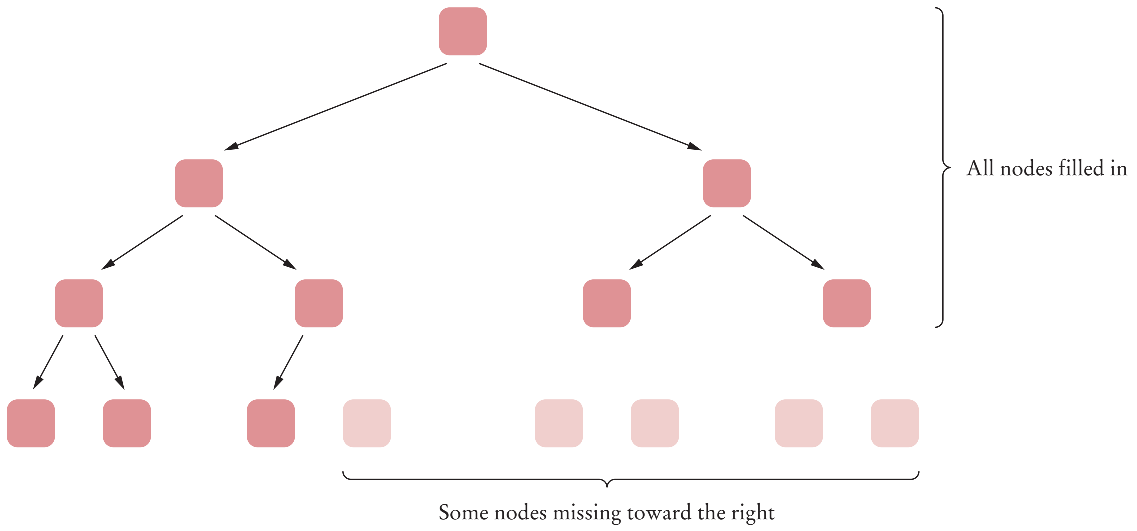
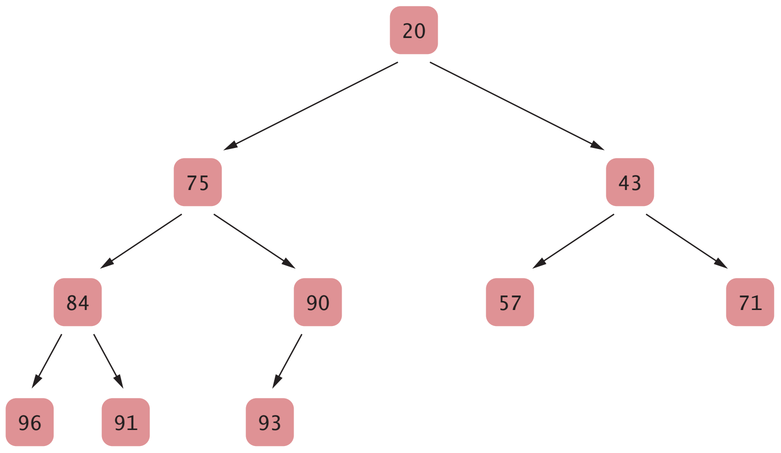


Figure 15 An Almost Completely Filled Tree

Figure 16
A Heap



1. The shape of a heap is very regular. Binary search trees can have arbitrary shapes.
2. In a heap, the left and right subtrees both store elements that are larger than the root element. In contrast, in a binary search tree, smaller elements are stored in the left subtree and larger elements are stored in the right subtree.

Suppose you have a heap and want to insert a new element. Afterwards, the heap property should again be fulfilled. The following algorithm carries out the insertion (see Figure 17).

1. First, add a vacant slot to the end of the tree.
2. Next, demote the parent of the empty slot if it is larger than the element to be inserted. That is, move the parent value into the vacant slot, and move the vacant slot up. Repeat this demotion as long as the parent of the vacant slot is larger than the element to be inserted. (See Figure 17 continued.)

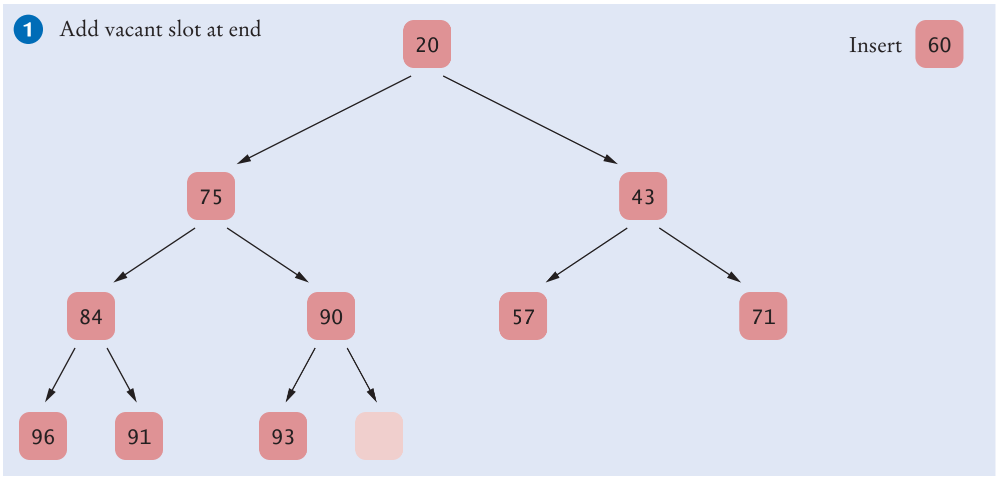


Figure 17 Inserting an Element into a Heap

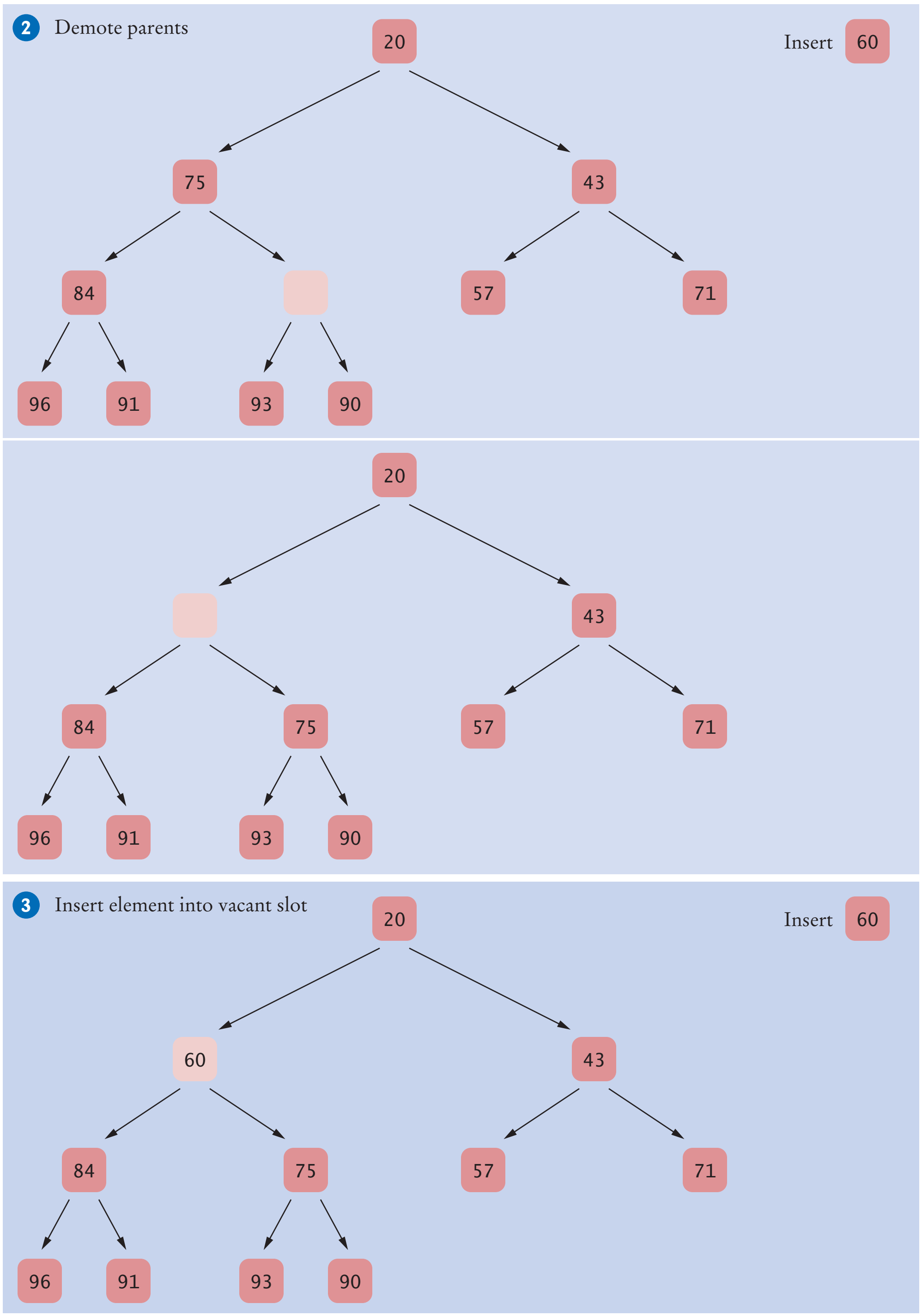


Figure 17 (continued) Inserting an Element into a Heap

3. At this point, either the vacant slot is at the root, or the parent of the vacant slot is smaller than the element to be inserted. Insert the element into the vacant slot.

We will not consider an algorithm for removing an arbitrary node from a heap. The only node that we will remove is the root node, which contains the minimum of all of the values in the heap. Figure 18 shows the algorithm in action.

1. Extract the root node value.
2. Move the value of the last node of the heap into the root node, and remove the last node. Now the heap property may be violated for the root node, because one or both of its children may be smaller.
3. Promote the smaller child of the root node. (See Figure 18 continued.) Now the root node again fulfills the heap property. Repeat this process with the demoted child. That is, promote the smaller of its children. Continue until the demoted child has no smaller children. The heap property is now fulfilled again. This process is called “fixing the heap”.

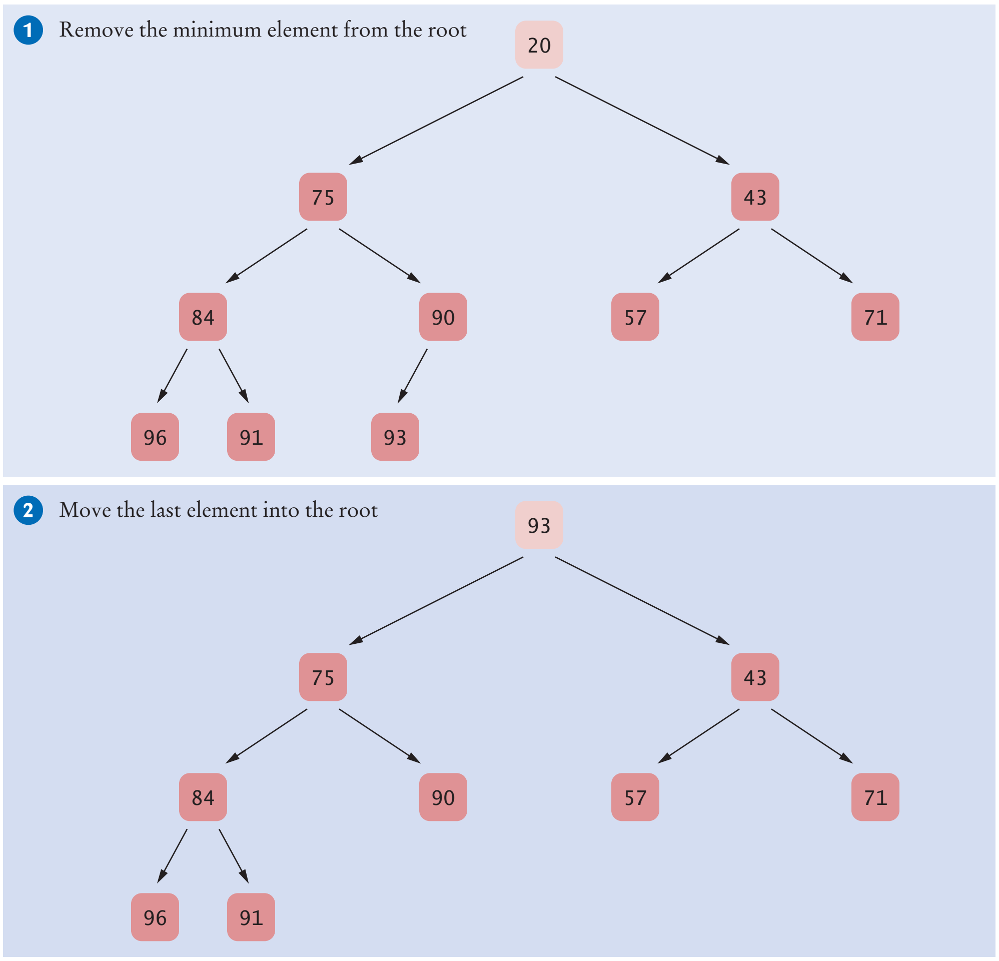

1 Remove the minimum element from the root
20
75
43
84
90
57
71
96
91
93
2 Move the last element into the root
93
75
43
84
90
57
71
96
91

Figure 18 Removing the Minimum Value from a Heap

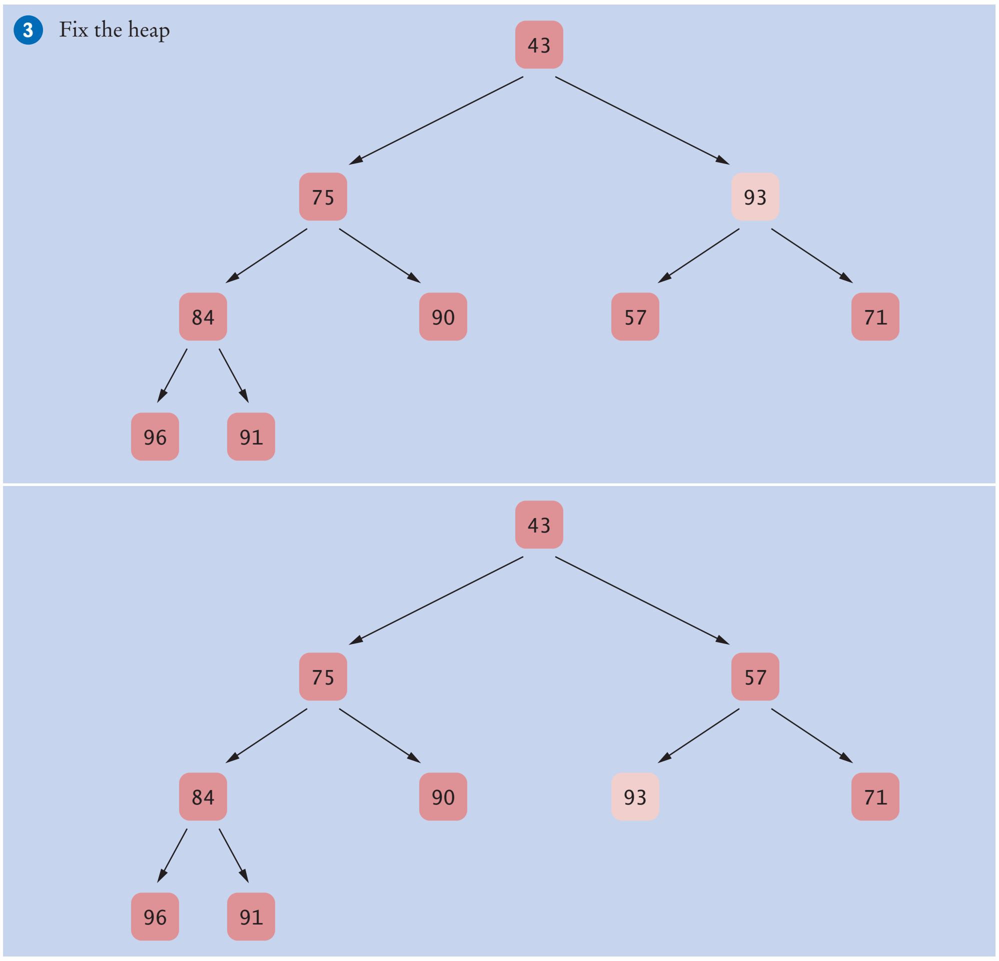


Figure 18 (continued) Removing the Minimum Value from a Heap

Inserting and removing heap elements is very efficient. The reason lies in the balanced shape of a heap. The insertion and removal operations visit at most h nodes, where h is the height of the tree. A heap of height h contains at least 2^{h-1} elements, but less than 2^h elements. In other words, if n is the number of elements, then

$$2^{h-1} \leq n < 2^h$$

or

$$h - 1 \leq \log_2(n) < h$$

Inserting or removing a heap element is an $O(\log(n))$ operation.

This argument shows that the insertion and removal operations in a heap with n elements take $O(\log(n))$ steps.

Contrast this finding with the situation of binary search trees. When a binary search tree is unbalanced, it can degenerate into a linked list, so that in the worst case insertion and removal are $O(n)$ operations.

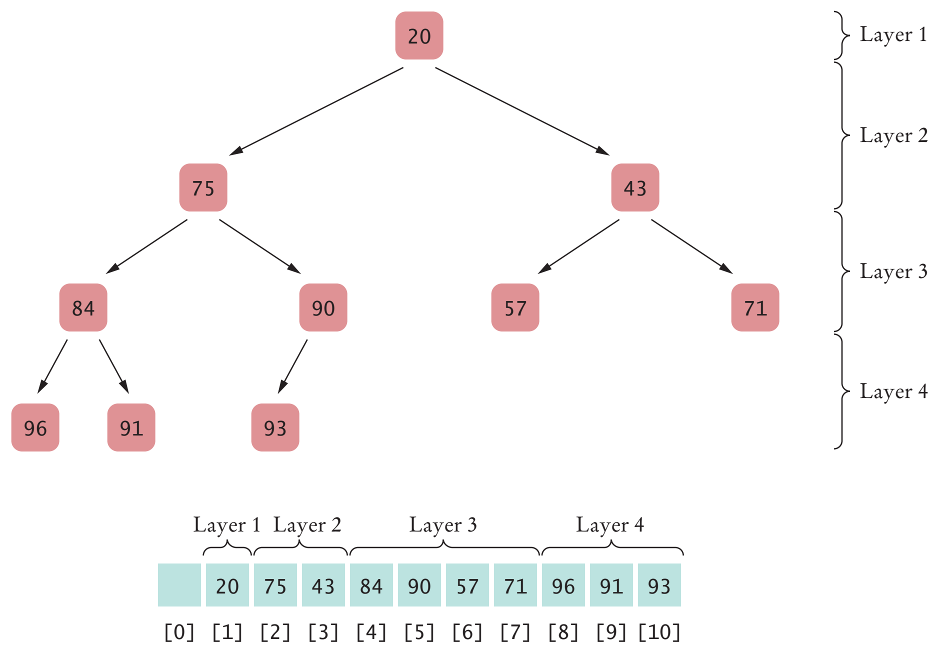


Figure 19 Storing a Heap in an Array

The regular layout of a heap makes it possible to store heap nodes efficiently in an array.

Heaps have another major advantage. Because of the regular layout of the heap nodes, it is easy to store the node values in an array or array list. First store the first layer, then the second, and so on (see Figure 19). For convenience, we leave the `0` element of the array empty. Then the child nodes of the node with index i have index $2 \cdot i$ and $2 \cdot i + 1$, and the parent node of the node with index i has index $i/2$. For example, as you can see in Figure 19, the children of node 4 are nodes 8 and 9, and the parent is node 2.

Storing the heap values in an array may not be intuitive, but it is very efficient. There is no need to allocate individual nodes or to store the links to the child nodes. Instead, child and parent positions can be determined by very simple computations.

The program at the end of this section contains an implementation of a heap. For greater clarity, the computation of the parent and child index positions is carried out in methods `getParentIndex`, `getLeftChildIndex`, and `getRightChildIndex`. For greater efficiency, the method calls could be avoided by using expressions `index / 2`, `2 * index`, and `2 * index + 1` directly.

In this section, we have organized our heaps such that the smallest element is stored in the root. It is also possible to store the largest element in the root, simply by reversing all comparisons in the heap-building algorithm. If there is a possibility of misunderstanding, it is best to refer to the data structures as min-heap or max-heap.

The test program demonstrates how to use a min-heap as a priority queue.

ch16/pqueue/MinHeap.java

```java
import java.util.*;

/**
   This class implements a heap.
*/
public class MinHeap
{
   private ArrayList<Comparable> elements;

   /**
      Constructs an empty heap.
   */
   public MinHeap()
   {
      elements = new ArrayList<Comparable>();
      elements.add(null);
   }

   /**
      Adds a new element to this heap.
      @param newElement the element to add
   */
   public void add(Comparable newElement)
   {
      // Add a new leaf
      elements.add(null);
      int index = elements.size() - 1;

      // Demote parents that are larger than the new element
      while (index > 1
            && getParent(index).compareTo(newElement) > 0)
      {
         elements.set(index, getParent(index));
         index = getParentIndex(index);
      }

      // Store the new element in the vacant slot
      elements.set(index, newElement);
   }

   /**
      Gets the minimum element stored in this heap.
      @return the minimum element
   */
   public Comparable peek()
   {
      return elements.get(1);
   }

   /**
      Removes the minimum element from this heap.
      @return the minimum element
   */
   public Comparable remove()
   {
      Comparable minimum = elements.get(1);

      // Remove last element
      int lastIndex = elements.size() - 1;
      Comparable last = elements.remove(lastIndex);

      if (lastIndex > 1)
      {
         elements.set(1, last);
         fixHeap();
      }

      return minimum;
   }

   /**
      Turns the tree back into a heap, provided only the root
      node violates the heap condition.
   */
   private void fixHeap()
   {
      Comparable root = elements.get(1);

      int lastIndex = elements.size() - 1;
      // Promote children of removed root while they are smaller than last

      int index = 1;
      boolean more = true;
      while (more)
      {
         int childIndex = getLeftChildIndex(index);
         if (childIndex <= lastIndex)
         {
            // Get smaller child

            // Get left child first
            Comparable child = getLeftChild(index);

            // Use right child instead if it is smaller
            if (getRightChildIndex(index) <= lastIndex
                  && getRightChild(index).compareTo(child) < 0)
            {
               childIndex = getRightChildIndex(index);
               child = getRightChild(index);
            }

            // Check if larger child is smaller than root
            if (child.compareTo(root) < 0)
            {
               // Promote child
               elements.set(index, child);
               index = childIndex;
            }
            else
            {
               // Root is smaller than both children
               more = false;
            }
         }
         else
         {
               // No children
               more = false;
            }
         }

         // Store root element in vacant slot
         elements.set(index, root);
      }

      /**
         Returns the number of elements in this heap.
      */
      public int size()
      {
         return elements.size() - 1;
      }

      /**
         Returns the index of the left child.
         @param index the index of a node in this heap
         @return the index of the left child of the given node
      */
      private static int getLeftChildIndex(int index)
      {
         return 2 * index;
      }

      /**
         Returns the index of the right child.
         @param index the index of a node in this heap
         @return the index of the right child of the given node
      */
      private static int getRightChildIndex(int index)
      {
         return 2 * index + 1;
      }

      /**
         Returns the index of the parent.
         @param index the index of a node in this heap
         @return the index of the parent of the given node
      */
      private static int getParentIndex(int index)
      {
         return index / 2;
      }

      /**
         Returns the value of the left child.
         @param index the index of a node in this heap
         @return the value of the left child of the given node
      */
      private Comparable getLeftChild(int index)
      {
         return elements.get(2 * index);
      }

```

```
   /**
      Returns the value of the right child.
      @param index the index of a node in this heap
      @return the value of the right child of the given node
   */
   private Comparable getRightChild(int index)
   {
      return elements.get(2 * index + 1);
   }

   /**
      Returns the value of the parent.
      @param index the index of a node in this heap
      @return the value of the parent of the given node
   */
   private Comparable getParent(int index)
   {
      return elements.get(index / 2);
   }
}
```

ch16/pqueue/WorkOrder.java

```
/**
   This class encapsulates a work order with a priority.
*/
public class WorkOrder implements Comparable
{
   private int priority;
   private String description;

   /**
      Constructs a work order with a given priority and description.
      @param aPriority the priority of this work order
      @param aDescription the description of this work order
   */
   public WorkOrder(int aPriority, String aDescription)
   {
      priority = aPriority;
      description = aDescription;
   }

   public String toString()
   {
      return "priority=" + priority + ", description=" + description;
   }

   public int compareTo(Object otherObject)
   {
      WorkOrder other = (WorkOrder) otherObject;
      if (priority < other.priority) return -1;
      if (priority > other.priority) return 1;
      return 0;
   }
}
```

ch16/pqueue/HeapDemo.java

```java
/**
   This program demonstrates the use of a heap as a priority queue.
*/
public class HeapDemo
{
   public static void main(String[] args)
   {
      MinHeap q = new MinHeap();
      q.add(new WorkOrder(3, "Shampoo carpets"));
      q.add(new WorkOrder(7, "Empty trash"));
      q.add(new WorkOrder(8, "Water plants"));
      q.add(new WorkOrder(10, "Remove pencil sharpener shavings"));
      q.add(new WorkOrder(6, "Replace light bulb"));
      q.add(new WorkOrder(1, "Fix broken sink"));
      q.add(new WorkOrder(9, "Clean coffee maker"));
      q.add(new WorkOrder(2, "Order cleaning supplies"));

      while (q.size() > 0)
         System.out.println(q.remove());
   }
}
```

Program Run

```
priority=1, description=Fix broken sink
priority=2, description=Order cleaning supplies
priority=3, description=Shampoo carpets
priority=6, description=Replace light bulb
priority=7, description=Empty trash
priority=8, description=Water plants
priority=9, description=Clean coffee maker
priority=10, description=Remove pencil sharpener shavings
```

SELF CHECK

15. The software that controls the events in a user interface keeps the events in a data structure. Whenever an event such as a mouse move or repaint request occurs, the event is added. Events are retrieved according to their importance. What abstract data type is appropriate for this application?

16. Could we store a binary search tree in an array so that we can quickly locate the children by looking at array locations `2 * index` and `2 * index + 1`?

16.9 The Heapsort Algorithm

The heapsort algorithm is based on inserting elements into a heap and removing them in sorted order.

Heapsort is an $O(n \log(n))$ algorithm.

Heaps are not only useful for implementing priority queues, they also give rise to an efficient sorting algorithm, heapsort. In its simplest form, the algorithm works as follows. First insert all elements to be sorted into the heap, then keep extracting the minimum.

This algorithm is an $O(n \log(n))$ algorithm: each insertion and removal is $O(\log(n))$, and these steps are repeated n times, once for each element in the sequence that is to be sorted.

The algorithm can be made a bit more efficient. Rather than inserting the elements one at a time, we will start with a sequence of values in an array. Of course, that array does not represent a heap. We will use the procedure of "fixing the heap" that you encountered in the preceding section as part of the element removal algorithm. "Fixing the heap" operates on a binary tree whose child trees are heaps but whose root value may not be smaller than the descendants. The procedure turns the tree into a heap, by repeatedly promoting the smallest child value, moving the root value to its proper location.

Of course, we cannot simply apply this procedure to the initial sequence of unsorted values—the child trees of the root are not likely to be heaps. But we can first fix small subtrees into heaps, then fix larger trees. Because trees of size 1 are automatically heaps, we can begin the fixing procedure with the subtrees whose roots are located in the next-to-last level of the tree.

The sorting algorithm uses a generalized `fixHeap` method that fixes a subtree:

```
void fixHeap(int rootIndex, int lastIndex)
```

The subtree is specified by the index of its root and of its last node.

The `fixHeap` method needs to be invoked on all subtrees whose roots are in the next-to-last level. Then the subtrees whose roots are in the next level above are fixed, and so on. Finally, the fixup is applied to the root node, and the tree is turned into a heap (see Figure 20).

That repetition can be programmed easily. Start with the *last* node on the next-to-lowest level and work toward the left. Then go to the next higher level. The node index values then simply run backwards from the index of the last node to the index of the root.

```
int n = a.length - 1;
for (int i = (n - 1) / 2; i >= 0; i--)
   fixHeap(i, n);
```

It can be shown that this procedure turns an arbitrary array into a heap in $O(n)$ steps.

Note that the loop ends with index `0`. When working with a given array, we don't have the luxury of skipping the `0` entry. We consider the `0` entry the root and adjust the formulas for computing the child and parent index values.

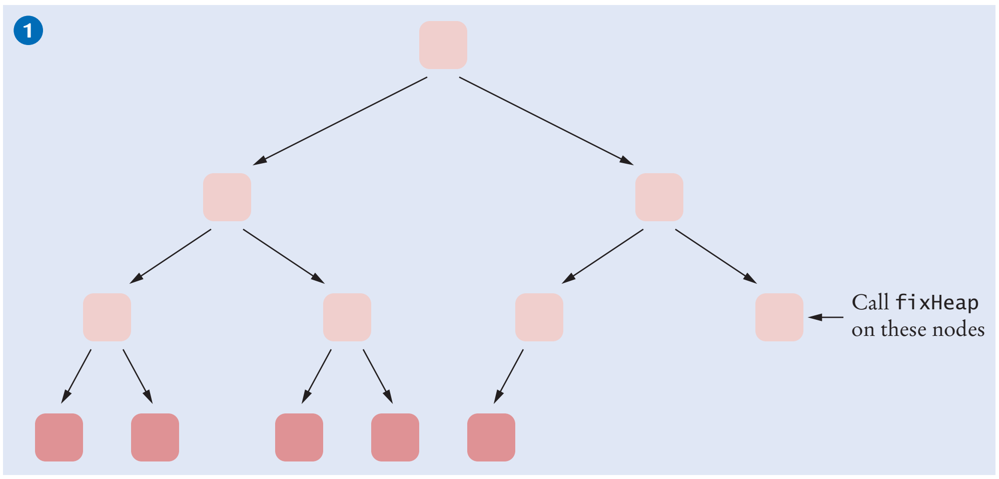


Figure 20 Turning a Tree into a Heap

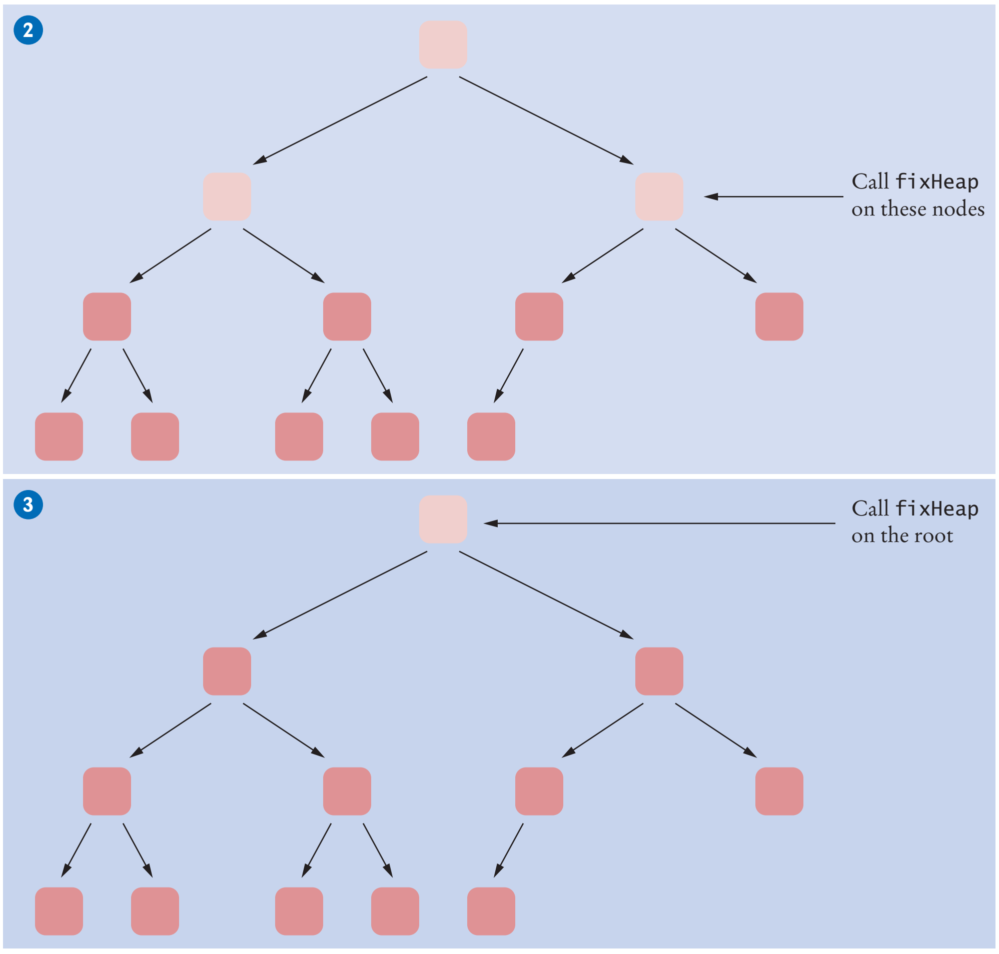


Figure 20 (continued) Turning a Tree into a Heap

After the array has been turned into a heap, we repeatedly remove the root element. Recall from the preceding section that removing the root element is achieved by placing the last element of the tree in the root and calling the `fixHeap` method. Because we call the $O(\log(n))$ `fixHeap` method n times, this process requires $O(n \log(n))$ steps.

Rather than moving the root element into a separate array, we can *swap* the root element with the last element of the tree and then reduce the tree length. Thus, the removed root ends up in the last position of the array, which is no longer needed by the heap. In this way, we can use the same array both to hold the heap (which gets shorter with each step) and the sorted sequence (which gets longer with each step).

```
while (n > 0)
{
   swap(0, n);
   n--;
   fixHeap(0, n);
}
```

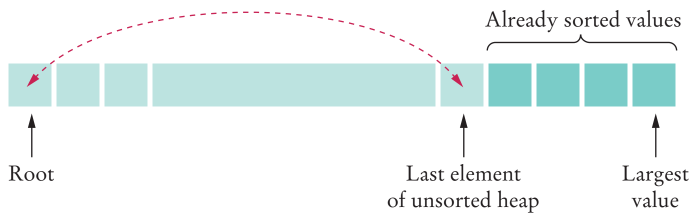


Figure 21 Using Heapsort to Sort an Array

There is just a minor inconvenience. When we use a min-heap, the sorted sequence is accumulated in reverse order, with the smallest element at the end of the array. We could reverse the sequence after sorting is complete. However, it is easier to use a max-heap rather than a min-heap in the heapsort algorithm. With this modification, the largest value is placed at the end of the array after the first step. After the next step, the next-largest value is swapped from the heap root to the second position from the end, and so on (see Figure 21).

The following class implements the heapsort algorithm.

ch16/heapsort/HeapSorter.java

```java
/**
   This class applies the heapsort algorithm to sort an array.
*/
public class HeapSorter
{
   private int[] a;

   /**
      Constructs a heap sorter that sorts a given array.
      @param anArray an array of integers
   */
   public HeapSorter(int[] anArray)
   {
      a = anArray;
   }

   /**
      Sorts the array managed by this heap sorter.
   */
   public void sort()
   {
      int n = a.length - 1;
      for (int i = (n - 1) / 2; i >= 0; i--)
         fixHeap(i, n);
      while (n > 0)
      {
         swap(0, n);
         n--;
         fixHeap(0, n);
      }
   }

   /**
      Ensures the heap property for a subtree, provided its
      children already fulfill the heap property.
      @param rootIndex the index of the subtree to be fixed
      @param lastIndex the last valid index of the tree that
      contains the subtree to be fixed
   */
   private void fixHeap(int rootIndex, int lastIndex)
   {
      // Remove root
      int rootValue = a[rootIndex];

      // Promote children while they are larger than the root

      int index = rootIndex;
      boolean more = true;
      while (more)
      {
         int childIndex = getLeftChildIndex(index);
         if (childIndex <= lastIndex)
         {
            // Use right child instead if it is larger
            int rightChildIndex = getRightChildIndex(index);
            if (rightChildIndex <= lastIndex
                  && a[rightChildIndex] > a[childIndex])
            {
               childIndex = rightChildIndex;
            }

            if (a[childIndex] > rootValue)
            {
               // Promote child
               a[index] = a[childIndex];
               index = childIndex;
            }
            else
            {
               // Root value is larger than both children
               more = false;
            }
         }
         else
         {
            // No children
            more = false;
         }
      }

      // Store root value in vacant slot
      a[index] = rootValue;
   }

   /**
      Swaps two entries of the array.
      @param i the first position to swap
      @param j the second position to swap
   */
   private void swap(int i, int j)
   {
         int temp = a[i];
         a[i] = a[j];
         a[j] = temp;
      }

      /**
         Returns the index of the left child.
         @param index the index of a node in this heap
         @return the index of the left child of the given node
      */
      private static int getLeftChildIndex(int index)
      {
         return 2 * index + 1;
      }

      /**
         Returns the index of the right child.
         @param index the index of a node in this heap
         @return the index of the right child of the given node
      */
      private static int getRightChildIndex(int index)
      {
         return 2 * index + 2;
      }
   }
```

SELF CHECK

17. Which algorithm requires less storage, heapsort or merge sort?

18. Why are the computations of the left child index and the right child index in the `HeapSorter` different than in `MinHeap`?

Random Fact 16.1

Software Piracy

As you read this, you have written a few computer programs, and you have experienced firsthand how much effort it takes to write even the humblest of programs. Writing a real software product, such as a financial application or a computer game, takes a lot of time and money. Few people, and fewer companies, are going to spend that kind of time and money if they don't have a reasonable chance to make more money from their effort. (Actually, some companies give away their software in the hope that users will upgrade to more elaborate paid versions. Other companies give away the software that enables users to read and use files but sell the software needed to create those files. Finally, there are individuals who donate their time, out of enthusiasm, and produce programs that you can copy freely.)

When selling software, a company must rely on the honesty of its customers. It is an easy matter for an unscrupulous person to make copies of computer programs without paying for them. In most countries that is illegal. Most governments provide legal protection, such as copyright laws and patents, to encourage the development of new products. Countries that tolerate widespread piracy have found that they have an ample cheap supply of foreign software, but no local manufacturers willing to design good software for their own citizens, such as word processors in the local script or financial programs adapted to the local tax laws.

When a mass market for software first appeared, vendors were enraged by the money they lost through piracy. They tried to fight back by various schemes to ensure that only the legitimate owner could use the software. Some manufacturers used *key disks:* disks with special patterns of holes burned in by a laser, which couldn't be copied. Others used *dongles:* devices that are attached to a printer port. Legitimate users hated these measures. They paid for the software, but they had to suffer through the inconvenience of inserting a key disk every time they started the software or having multiple dongles stick out from their computer. In the United States, market pressures forced most vendors to give up on these copy protection schemes, but they are still commonplace in other parts of the world.

Because it is so easy and inexpensive to pirate software, and the chance of being found out is minimal, you have to make a moral choice for yourself. If a package that you would really like to have is too expensive for your budget, do you steal it, or do you stay honest and get by with a more affordable product?

Of course, piracy is not limited to software. The same issues arise for other digital products as well. You may have had the opportunity to obtain copies of songs or movies without payment. Or you may have been frustrated by a copy protection device on your music player that made it difficult for you to listen to songs that you paid for. Admittedly, it can be difficult to have a lot of sympathy for a musical ensemble whose publisher charges a lot of money for what seems to have been very little effort on their part, at least when compared to the effort that goes into designing and implementing a software package. Nevertheless, it seems only fair that artists and authors receive some compensation for their efforts. How to pay artists, authors, and programmers fairly, without burdening honest customers, is an unsolved problem at the time of this writing, and many computer scientists are engaged in research in this area.

Summary of Learning Objectives

Describe the abstract set type and its implementations in the Java library.

- A set is an unordered collection of distinct elements. Elements can be added, located, and removed.
- Sets don't have duplicates. Adding a duplicate of an element that is already present is silently ignored.
- The `HashSet` and `TreeSet` classes both implement the `Set` interface.
- To visit all elements in a set, use an iterator.
- A set iterator visits elements in seemingly random order (`HashSet`) or sorted order (`TreeSet`).
- You cannot add an element to a set at an iterator position.

Describe the abstract map type and its implementations in the Java library.

- A map keeps associations between key and value objects.
- The `HashMap` and `TreeMap` classes both implement the `Map` interface.
- To find all keys and values in a map, iterate through the key set and find the values that correspond to the keys.

Explain the implementation of a hash table and its performance characteristics.

- A hash function computes an integer value from an object.
- A good hash function minimizes *collisions*—identical hash codes for different objects.

- A hash table can be implemented as an array of *buckets*—sequences of nodes that hold elements with the same hash code.
- If there are no or only a few collisions, then adding, locating, and removing hash table elements takes constant or $O(1)$ time.

Develop a `hashCode` method that is appropriate for a given class.

- When implementing the `hashCode` method, combine the hash codes for the instance variables.
- Your `hashCode` method must be compatible with the `equals` method.
- If a class provides neither `equals` nor `hashCode`, then objects are compared by identity.
- In a hash map, only the keys are hashed.

Explain the implementation of a binary search tree and its performance characteristics.

- A binary tree consists of nodes, each of which has at most two child nodes.
- All nodes in a binary search tree fulfill the property that the descendants to the left have smaller data values than the node data value, and the descendants to the right have larger data values.
- To insert a value into a binary search tree, keep comparing the value with the node data and follow the nodes to the left or right, until reaching a `null` node.
- When removing a node with only one child from a binary search tree, the child replaces the node to be removed.
- When removing a node with two children from a binary search tree, replace it with the smallest node of the right subtree.
- In a balanced tree, all paths from the root to the leaves have about the same length.
- Adding, finding, and removing an element in a tree set is proportional to the height of the tree.
- If a binary search tree is balanced, then adding, locating, or removing an element takes $O(\log(n))$ time.

Describe preorder, inorder, and postorder tree traversal.

- To visit all elements in a tree, visit the root and recursively visit the subtrees. We distinguish between preorder, inorder, and postorder traversal.
- Postorder traversal of an expression tree yields the instructions for evaluating the expression on a stack-based calculator.

Describe the behavior of the priority queue data type.

- When removing an element from a priority queue, the element with the highest priority is retrieved.

Describe the heap data structure and the efficiency of its operations.

- A heap is an almost completely filled tree in which the values of all nodes are at most as large as those of their descendants.
- Inserting or removing a heap element is an $O(\log(n))$ operation.
- The regular layout of a heap makes it possible to store heap nodes efficiently in an array.

Describe the heapsort algorithm and its run-time performance.

- The heapsort algorithm is based on inserting elements into a heap and removing them in sorted order.
- Heapsort is an $O(n \log(n))$ algorithm.

Classes, Objects, and Methods Introduced in this Chapter

`java.util.Collection<E>`
  `contains`
  `remove`
  `size`
`java.util.HashMap<K, V>`
`java.util.HashSet<K, V>`
`java.util.Map<K, V>`
  `get`
  `keySet`
  `put`
  `remove`
`java.util.PriorityQueue<E>`
  `remove`
`java.util.Set<E>`
`java.util.TreeMap<K, V>`
`java.util.TreeSet<K, V>`

Media Resources

www.wiley.com/college/horstmann

- ***Worked Example*** Word Frequency
- Lab Exercises
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★ **R16.1** What is the difference between a set and a map?

★ **R16.2** What implementations does the Java library provide for the abstract set type?

★★ **R16.3** What are the fundamental operations on the abstract set type? What additional methods does the `Set` interface provide? (Look up the interface in the API documentation.)

★★ **R16.4** The union of two sets *A* and *B* is the set of all elements that are contained in *A*, *B*, or both. The intersection is the set of all elements that are contained in *A* and *B*. How can you compute the union and intersection of two sets, using the four fundamental set operations described on page 666?

★★ **R16.5** How can you compute the union and intersection of two sets, using some of the methods that the `java.util.Set` interface provides? (Look up the interface in the API documentation.)

★ **R16.6** Can a map have two keys with the same value? Two values with the same key?

★ **R16.7** A map can be implemented as a set of (*key*, *value*) pairs. Explain.

★★ **R16.8** When implementing a map as a hash set of (*key*, *value*) pairs, how is the hash code of a pair computed?

★ **R16.9** Verify the hash codes of the strings `"Jim"` and `"Joe"` in Table 1.

★ **R16.10** From the hash codes in Table 1, show that Figure 6 accurately shows the locations of the strings if the hash table size is 101.

★ **R16.11** What is the difference between a binary tree and a binary search tree? Give examples of each.

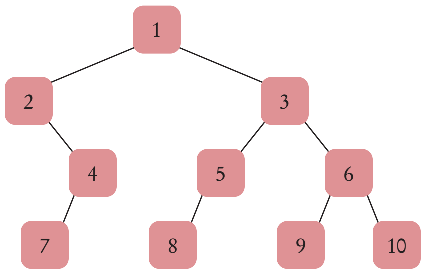
★ **R16.12** What is the difference between a balanced tree and an unbalanced tree? Give examples of each.

★ **R16.13** The following elements are inserted into a binary search tree. Make a drawing that shows the resulting tree after each insertion.

```
Adam
Eve
Romeo
Juliet
Tom
Diana
Harry
```

★★ **R16.14** Insert the elements of Exercise R16.13 in opposite order. Then determine how the `BinarySearchTree.print` method prints out both the tree from Exercise R16.13 and this tree. Explain how the printouts are related.

★★ **R16.15** Consider the following tree. In which order are the nodes printed by the `BinarySearchTree.print` method? The numbers identify the nodes. The data stored in the nodes is not shown.



★★ **R16.16** Could a priority queue be implemented efficiently as a binary search tree? Give a detailed argument for your answer.

★★★ **R16.17** Will preorder, inorder, or postorder traversal print a heap in sorted order? Why or why not?

★★★ **R16.18** Prove that a heap of height h contains at least 2^{h-1} elements but less than 2^h elements.

★★★ **R16.19** Suppose the heap nodes are stored in an array, starting with index 1. Prove that the child nodes of the heap node with index i have index $2 \cdot i$ and $2 \cdot i + 1$, and the parent heap node of the node with index i has index $\lfloor i/2 \rfloor$.

★★ **R16.20** Simulate the heapsort algorithm manually to sort the array

```
11 27 8 14 45 6 24 81 29 33
```

Show all steps.

Programming Exercises

★ **P16.1** Write a program that reads text from `System.in` and breaks it up into individual words. Insert the words into a tree set. At the end of the input file, print all words, followed by the size of the resulting set. This program determines how many unique words a text file has.

★ **P16.2** Insert the 13 standard colors that the `Color` class declares (that is, `Color.PINK`, `Color.GREEN`, and so on) into a set. Prompt the user to enter a color by specifying red, green, and blue integer values between `0` and 255. Then tell the user whether the resulting color is in the set.

★★ **P16.3** Implement the *sieve of Eratosthenes:* a method for computing prime numbers, known to the ancient Greeks. Choose an n. This method will compute all prime numbers up to n. First insert all numbers from 2 to n into a set. Then erase all multiples of 2 (except 2); that is, 4, 6, 8, 10, 12, ... Erase all multiples of 3; that is, 6, 9, 12, 15, ... Go up to $\sqrt{n}$. Then print the set.

★ **P16.4** Insert all words from a large file (such as the novel "War and Peace", which is available on the Internet) into a hash set and a tree set. Time the results. Which data structure is faster?

★★★ **P16.5** Write a program that reads a Java source file and produces an index of all identifiers in the file. For each identifier, print all lines in which it occurs.
Hint: Call `in.useDelimiter("[^A-Za-z0-9_]+")`. Then each call to `next` returns a string consisting only of letters, numbers, and underscores.

★★ **P16.6** Try to find two words with the same hash code in a large file, such as the `/usr/share/dict/words` file on a Linux system. Keep a `Map<Integer, HashSet<String>>`. When you read in a word, compute its hash code h and put the word in the set whose key is h. Then iterate through all keys and print the sets whose size is > 1.

★★ **P16.7** Write a program that keeps a map in which both keys and values are strings—the names of students and their course grades. Prompt the user of the program to add or remove students, to modify grades, or to print all grades. The printout should be sorted by name and formatted like this:

```
Carl: B+
Joe: C
Sarah: A
```

★★★ **P16.8** Reimplement Exercise P16.7 so that the keys of the map are objects of class `Student`. A student should have a first name, a last name, and a unique integer ID. For grade changes and removals, lookup should be by ID. The printout should be sorted by last name. If two students have the same last name, then use the first name as tie breaker. If the first names are also identical, then use the integer ID. *Hint:* Use two maps.

★★★ **P16.9** Add a `debug` method to the `HashSet` implementation in Section 16.4 that prints the nonempty buckets of the hash table. Run the test program at the end of Section 16.4. Call the `debug` method after all additions and removals and verify that Figure 6 accurately represents the state of the hash table.

★★ **P16.10** Supply compatible `hashCode` and `equals` methods to the `Student` class described in Exercise P16.8. Test the hash code by adding `Student` objects to a hash set.

★ **P16.11** Supply compatible `hashCode` and `equals` methods to the `BankAccount` class of Chapter 7. Test the `hashCode` method by printing out hash codes and by adding `BankAccount` objects to a hash set.

★ **P16.12** A labeled point has *x*- and *y*-coordinates and a string label. Provide a class `LabeledPoint` with a constructor `LabeledPoint(int x, int y, String label)` and `hashCode` and `equals` methods. Two labeled points are considered the same when they have the same location and label.

★ **P16.13** Reimplement the `LabeledPoint` class of Exercise P16.12 by storing the location in a `java.awt.Point` object. Your `hashCode` and `equals` methods should call the `hashCode` and `equals` methods of the `Point` class.

★ **P16.14** Modify the `LabeledPoint` class of Exercise P16.13 so that it implements the `Comparable` interface. Sort points first by their *x*-coordinates. If two points have the same *x*-coordinate, sort them by their *y*-coordinates. If two points have the same *x*- and *y*-coordinates, sort them by their label. Write a tester program that checks all cases.

★★ **P16.15** Design a data structure `IntSet` that can hold a set of integers. Hide the private implementation: a binary search tree of `Integer` objects. Provide the following methods:

- A constructor to make an empty set
- `void add(int x)` to add `x` if it is not present
- `void remove(int x)` to remove `x` if it is present
- `void print()` to print all elements currently in the set
- `boolean contains(int x)` to test whether `x` is present

★★ **P16.16** Reimplement the set class from Exercise P16.15 by using a `TreeSet<Integer>`. In addition to the methods specified in Exercise P16.15, supply an `iterator` method yielding an object that supports *only* the `hasNext`/`next` methods.

The `next` method should return an `int`, not an object. For that reason, you cannot simply return the iterator of the tree set.

★ **P16.17** Reimplement the set class from Exercise P16.15 by using a `TreeSet<Integer>`. In addition to the methods specified in Exercise P16.15, supply methods

```
IntSet union(IntSet other)
IntSet intersection(IntSet other)
```

that compute the union and intersection of two sets.

★ **P16.18** Write a method of the `BinarySearchTree` class

```
Comparable smallest()
```

that returns the smallest element of a tree. You will also need to add a method to the `Node` class.

★★★ **P16.19** Change the `BinarySearchTree.print` method to print the tree as a tree shape. You can print the tree sideways. Extra credit if you instead display the tree with the root node centered on the top.

★ **P16.20** Implement methods that use preorder and postorder traversal to print the elements in a binary search tree.

★★★ **P16.21** In the `BinarySearchTree` class, modify the `remove` method so that a node with two children is replaced by the largest child of the left subtree.

★★ **P16.22** Suppose an interface `Visitor` has a single method

```
void visit(Object obj)
```

Supply methods

```
void inOrder(Visitor v)
void preOrder(Visitor v)
void postOrder(Visitor v)
```

to the `BinarySearchTree` class. These methods should visit the tree nodes in the specified traversal order and apply the `visit` method to the data of the visited node.

★★ **P16.23** Apply Exercise P16.22 to compute the average value of the elements in a binary search tree filled with `Integer` objects. That is, supply an object of an appropriate class that implements the `Visitor` interface.

★★ **P16.24** Modify the implementation of the `MinHeap` class so that the parent and child index positions and elements are computed directly, without calling helper methods.

★★★ **P16.25** Modify the implementation of the `MinHeap` class so that the `0` element of the array is not wasted.

★ **P16.26** Time the results of heapsort and merge sort. Which algorithm behaves better in practice?

Programming Projects

Project 16.1 Implement a `BinaryTreeSet` class that uses a `TreeSet` to store its elements. You will need to implement an iterator that iterates through the nodes in sorted order. This iterator is somewhat complex, because sometimes you need to backtrack. You can either add a reference to the parent node in each `Node` object, or have your iterator object store a stack of the visited nodes.

Project 16.2 Implement an expression evaluator that uses a parser to build an expression tree, such as in Section 16.7. (Note that the resulting tree is a binary tree but not a binary search tree.) Then use postorder traversal to evaluate the expression, using a stack for the intermediate results.

Project 16.3 Program an animation of the heapsort algorithm, displaying the tree graphically and stopping after each call to `fixHeap`.

Answers to Self-Check Questions

1. Efficient set implementations can quickly test whether a given element is a member of the set.
2. Sets do not have an ordering, so it doesn't make sense to add an element at a particular iterator position, or to traverse a set backwards.
3. The words would be listed in sorted order.
4. When it is desirable to visit the set elements in sorted order.
5. A set stores elements. A map stores associations between keys and values.

6. The ordering does not matter, and you cannot have duplicates.
7. Yes, the hash set will work correctly. All elements will be inserted into a single bucket.
8. It locates the next bucket in the bucket array and points to its first element.
9. $31 \times 116 + 111 = 3707$.
10. 13.
11. In a tree, each node can have any number of children. In a binary tree, a node has at most two children. In a balanced binary tree, all nodes have approximately as many descendants to the left as to the right.
12. For example, `Sarah`. Any string between `Romeo` and `Tom` will do.
13. For both trees, the inorder traversal is `3 + 4 * 5`.
14. No—for example, consider the children of `+`. Even without looking up the Unicode codes for `3`, `4`, and `+`, it is obvious that `+` isn't between `3` and `4`.
15. A priority queue is appropriate because we want to get the important events first, even if they have been inserted later.
16. Yes, but a binary search tree isn't almost filled, so there may be holes in the array. We could indicate the missing nodes with `null` elements.
17. Heapsort requires less storage because it doesn't need an auxiliary array.
18. The `MinHeap` wastes the `0` entry to make the formulas more intuitive. When sorting an array, we don't want to waste the `0` entry, so we adjust the formulas instead.

Chapter 17

Generic Programming

CHAPTER GOALS

- To understand the objective of generic programming
- To be able to implement generic classes and methods
- To understand the execution of generic methods in the virtual machine
- To know the limitations of generic programming in Java

Generic programming involves the design and implementation of data structures and algorithms that work for multiple types. You are already familiar with the generic `ArrayList` class that can be used to collect elements of arbitrary types. In this chapter, you will learn how to implement your own generic classes.

CHAPTER CONTENTS

17.1 Generic Classes and Type Parameters 724

17.2 Implementing Generic Types 725

SYNTAX 17.1: Declaring a Generic Class 727

17.3 Generic Methods 728

SYNTAX 17.2: Declaring a Generic Method 729

17.4 Constraining Type Parameters 730

COMMON ERROR 17.1: Genericity and Inheritance 731

SPECIAL TOPIC 17.1: Wildcard Types 731

17.5 Type Erasure 732

COMMON ERROR 17.2: Using Generic Types in a Static Context 735

17.1 Generic Classes and Type Parameters

Generic programming is the creation of programming constructs that can be used with many different types. For example, the Java library programmers who implemented the `ArrayList` class used the technique of generic programming. As a result, you can form array lists that collect elements of different types, such as `ArrayList<String>`, `ArrayList<BankAccount>`, and so on.

In Java, generic programming can be achieved with inheritance or with type parameters.

The `LinkedList` class that we implemented in Section 15.2 is also an example of generic programming—you can store objects of any class inside a `LinkedList`. That `LinkedList` class achieves genericity by using *inheritance.* It uses references of type `Object` and is therefore capable of storing objects of any class. In contrast, the `ArrayList` class is a *generic class:* a class with a **type parameter** that is used to specify the type of the objects that you want to store. (Note that only our `LinkedList` implementation of Chapter 15 uses inheritance. The standard Java library has a generic `LinkedList` class that uses type parameters.)

A generic class has one or more type parameters.

When declaring a generic class, you specify a type variable for each type parameter. Here is how the standard Java library declares the `ArrayList` class, using the type variable `E` for the element type:

```
public class ArrayList<E>
{
   public ArrayList() { . . . }
   public void add(E element) { . . . }
   . . .
}
```

Here, `E` is a type variable, not a Java reserved word. You could use another name, such as `ElementType`, instead of `E`. However, it is customary to use short, uppercase names for type parameters.

Type parameters can be instantiated with class or interface types.

In order to use a generic class, you need to *instantiate* the type parameter, that is, supply an actual type. You can supply any class or interface type, for example

```
ArrayList<BankAccount>
ArrayList<Measurable>
```

However, you cannot substitute any of the eight primitive types for a type parameter. It would be an error to declare an `ArrayList<double>`. Use the corresponding wrapper class instead, such as `ArrayList<Double>`.

When you instantiate a generic class, the type that you supply replaces all occurrences of the type variable in the declaration of the class. For example, the `add` method for ArrayList<BankAccount> has the type variable E replaced with the type BankAccount:

```
public void add(BankAccount element)
```

Contrast that with the add method of the LinkedList class in Chapter 15:

```
public void add(Object element)
```

The add method of the generic ArrayList class is safer. It is impossible to add a String object into an ArrayList<BankAccount>, but you can accidentally add a String into a LinkedList that is intended to hold bank accounts.

```
ArrayList<BankAccount> accounts1 = new ArrayList<BankAccount>();
LinkedList accounts2 = new LinkedList(); // Should hold BankAccount objects
accounts1.add("my savings"); // Compile-time error
accounts2.add("my savings"); // Not detected at compile time
```

The latter will result in a class cast exception when some other part of the code retrieves the string, believing it to be a bank account:

```
BankAccount account = (BankAccount) accounts2.getFirst(); // Run-time error
```

Type parameters make generic code safer and easier to read.

Code that uses the generic ArrayList class is also easier to read. When you spot an ArrayList<BankAccount>, you know right away that it must contain bank accounts. When you see a LinkedList, you have to study the code to find out what it contains.

In Chapters 15 and 16, we used inheritance to implement generic linked lists, hash tables, and binary trees, because you were already familiar with the concept of inheritance. Using type parameters requires new syntax and additional techniques—those are the topic of this chapter.

SELF CHECK

1. The standard library provides a class HashMap<K, V> with key type K and value type V. Declare a hash map that maps strings to integers.
2. The binary search tree class in Chapter 16 is an example of generic programming because you can use it with any classes that implement the Comparable interface. Does it achieve genericity through inheritance or type parameters?

17.2 Implementing Generic Types

In this section, you will learn how to implement your own generic classes. We will write a very simple generic class that stores *pairs* of objects, each of which can have an arbitrary type. For example,

```
Pair<String, Integer> result = new Pair<String, Integer>("Harry Morgan", 1729);
```

The getFirst and getSecond methods retrieve the first and second values of the pair.

```
String name = result.getFirst();
Integer number = result.getSecond();
```

This class can be useful when you implement a method that computes two values at the same time. A method cannot simultaneously return a String and an Integer, but it can return a single object of type Pair<String, Integer>.

The generic Pair class requires two type parameters, one for the type of the first element and one for the type of the second element.

We need to choose variables for the type parameters. It is considered good form to use short uppercase names for type variables, such as those in the following table:

Type Variable	Meaning
E	Element type in a collection
K	Key type in a map
V	Value type in a map
T	General type
S, U	Additional general types

Type variables of a generic class follow the class name and are enclosed in angle brackets.

You place the type variables for a generic class after the class name, enclosed in angle brackets (< and >):

```
public class Pair<T, S>
```

When you declare the instance variables and methods of the Pair class, use the variable T for the first element type and S for the second element type:

```
public class Pair<T, S>
{
   private T first;
   private S second;

   public Pair(T firstElement, S secondElement)
   {
      first = firstElement;
      second = secondElement;
   }
   public T getFirst() { return first; }
   public S getSecond() { return second; }
}
```

Use type parameters for the types of generic instance variables, method parameters, and return values.

Some people find it simpler to start out with a regular class, choosing some actual types instead of the type parameters. For example,

```
public class Pair // Here we start out with a pair of String and Integer values
{
   private String first;
   private Integer second;

   public Pair(String firstElement, Integer secondElement)
   {
      first = firstElement;
      second = secondElement;
   }
   public String getFirst() { return first; }
   public Integer getSecond() { return second; }
}
```

Now it is an easy matter to replace all String types with the type variable S and all Integer types with the type variable T.

This completes the declaration of the generic Pair class. It is ready to use whenever you need to form a pair of two objects of arbitrary types. The following sample program shows how to make use of a Pair for returning two values from a method.

Syntax 17.1 Declaring a Generic Class

Syntax

```
accessSpecifier class GenericClassName<TypeVariable1, TypeVariable2, . . .>
{
   instance variables
   constructors
   methods
}
```

Example

```
public class Pair<T, S>
{
   private T first;
   private S second;
   . . .
   public T getFirst() { return first; }
   . . .
}
```

Supply a variable for each type parameter.

Instance variables with a variable data type

A method with a variable return type

ch17/pair/Pair.java

```
/**
   This class collects a pair of elements of different types.
*/
public class Pair<T, S>
{
   private T first;
   private S second;

   /**
      Constructs a pair containing two given elements.
      @param firstElement the first element
      @param secondElement the second element
   */
   public Pair(T firstElement, S secondElement)
   {
      first = firstElement;
      second = secondElement;
   }

   /**
      Gets the first element of this pair.
      @return the first element
   */
   public T getFirst() { return first; }

   /**
      Gets the second element of this pair.
      @return the second element
   */
   public S getSecond() { return second; }

   public String toString() { return "(" + first + ", " + second + ")"; }
}
```

ch17/pair/PairDemo.java

```java
public class PairDemo
{
   public static void main(String[] args)
   {
      String[] names = { "Tom", "Diana", "Harry" };
      Pair<String, Integer> result = firstContaining(names, "a");
      System.out.println(result.getFirst());
      System.out.println("Expected: Diana");
      System.out.println(result.getSecond());
      System.out.println("Expected: 1");
   }

   /**
      Gets the first String containing a given string, together
      with its index.
      @param strings an array of strings
      @param sub a string
      @return a pair (strings[i], i) where strings[i] is the first
      strings[i] containing str, or a pair (null, -1) if there is no
      match.
   */
   public static Pair<String, Integer> firstContaining(
      String[] strings, String sub)
   {
      for (int i = 0; i < strings.length; i++)
      {
         if (strings[i].contains(sub))
         {
            return new Pair<String, Integer>(strings[i], i);
         }
      }
      return new Pair<String, Integer>(null, -1);
   }
}
```

Program Run

```
Diana
Expected: Diana
1
Expected: 1
```

SELF CHECK

3. How would you use the generic `Pair` class to construct a pair of strings `"Hello"` and `"World"`?
4. What is the difference between an `ArrayList<Pair<String, Integer>>` and a `Pair<ArrayList<String>, Integer>`?

17.3 Generic Methods

A generic method is a method with a type parameter.

A generic method is a method with a type parameter. Such a method can occur in a class that in itself is not generic. You can think of it as a template for a set of methods that differ only by one or more types. For example, we may want to declare a method that can print an array of any type:

```
public class ArrayUtil
{
   /**
      Prints all elements in an array.
      @param a  the array to print
   */
   public <T> static void print(T[] a)
   {
      . . .
   }
   . . .
}
```

As described in the previous section, it is often easier to see how to implement a generic method by starting with a concrete example. This method prints the elements in an array of *strings*.

```
public class ArrayUtil
{
   public static void print(String[] a)
   {
      for (String e : a)
         System.out.print(e + " ");
      System.out.println();
   }
   . . .
}
```

Supply the type parameters of a generic method between the modifiers and the method return type.

In order to make the method into a generic method, replace `String` with a type parameter, say `E`, to denote the element type of the array. Add a type parameter list, enclosed in angle brackets, between the modifiers (`public static`) and the return type (`void`):

```
public static <E> void print(E[] a)
{
   for (E e : a)
      System.out.print(e + " ");
   System.out.println();
}
```

Syntax 17.2 Declaring a Generic Method

Syntax *modifiers* <*TypeVariable*$_1$, *TypeVariable*$_2$, . . .> *returnType* *methodName*(*parameters*)
{
   body
}

Example

Supply the type variable before the return type.

```
public static <E> void print(E[] a)
{
   for (E e : a)
      System.out.print(e + " ");
   System.out.println();
}
```

Local variable with a variable data type

When you call the generic method, you need not specify which type to use for the type parameter. (In this regard, generic methods differ from generic classes.) Simply call the method with appropriate parameters, and the compiler will match up the type parameters with the parameter types. For example, consider this method call:

```
Rectangle[] rectangles = . . .;
ArrayUtil.print(rectangles);
```

When calling a generic method, you need not instantiate the type parameters.

The type of the `rectangles` parameter is `Rectangle[]`, and the type of the parameter variable is `E[]`. The compiler deduces that `E` is `Rectangle`.

This particular generic method is a static method in an ordinary class. You can also declare generic methods that are not static. You can even have generic methods in generic classes.

As with generic classes, you cannot replace type parameters with primitive types. The generic `print` method can print arrays of any type *except* the eight primitive types. For example, you cannot use the generic `print` method to print an array of type `int[]`. That is not a major problem. Simply implement a `print(int[] a)` method in addition to the generic `print` method.

SELF CHECK

5. Exactly what does the generic `print` method print when you pass an array of `BankAccount` objects containing two bank accounts with zero balances?
6. Is the `getFirst` method of the `Pair` class a generic method?

17.4 Constraining Type Parameters

Type parameters can be constrained with bounds.

It is often necessary to specify what types can be used in a generic class or method. Consider a generic `min` method that finds the smallest element in an array list of objects. How can you find the smallest element when you know nothing about the element type? You need to have a mechanism for comparing array elements. One solution is to require that the elements belong to a type that implements the `Comparable` interface. In this situation, we need to *constrain* the type parameter.

```
public static <E extends Comparable> E min(E[] a)
{
   E smallest = a[0];
   for (int i = 1; i < a.length; i++)
      if (a[i].compareTo(smallest) < 0) smallest = a[i];
   return smallest;
}
```

You can call `min` with a `String[]` array but not with a `Rectangle[]` array—the `String` class implements `Comparable`, but `Rectangle` does not.

The `Comparable` bound is necessary for calling the `compareTo` method. Had it been omitted, then the `min` method would not have compiled. It would have been illegal to call `compareTo` on `a[i]` if nothing is known about its type. (Actually, the `Comparable` interface is itself a generic type, but for simplicity we do not supply a type parameter. See Special Topic 17.1 on page 731 for more information.)

Very occasionally, you need to supply two or more type bounds. Then you separate them with the `&` character, for example

```
<E extends Comparable & Cloneable>
```

The `extends` reserved word, when applied to type parameters, actually means "extends or implements". The bounds can be either classes or interfaces, and the type parameter can be replaced with a class or interface type.

SELF CHECK

7. How would you constrain the type parameter for a generic `BinarySearchTree` class?
8. Modify the `min` method to compute the minimum of an array of elements that implements the `Measurable` interface of Chapter 9.

Common Error 17.1

Genericity and Inheritance

If `SavingsAccount` is a subclass of `BankAccount`, is `ArrayList<SavingsAccount>` a subclass of `ArrayList<BankAccount>`? Perhaps surprisingly, it is not. Inheritance of type parameters does not lead to inheritance of generic classes. There is no relationship between `ArrayList<SavingsAccount>` and `ArrayList<BankAccount>`.

This restriction is necessary for type checking. Without the restriction, it would be possible to add objects of unrelated types to a collection. Suppose it was possible to assign an `ArrayList<SavingsAccount>` object to a variable of type `ArrayList<BankAccount>`:

```
ArrayList<SavingsAccount> savingsAccounts = new ArrayList<SavingsAccount>();
ArrayList<BankAccount> bankAccounts = savingsAccounts;
   // Not legal, but suppose it was
BankAccount harrysChecking = new CheckingAccount();
   // CheckingAccount is another subclass of BankAccount
bankAccounts.add(harrysChecking); // OK—can add BankAccount object
```

But `bankAccounts` and `savingsAccounts` refer to the same array list! If the assignment was legal, we would be able to add a `CheckingAccount` into an `ArrayList<SavingsAccount>`.

In many situations, this limitation can be overcome by using wildcards—see Special Topic 17.1.

Special Topic 17.1

Wildcard Types

It is often necessary to formulate subtle constraints of type parameters. Wildcard types were invented for this purpose. There are three kinds of wildcard types:

Name	Syntax	Meaning
Wildcard with lower bound	`? extends B`	Any subtype of `B`
Wildcard with upper bound	`? super B`	Any supertype of `B`
Unbounded wildcard	`?`	Any type

A wildcard type is a type that can remain unknown. For example, we can declare the following method in the LinkedList<E> class:

```
public void addAll(LinkedList<? extends E> other)
{
   ListIterator<E> iter = other.listIterator();
   while (iter.hasNext()) add(iter.next());
}
```

The method adds all elements of other to the end of the linked list.

The addAll method doesn't require a specific type for the element type of other. Instead, it allows you to use any type that is a subtype of E. For example, you can use addAll to add a LinkedList<SavingsAccount> to a LinkedList<BankAccount>.

To see a wildcard with a super bound, have another look at the min method of the preceding section. Recall that Comparable is a generic interface; the type parameter of the Comparable interface specifies the parameter type of the compareTo method.

```
public interface Comparable<T>
{
   int compareTo(T other)
}
```

Therefore, we might want to specify a type bound:

```
public static <E extends Comparable<E>> E min(E[] a)
```

However, this bound is too restrictive. Suppose the BankAccount class implements Comparable<BankAccount>. Then the subclass SavingsAccount also implements Comparable<BankAccount> and *not* Comparable<SavingsAccount>. If you want to use the min method with a SavingsAccount array, then the type parameter of the Comparable interface should be *any supertype* of the array element type:

```
public static <E extends Comparable<? super E>> E min(E[] a)
```

Here is an example of an unbounded wildcard. The Collections class declares a method

```
public static void reverse(List<?> list)
```

You can think of that declaration as a shorthand for

```
public static <T> void reverse(List<T> list)
```

17.5 Type Erasure

The virtual machine erases type parameters, replacing them with their bounds or Objects.

Because generic types are a fairly recent addition to the Java language, the virtual machine that executes Java programs does not work with generic classes or methods. Instead, type parameters are "erased", that is, they are replaced with ordinary Java types. Each type parameter is replaced with its bound, or with Object if it is not bounded.

For example, the generic class Pair<T, S> turns into the following raw class:

```
public class Pair
{
   private Object first;
   private Object second;

   public Pair(Object firstElement, Object secondElement)
   {
      first = firstElement;
      second = secondElement;
   }
   public Object getFirst() { return first; }
   public Object getSecond() { return second; }
}
```

As you can see, the type parameters `T` and `S` have been replaced by `Object`. The result is an ordinary class.

The same process is applied to generic methods. After erasing the type parameter, the `min` method of the preceding section turns into an ordinary method. Note that in this example, the type parameter is replaced with its bound, the `Comparable` interface:

```
public static Comparable min(Comparable[] a)
{
   Comparable smallest = a[0];
   for (int i = 1; i < a.length; i++)
      if (a[i].compareTo(smallest) < 0) smallest = a[i];
   return smallest;
}
```

You cannot construct objects or arrays of a generic type.

Knowing about type erasure helps you understand limitations of Java generics. For example, you cannot construct new objects of a generic type. The following method, which tries to fill an array with copies of default objects, would be wrong:

```
public static <E> void fillWithDefaults(E[] a)
{
   for (int i = 0; i < a.length; i++)
      a[i] = new E(); // ERROR
}
```

To see why this is a problem, carry out the type erasure process, as if you were the compiler:

```
public static void fillWithDefaults(Object[] a)
{
   for (int i = 0; i < a.length; i++)
      a[i] = new Object(); // Not useful
}
```

Of course, if you start out with a `Rectangle[]` array, you don't want it to be filled with `Object` instances. But that's what the code would do after erasing types.

In situations such as this one, the compiler will report an error. You then need to come up with another mechanism for solving your problem. In this particular example, you can supply a default object:

```
public static <E> void fillWithDefaults(E[] a, E defaultValue)
{
   for (int i = 0; i < a.length; i++)
      a[i] = defaultValue;
}
```

Similarly, you cannot construct an array of a generic type.

```
public class Stack<E>
{
   private E[] elements;
   . . .
   public Stack()
   {
      elements = new E[MAX_SIZE]; // Error
   }
}
```

Because the array construction expression `new E[]` would be erased to `new Object[]`, the compiler disallows it. A remedy is to use an array list instead:

```
public class Stack<E>
{
   private ArrayList<E> elements;
   . . .
   public Stack()
   {
      elements = new ArrayList<E>(); // Ok
   }
   . . .
}
```

Another solution is to use an array of objects and provide a cast when reading elements from the array:

```
public class Stack<E>
{
   private Object[] elements;
   private int size;
   . . .
   public Stack()
   {
      elements = new Object[MAX_SIZE]; // Ok
   }
   . . .
   public E pop()
   {
      size--;
      return (E) elements[size];
   }
}
```

The cast `(E)` generates a warning because it cannot be checked at run time.

These limitations are frankly awkward. It is hoped that a future version of Java will no longer erase types so that the current restrictions that are the consequence of erasure can be lifted.

SELF CHECK

9. What is the erasure of the `print` method in Section 17.3?

10. Could the `Stack` example be implemented as follows?

```
public class Stack<E>
{
   private E[] elements;
   . . .
   public Stack()
   {
      elements = (E[]) new Object[MAX_SIZE];
   }
   . . .
}
```

Common Error 17.2

Using Generic Types in a Static Context

You cannot use type parameters to declare static variables, static methods, or static inner classes. For example, the following would be illegal:

```
public class LinkedList<E>
{
   private static E defaultValue; // ERROR
   . . .
   public static List<E> replicate(E value, int n) { . . . } // ERROR
   private static class Node { public E data; public Node next; } // ERROR
}
```

In the case of static variables, this restriction is very sensible. After the generic types are erased, there is only a single variable `LinkedList.defaultValue`, whereas the static variable declaration gives the false impression that there is a separate variable for each `LinkedList<E>`.

For static methods and inner classes, there is an easy workaround; simply add a type parameter:

```
public class LinkedList<E>
{
   . . .
   public static <T> List<T> replicate(T value, int n) { . . . } // OK
   private static class Node<T> { public T data; public Node<T> next; } // OK
}
```

Summary of Learning Objectives

Describe generic classes and type parameters.

- In Java, generic programming can be achieved with inheritance or with type parameters.
- A generic class has one or more type parameters.
- Type parameters can be instantiated with class or interface types.
- Type parameters make generic code safer and easier to read.

Implement generic classes and interfaces.

- Type variables of a generic class follow the class name and are enclosed in angle brackets.
- Use type parameters for the types of generic instance variables, method parameters, and return values.

Implement generic methods.

- A generic method is a method with a type parameter.
- Supply the type parameters of a generic method between the modifiers and the method return type.
- When calling a generic method, you need not instantiate the type parameters.

Specify constraints on type parameters.

- Type parameters can be constrained with bounds.

Recognize how erasure of type parameters places limitations on generic programming in Java.

- The virtual machine erases type parameters, replacing them with their bounds or `Objects`.
- You cannot construct objects or arrays of a generic type.

Media Resources

www.wiley.com/college/horstmann

- Lab Exercises
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★ **R17.1** What is a type parameter?

★ **R17.2** What is the difference between a generic class and an ordinary class?

★ **R17.3** What is the difference between a generic class and a generic method?

★ **R17.4** Find an example of a non-static generic method in the standard Java library.

★★ **R17.5** Find four examples of a generic class with two type parameters in the standard Java library.

★★ **R17.6** Find an example of a generic class in the standard library that is not a collection class.

★ **R17.7** Why is a bound required for the type parameter `T` in the following method?

```
<T extends Comparable> int binarySearch(T[] a, T key)
```

★★ **R17.8** Why is a bound not required for the type parameter `E` in the `HashSet<E>` class?

★ **R17.9** What is an `ArrayList<Pair<T, T>>`?

★★ **R17.10** Explain the type bounds of the following method of the `Collections` class:

```
public static <T extends Comparable<? super T>> void sort(List<T> a)
```

Why doesn't `T extends Comparable` or `T extends Comparable<T>` suffice?

★ **R17.11** What happens when you pass an `ArrayList<String>` to a method with parameter `ArrayList`? Try it out and explain.

★★★ **R17.12** What happens when you pass an `ArrayList<String>` to a method with parameter `ArrayList`, and the method stores an object of type `BankAccount` into the array list? Try it out and explain.

★★ **R17.13** What is the result of the following test?

```
ArrayList<BankAccount> accounts = new ArrayList<BankAccount>();
if (accounts instanceof ArrayList<String>) . . .
```

Try it out and explain.

★★ **R17.14** The `ArrayList<E>` class in the standard Java library must manage an array of objects of type `E`, yet it is not legal to construct a generic array of type `E[]` in Java. Locate the implementation of the `ArrayList` class in the library source code that is a part of the JDK. Explain how this problem is overcome.

Programming Exercises

★ **P17.1** Modify the generic `Pair` class so that both values have the same type.

★ **P17.2** Add a method `swap` to the `Pair` class of Exercise P17.1 that swaps the first and second elements of the pair.

★★ **P17.3** Implement a static generic method `PairUtil.swap` whose parameter is a `Pair` object, using the generic class declared in Section 17.2. The method should return a new pair, with the first and second element swapped.

★★ **P17.4** Write a static generic method `PairUtil.minmax` that computes the minimum and maximum elements of an array of type `T` and returns a pair containing the minimum and maximum value. Require that the array elements implement the `Measurable` interface of Chapter 9.

★★ **P17.5** Repeat the problem of Exercise P17.4, but require that the array elements implement the `Comparable` interface.

★★★ **P17.6** Repeat the problem of Exercise P17.5, but refine the bound of the type parameter to extend the generic `Comparable` type.

★★ **P17.7** Implement a generic version of the binary search algorithm.

★★★ **P17.8** Implement a generic version of the merge sort algorithm. Your program should compile without warnings.

P17.9 Implement a generic version of the `LinkedList` class of Chapter 15.

★★ **P17.10** Implement a generic version of the `BinarySearchTree` class of Chapter 16.

★★ **P17.11** Turn the `HashSet` implementation of Chapter 16 into a generic class. Use an array list instead of an array to store the buckets.

★★ **P17.12** Provide suitable `hashCode` and `equals` methods for the `Pair` class of Section 17.2 and implement a `HashMap` class, using a `HashSet<Pair<K, V>>`.

★★★ **P17.13** Implement a generic version of the permutation generator in Section 13.2. Generate all permutations of a `List<E>`.

★★ **P17.14** Write a generic static method `print` that prints the elements of any object that implements the `Iterable<E>` interface. The elements should be separated by commas. Place your method into an appropriate utility class.

Programming Projects

Project 17.1 Design and implement a generic version of the `DataSet` class of Chapter 9 that can be used to analyze data of any class that implements the `Measurable` interface. Make the `Measurable` interface generic as well. Supply an `addAll` method that lets you add all values from another data set with a compatible type. Supply a generic `Measurer<T>` interface to allow the analysis of data whose classes don't implement the `Measurable` type.

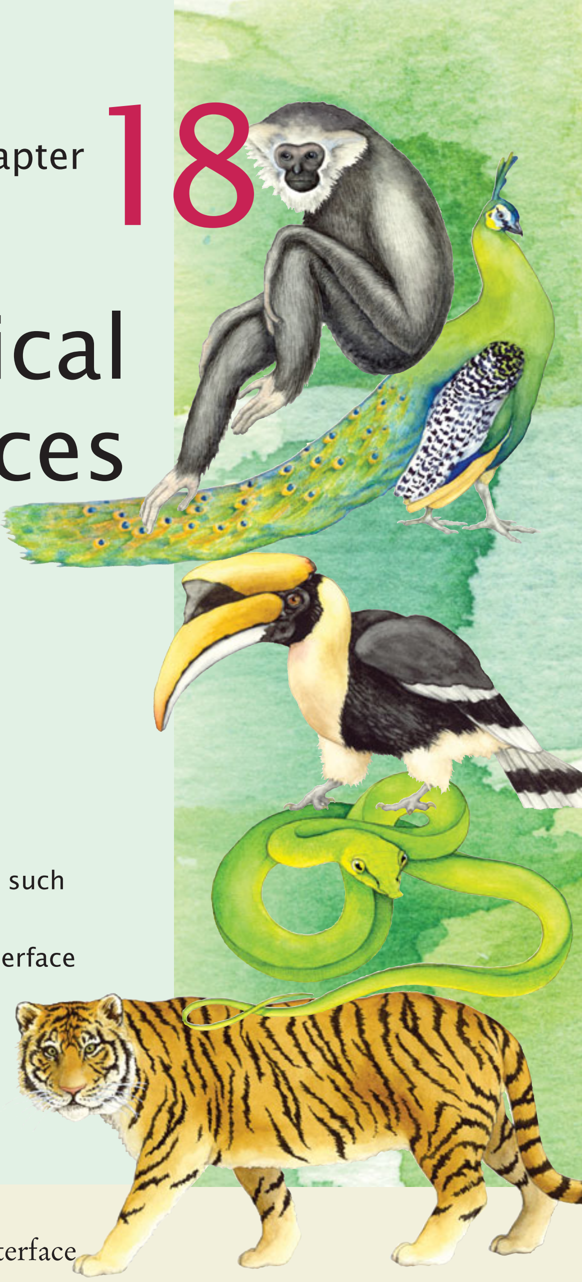
Project 17.2 Turn the `MinHeap` class of Chapter 16 into a generic class. As with the `TreeSet` class of the standard library, allow a `Comparator` to compare queue elements. If no comparator is supplied, assume that the element type implements the `Comparable` interface.

Answers to Self-Check Questions

1. `HashMap<String, Integer>`
2. It uses inheritance.
3. `new Pair<String, String>("Hello", "World")`
4. An `ArrayList<Pair<String, Integer>>` contains multiple pairs, for example `[(Tom, 1), (Harry, 3)]`. A `Pair<ArrayList<String>, Integer>` contains a list of strings and a single integer, such as `([Tom, Harry], 1)`.
5. The output depends on the implementation of the `toString` method in the `BankAccount` class.
6. No—the method has no type parameters. It is an ordinary method in a generic class.
7. `public class BinarySearchTree<E extends Comparable>`
8.
```
public static <E extends Measurable> E min(E[] a)
{
   E smallest = a[0];
   for (int i = 1; i < a.length; i++)
      if (a[i].getMeasure() < smallest.getMeasure())
         smallest = a[i];
   return smallest;
}
```
9.
```
public static void print(Object[] a)
{
   for (Object e : a)
      System.out.print(e + " ");
   System.out.println();
}
```
10. This code compiles (with a warning), but it is a poor technique. In the future, if type erasure no longer happens, the code will be *wrong*. The cast from `Object[]` to `String[]` will cause a class cast exception.

Chapter 18

Graphical User Interfaces



CHAPTER GOALS

- **G** To become familiar with common user-interface components, such as text components, radio buttons, check boxes, and menus
- **G** To understand the use of layout managers to arrange user-interface components in a container
- **G** To build programs that handle events from user-interface components
- ● To learn how to browse the Java documentation

In this chapter, we will delve more deeply into graphical user interface programming. The graphical applications with which you are familiar have many visual gadgets for information entry: text components, buttons, scroll bars, menus, and so on. In this chapter, you will learn how to use the most common user-interface components in the Java Swing user-interface toolkit. Swing has many more components than can be mastered in a first course, and even the basic components have advanced options that can't be covered here. In fact, few programmers try to learn everything about a particular user-interface component. It is more important to understand the concepts and to search the Java documentation for the details. This chapter walks you through one example to show you how the Java documentation is organized and how you can rely on it for your programming.

CHAPTER CONTENTS

18.1G Processing Text Input 740

18.2G Text Areas 743

18.3G Layout Management 746

18.4G Choices 748

How To 18.1: Laying Out a User Interface 755

Productivity Hint 18.1: Use a GUI Builder 757

18.5G Menus 758

How To 18.2: Implementing a Graphical User Interface (GUI) 763

18.6G Exploring the Swing Documentation 764

18.1 Processing Text Input

We start our discussion of graphical user interfaces with text input. Of course, a graphical application can receive text input by calling the `showInputDialog` method of the `JOptionPane` class, but popping up a separate dialog box for each input is not a natural user interface. Most graphical programs collect text input through **text fields** (see Figure 1). In this section, you will learn how to add text fields to a graphical application, and how to read what the user types into them.

Use `JTextField` components to provide space for user input. Place a `JLabel` next to each text field.

The `JTextField` class provides a text field. When you construct a text field, you need to supply the width—the approximate number of characters that you expect the user to type.

```
final int FIELD_WIDTH = 10;
final JTextField rateField = new JTextField(FIELD_WIDTH);
```

Users can type additional characters, but then a part of the contents of the field becomes invisible.

You will want to label each text field so that the user knows what to type into it. Construct a `JLabel` object for each label:

```
JLabel rateLabel = new JLabel("Interest Rate: ");
```

You want to give the user an opportunity to enter all information into the text fields before processing it. Therefore, you should supply a button that the user can press to indicate that the input is ready for processing.

When that button is clicked, its `actionPerformed` method reads the user input from the text field, using the `getText` method of the `JTextField` class. The `getText` method returns a `String` object. In our sample program, we turn the string into a number, using the `Double.parseDouble` method. After updating the account, we show the balance in another label.

```
class AddInterestListener implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      double rate = Double.parseDouble(rateField.getText());
      double interest = account.getBalance() * rate / 100;
      account.deposit(interest);
      resultLabel.setText("balance: " + account.getBalance());
   }
}
```

The following application is a useful prototype for a graphical user-interface front end for arbitrary calculations. You can easily modify it for your own needs. Place

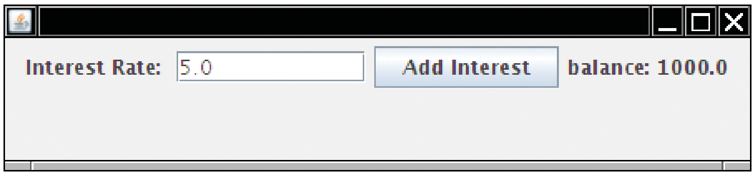


Figure 1 An Application with a Text Field

other input components into the frame. Change the contents of the `actionPerformed` method to carry out other calculations. Display the result in a label.

ch18/textfield/InvestmentViewer3.java

```java
import javax.swing.JFrame;

/**
   This program displays the growth of an investment.
*/
public class InvestmentViewer3
{
   public static void main(String[] args)
   {
      JFrame frame = new InvestmentFrame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

ch18/textfield/InvestmentFrame.java

```java
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JTextField;

/**
   A frame that shows the growth of an investment with variable interest.
*/
public class InvestmentFrame extends JFrame
{
   private static final int FRAME_WIDTH = 450;
   private static final int FRAME_HEIGHT = 100;

   private static final double DEFAULT_RATE = 5;
   private static final double INITIAL_BALANCE = 1000;

   private JLabel rateLabel;
   private JTextField rateField;
   private JButton button;
   private JLabel resultLabel;
   private JPanel panel;
   private BankAccount account;

   public InvestmentFrame()
   {
      account = new BankAccount(INITIAL_BALANCE);

      // Use instance variables for components
      resultLabel = new JLabel("balance: " + account.getBalance());

      // Use helper methods
      createTextField();
      createButton();
      createPanel();

      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }

   private void createTextField()
   {
      rateLabel = new JLabel("Interest Rate: ");

      final int FIELD_WIDTH = 10;
      rateField = new JTextField(FIELD_WIDTH);
      rateField.setText("" + DEFAULT_RATE);
   }

   private void createButton()
   {
      button = new JButton("Add Interest");

      class AddInterestListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            double rate = Double.parseDouble(rateField.getText());
            double interest = account.getBalance() * rate / 100;
            account.deposit(interest);
            resultLabel.setText("balance: " + account.getBalance());
         }
      }

      ActionListener listener = new AddInterestListener();
      button.addActionListener(listener);
   }

   private void createPanel()
   {
      panel = new JPanel();
      panel.add(rateLabel);
      panel.add(rateField);
      panel.add(button);
      panel.add(resultLabel);
      add(panel);
   }
}
```

SELF CHECK

1. What happens if you omit the first `JLabel` object?
2. If a text field holds an integer, what expression do you use to read its contents?

18.2 Text Areas

Use a JTextArea to show multiple lines of text.

In the preceding section, you saw how to construct text fields. A text field holds a single line of text. To display multiple lines of text, use the JTextArea class.

When constructing a text area, you can specify the number of rows and columns:

```
final int ROWS = 10;
final int COLUMNS = 30;
JTextArea textArea = new JTextArea(ROWS, COLUMNS);
```

Use the setText method to set the text of a text field or text area. The append method adds text to the end of a text area. Use newline characters to separate lines, like this:

```
textArea.append(account.getBalance() + "\n");
```

If you want to use a text field or text area for display purposes only, call the setEditable method like this

```
textArea.setEditable(false);
```

Now the user can no longer edit the contents of the field, but your program can still call setText and append to change it.

As shown in Figure 2, the JTextField and JTextArea classes are subclasses of the class JTextComponent. The methods setText and setEditable are declared in the JTextComponent class and inherited by JTextField and JTextArea. However, the append method is declared in the JTextArea class.

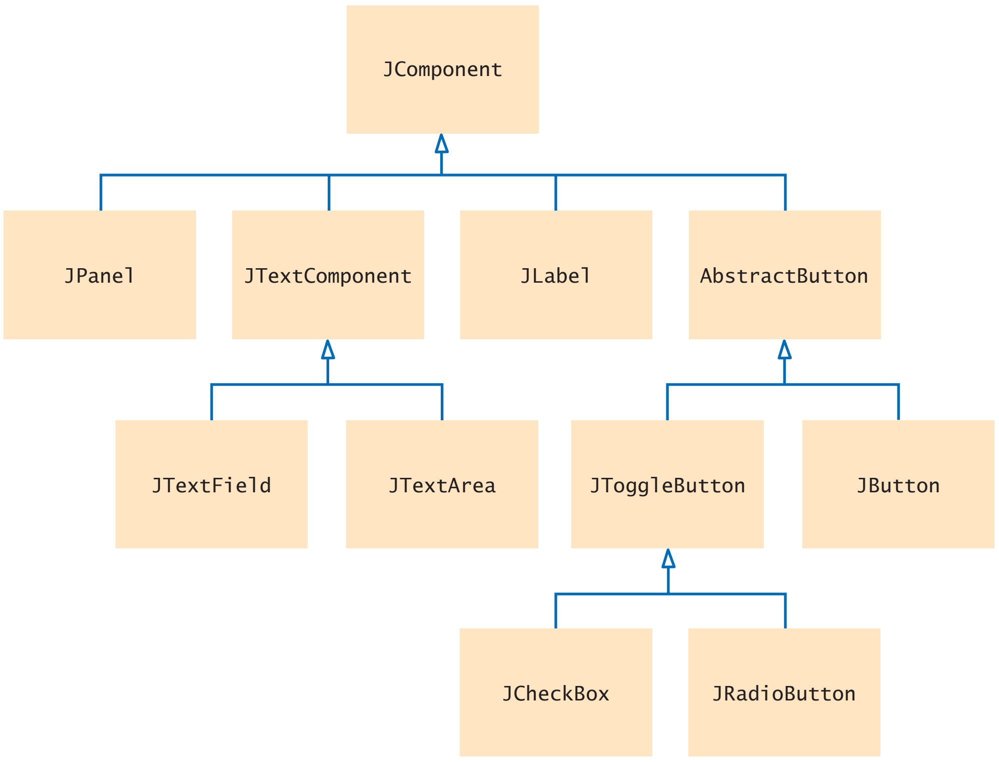
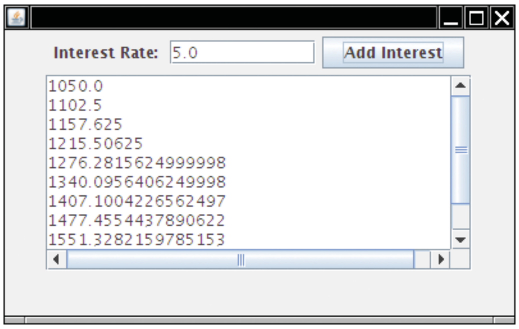


Figure 2 A Part of the Hierarchy of Swing User-Interface Components



```
1050.0
1102.5
1157.625
1215.50625
1276.2815624999998
1340.0956406249998
1407.1004226562497
1477.4554437890622
1551.3282159785153
```

Figure 3 The Investment Application with a Text Area

You can add scroll bars to any component with a `JScrollPane`.

To add scroll bars to a text area, use a `JScrollPane`, like this:

```
JTextArea textArea = new JTextArea(ROWS, COLUMNS);
JScrollPane scrollPane = new JScrollPane(textArea);
```

Then add the scroll pane to the panel. Figure 3 shows the result.

The following sample program puts these concepts together. A user can enter numbers into the interest rate text field and then click on the “Add Interest” button). The interest rate is applied, and the updated balance is appended to the text area. The text area has scroll bars and is not editable.

This program is similar to the previous investment viewer program, but it keeps track of all the bank balances, not just the last one.

ch18/textarea/InvestmentFrame.java

```java
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JScrollPane;
import javax.swing.JTextArea;
import javax.swing.JTextField;

/**
   A frame that shows the growth of an investment with variable interest.
*/
public class InvestmentFrame extends JFrame
{
   private static final int FRAME_WIDTH = 400;
   private static final int FRAME_HEIGHT = 250;

   private static final int AREA_ROWS = 10;
   private static final int AREA_COLUMNS = 30;
   private static final double DEFAULT_RATE = 5;
   private static final double INITIAL_BALANCE = 1000;

   private JLabel rateLabel;
   private JTextField rateField;
   private JButton button;
   private JTextArea resultArea;
   private JPanel panel;
   private BankAccount account;

   public InvestmentFrame()
   {
      account = new BankAccount(INITIAL_BALANCE);
      resultArea = new JTextArea(AREA_ROWS, AREA_COLUMNS);
      resultArea.setEditable(false);

      // Use helper methods
      createTextField();
      createButton();
      createPanel();

      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }

   private void createTextField()
   {
      rateLabel = new JLabel("Interest Rate: ");

      final int FIELD_WIDTH = 10;
      rateField = new JTextField(FIELD_WIDTH);
      rateField.setText("" + DEFAULT_RATE);
   }

   private void createButton()
   {
      button = new JButton("Add Interest");

   class AddInterestListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            double rate = Double.parseDouble(rateField.getText());
            double interest = account.getBalance() * rate / 100;
            account.deposit(interest);
            resultArea.append(account.getBalance() + "\n");
         }
      }

      ActionListener listener = new AddInterestListener();
      button.addActionListener(listener);
   }

   private void createPanel()
   {
      panel = new JPanel();
      panel.add(rateLabel);
      panel.add(rateField);
      panel.add(button);
      JScrollPane scrollPane = new JScrollPane(resultArea);
      panel.add(scrollPane);
      add(panel);
   }
}
```

SELF CHECK

3. What is the difference between a text field and a text area?
4. Why did the `InvestmentFrame` program call `resultArea.setEditable(false)`?
5. How would you modify the `InvestmentFrame` program if you didn't want to use scroll bars?

18.3 Layout Management

User-interface components are arranged by placing them inside containers.

Up to now, you have had limited control over the layout of user-interface components. You learned how to add components to a panel. The panel arranged the components from the left to the right. However, in many applications, you need more sophisticated arrangements.

Each container has a layout manager that directs the arrangement of its components.

In Java, you build up user interfaces by adding components into containers such as panels. Each container has its own **layout manager**, which determines how the components are laid out.

Three useful layout managers are the border layout, flow layout, and grid layout.

By default, a `JPanel` uses a **flow layout**. A flow layout simply arranges its components from left to right and starts a new row when there is no more room in the current row.

Another commonly used layout manager is the **border layout**. The border layout groups components into five areas: center, north, west, south, and east (see Figure 4). Not all of the areas need to be occupied.

The border layout is the default layout manager for a frame (or, more technically, the frame's content pane). But you can also use the border layout in a panel:

When adding a component to a container with the border layout, specify the `NORTH`, `EAST`, `SOUTH`, `WEST`, or `CENTER` position.

```
panel.setLayout(new BorderLayout());
```

Now the panel is controlled by a border layout, not the flow layout. When adding a component, you specify the position, like this:

```
panel.add(component, BorderLayout.NORTH);
```

The content pane of a frame has a border layout by default. A panel has a flow layout by default.

The **grid layout** is a third layout that is sometimes useful. The grid layout arranges components in a grid with a fixed number of rows and columns, resizing each of the components so that they all have the same size. Like the border layout, it also expands each component to fill the entire allotted area. (If that is not desirable, you need to place each component inside a panel.) Figure 5 shows a number pad panel that uses a grid layout. To create a grid layout, you supply the number of rows and columns in the constructor, then add the components, row by row, left to right:

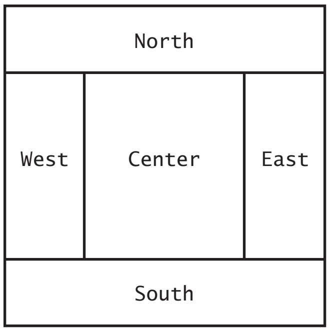
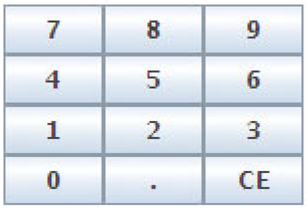


Figure 4
Components Expand to Fill Space in the Border Layout

Figure 5
The Grid Layout



```
JPanel buttonPanel = new JPanel();
buttonPanel.setLayout(new GridLayout(4, 3));
buttonPanel.add(button7);
buttonPanel.add(button8);
buttonPanel.add(button9);
buttonPanel.add(button4);
. . .
```

Sometimes you want to have a tabular arrangement of the components where columns have different sizes or one component spans multiple columns. A more complex layout manager called the *grid bag layout* can handle these situations. The grid bag layout is quite complex to use, however, and we do not cover it in this book; see, for example, Cay S. Horstmann and Gary Cornell, *Core Java 2 Volume 1: Fundamentals,* 8th edition (Prentice Hall, 2008), for more information. Java 6 introduces a group layout that is designed for use by interactive tools—see Productivity Hint 18.1 on page 757.

Fortunately, you can create acceptable-looking layouts in nearly all situations by nesting panels. You give each panel an appropriate layout manager. Panels don't have visible borders, so you can use as many panels as you need to organize your components. Figure 6 shows an example. The keypad buttons are contained in a panel with grid layout. That panel is itself contained in a larger panel with border layout. The text field is in the northern position of the larger panel. The following code produces this arrangement:

```
JPanel keypadPanel = new JPanel();
keypadPanel.setLayout(new BorderLayout());
buttonPanel = new JPanel();
buttonPanel.setLayout(new GridLayout(4, 3));
buttonPanel.add(button7);
buttonPanel.add(button8);
// . . .
keypadPanel.add(buttonPanel, BorderLayout.CENTER);
JTextField display = new JTextField();
keypadPanel.add(display, BorderLayout.NORTH);
```

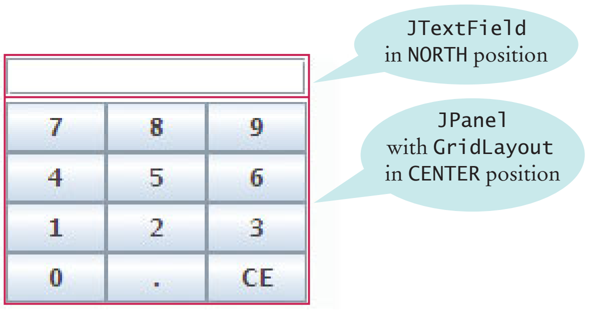


Figure 6
Nesting Panels

SELF CHECK

6. How do you add two buttons to the north area of a frame?
7. How can you stack three buttons on top of each other?

18.4 Choices

In the following sections, you will see how to present a finite set of choices to the user. Which Swing component you use depends on whether the choices are mutually exclusive or not, and on the amount of space you have for displaying the choices.

18.4.1 Radio Buttons

For a small set of mutually exclusive choices, use a group of radio buttons or a combo box.

If the choices are mutually exclusive, use a set of **radio buttons**. In a radio button set, only one button can be selected at a time. When the user selects another button in the same set, the previously selected button is automatically turned off. (These buttons are called radio buttons because they work like the station selector buttons on a car radio: If you select a new station, the old station is automatically deselected.) For example, in Figure 7, the font sizes are mutually exclusive. You can select small, medium, or large, but not a combination of them.

Add radio buttons into a ButtonGroup so that only one button in the group is on at any time.

To create a set of radio buttons, first create each button individually, and then add all buttons of the set to a ButtonGroup object:

```
JRadioButton smallButton = new JRadioButton("Small");
JRadioButton mediumButton = new JRadioButton("Medium");
JRadioButton largeButton = new JRadioButton("Large");

ButtonGroup group = new ButtonGroup();
group.add(smallButton);
group.add(mediumButton);
group.add(largeButton);
```

Note that the button group does *not* place the buttons close to each other on the container. The purpose of the button group is simply to find out which buttons to turn off when one of them is turned on. It is still your job to arrange the buttons on the screen.

The isSelected method is called to find out whether a button is currently selected or not. For example,

```
if (largeButton.isSelected()) { size = LARGE_SIZE; }
```

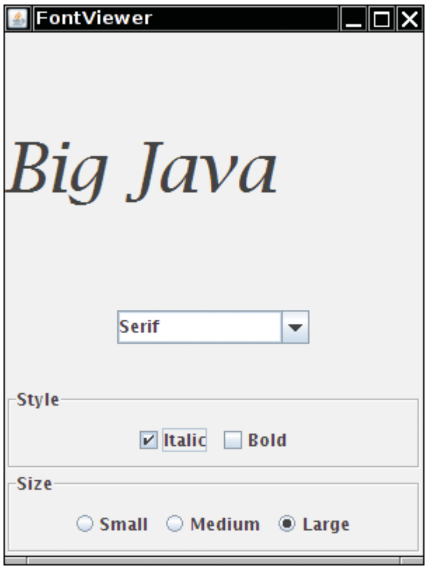
Because users will expect one radio button in a radio button group to be selected, call setSelected(true) on the default radio button before making the enclosing frame visible.

You can place a border around a panel to group its contents visually.

If you have multiple button groups, it is a good idea to group them together visually. It is a good idea to use a panel for each set of radio buttons, but the panels themselves are invisible. You can add a *border* to a panel to make it visible. In Figure 7, for example, the panels containing the Size radio buttons and Style check boxes have borders.

There are a large number of border types. We will show only a couple of variations and leave it to the border enthusiasts to look up the others in the Swing

Figure 7
A Combo Box, Check Boxes, and Radio Buttons



documentation. The `EtchedBorder` class yields a border with a three-dimensional, etched effect. You can add a border to any component, but most commonly you apply it to a panel:

```
JPanel panel = new JPanel();
panel.setBorder(new EtchedBorder());
```

If you want to add a title to the border (as in Figure 7), you need to construct a `TitledBorder`. You make a titled border by supplying a basic border and then the title you want. Here is a typical example:

```
panel.setBorder(new TitledBorder(new EtchedBorder(), "Size"));
```

18.4.2 Check Boxes

For a binary choice, use a check box.

A check box is a user-interface component with two states: checked and unchecked. You use a group of check boxes when one selection does not exclude another. For example, the choices for “Bold” and “Italic” in Figure 7 are not exclusive. You can choose either, both, or neither. Therefore, they are implemented as a set of separate check boxes. Radio buttons and check boxes have different visual appearances. Radio buttons are round and have a black dot when selected. Check boxes are square and have a check mark when selected.

You construct a check box by giving the name in the constructor:

```
JCheckBox italicCheckBox = new JCheckBox("Italic");
```

Because check box settings do not exclude each other, you do not place a set of check boxes inside a button group.

As with radio buttons, you use the `isSelected` method to find out whether a check box is currently checked or not.

18.4.3 Combo Boxes

For a large set of choices, use a combo box.

If you have a large number of choices, you don't want to make a set of radio buttons, because that would take up a lot of space. Instead, you can use a **combo box**. This component is called a combo box because it is a combination of a list and a text field. The text field displays the name of the current selection. When you click on the arrow to the right of the text field of a combo box, a list of selections drops down, and you can choose one of the items in the list (see Figure 8).

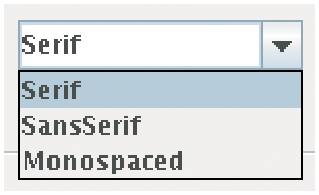


Figure 8
An Open Combo Box

If the combo box is *editable*, you can also type in your own selection. To make a combo box editable, call the `setEditable` method.

You add strings to a combo box with the `addItem` method.

```
JComboBox facenameCombo = new JComboBox();
facenameCombo.addItem("Serif");
facenameCombo.addItem("SansSerif");
. . .
```

You get the item that the user has selected by calling the `getSelectedItem` method. However, because combo boxes can store other objects in addition to strings, the `getSelectedItem` method has return type `Object`. Hence you must cast the returned value back to `String`.

```
String selectedString = (String) facenameCombo.getSelectedItem();
```

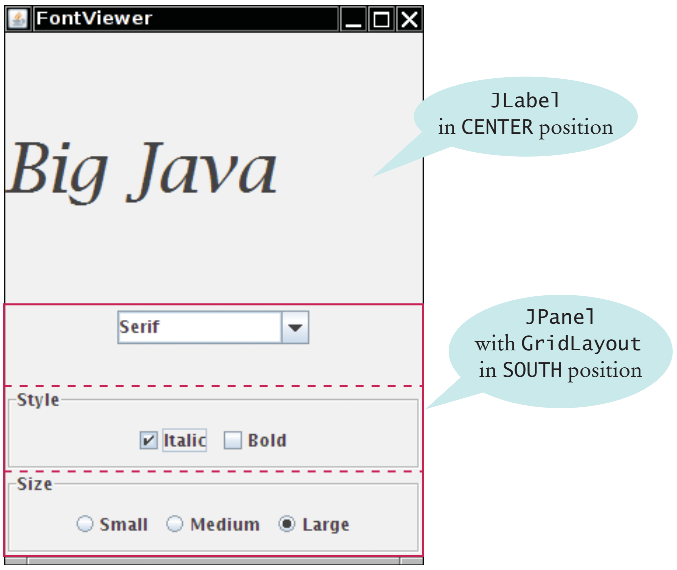

FontViewer
Big Java
Serif
Style
Italic
Bold
Size
Small
Medium
Large
JLabel in CENTER position
JPanel with GridLayout in SOUTH position

Figure 9 The Components of the `FontViewerFrame`

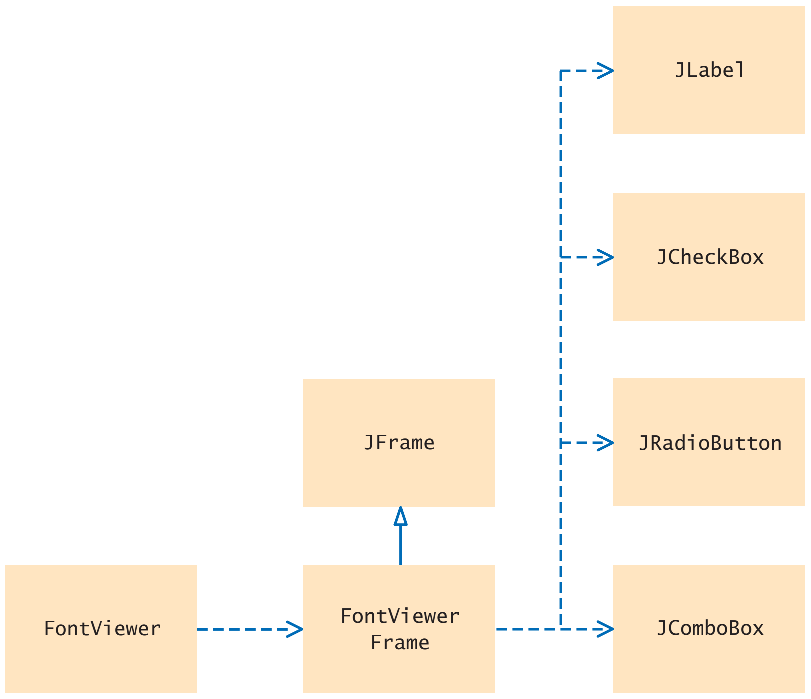


Figure 10 Classes of the Font Viewer Program

You can select an item for the user with the `setSelectedItem` method.

Radio buttons, check boxes, and combo boxes generate action events, just as buttons do.

Radio buttons, check boxes, and combo boxes generate an `ActionEvent` whenever the user selects an item. In the following program, we don't care which component was clicked—all components notify the same listener object. Whenever the user clicks on any one of them, we simply ask each component for its current content, using the `isSelected` and `getSelectedItem` methods. We then redraw the text sample with the new font.

Figure 9 shows how the components are arranged in the frame. Figure 10 shows the relationships between the classes used in the font viewer program.

ch18/choice/FontViewer.java

```
import javax.swing.JFrame;

/**
   This program allows the user to view font effects.
*/
public class FontViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new FontViewerFrame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setTitle("FontViewer");
      frame.setVisible(true);
   }
}
```

ch18/choice/FontViewerFrame.java

```java
import java.awt.BorderLayout;
import java.awt.Font;
import java.awt.GridLayout;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.ButtonGroup;
import javax.swing.JButton;
import javax.swing.JCheckBox;
import javax.swing.JComboBox;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JRadioButton;
import javax.swing.border.EtchedBorder;
import javax.swing.border.TitledBorder;

/**
   This frame contains a text field and a control panel
   to change the font of the text.
*/
public class FontViewerFrame extends JFrame
{
   private static final int FRAME_WIDTH = 300;
   private static final int FRAME_HEIGHT = 400;

   private JLabel sampleField;
   private JCheckBox italicCheckBox;
   private JCheckBox boldCheckBox;
   private JRadioButton smallButton;
   private JRadioButton mediumButton;
   private JRadioButton largeButton;
   private JComboBox facenameCombo;
   private ActionListener listener;

   /**
      Constructs the frame.
   */
   public FontViewerFrame()
   {
      // Construct text sample
      sampleField = new JLabel("Big Java");
      add(sampleField, BorderLayout.CENTER);

      // This listener is shared among all components
      class ChoiceListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            setSampleFont();
         }
      }

      listener = new ChoiceListener();

      createControlPanel();
      setSampleFont();
      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }

   /**
      Creates the control panel to change the font.
   */
   public void createControlPanel()
   {
      JPanel facenamePanel = createComboBox();
      JPanel sizeGroupPanel = createCheckBoxes();
      JPanel styleGroupPanel = createRadioButtons();

      // Line up component panels

      JPanel controlPanel = new JPanel();
      controlPanel.setLayout(new GridLayout(3, 1));
      controlPanel.add(facenamePanel);
      controlPanel.add(sizeGroupPanel);
      controlPanel.add(styleGroupPanel);

      // Add panels to content pane

      add(controlPanel, BorderLayout.SOUTH);
   }

   /**
      Creates the combo box with the font style choices.
      @return the panel containing the combo box
   */
   public JPanel createComboBox()
   {
      facenameCombo = new JComboBox();
      facenameCombo.addItem("Serif");
      facenameCombo.addItem("SansSerif");
      facenameCombo.addItem("Monospaced");
      facenameCombo.setEditable(true);
      facenameCombo.addActionListener(listener);

      JPanel panel = new JPanel();
      panel.add(facenameCombo);
      return panel;
   }

   /**
      Creates the check boxes for selecting bold and italic styles.
      @return the panel containing the check boxes
   */
   public JPanel createCheckBoxes()
   {
      italicCheckBox = new JCheckBox("Italic");
      italicCheckBox.addActionListener(listener);

      boldCheckBox = new JCheckBox("Bold");
      boldCheckBox.addActionListener(listener);

      JPanel panel = new JPanel();
      panel.add(italicCheckBox);
      panel.add(boldCheckBox);
      panel.setBorder(new TitledBorder(new EtchedBorder(), "Style"));

      return panel;
   }

   /**
      Creates the radio buttons to select the font size.
      @return the panel containing the radio buttons
   */
   public JPanel createRadioButtons()
   {
      smallButton = new JRadioButton("Small");
      smallButton.addActionListener(listener);

      mediumButton = new JRadioButton("Medium");
      mediumButton.addActionListener(listener);

      largeButton = new JRadioButton("Large");
      largeButton.addActionListener(listener);
      largeButton.setSelected(true);

      // Add radio buttons to button group

      ButtonGroup group = new ButtonGroup();
      group.add(smallButton);
      group.add(mediumButton);
      group.add(largeButton);

      JPanel panel = new JPanel();
      panel.add(smallButton);
      panel.add(mediumButton);
      panel.add(largeButton);
      panel.setBorder(new TitledBorder(new EtchedBorder(), "Size"));

      return panel;
   }

   /**
      Gets user choice for font name, style, and size
      and sets the font of the text sample.
   */
   public void setSampleFont()
   {
      // Get font name
      String facename
            = (String) facenameCombo.getSelectedItem();

      // Get font style

      int style = 0;
      if (italicCheckBox.isSelected())
      {
         style = style + Font.ITALIC;
      }
      if (boldCheckBox.isSelected())
      {
         style = style + Font.BOLD;
      }

      // Get font size

      int size = 0;
```

```

         final int SMALL_SIZE = 24;
         final int MEDIUM_SIZE = 36;
         final int LARGE_SIZE = 48;

         if (smallButton.isSelected()) { size = SMALL_SIZE; }
         else if (mediumButton.isSelected()) { size = MEDIUM_SIZE; }
         else if (largeButton.isSelected()) { size = LARGE_SIZE; }

         // Set font of text field

         sampleField.setFont(new Font(facename, style, size));
         sampleField.repaint();
      }
   }
```

SELF CHECK

8. What is the advantage of a `JComboBox` over a set of radio buttons? What is the disadvantage?
9. Why do all user-interface components in the `FontViewerFrame` class share the same listener?
10. Why was the combo box placed inside a panel? What would have happened if it had been added directly to the control panel?

How To 18.1 Laying Out a User Interface

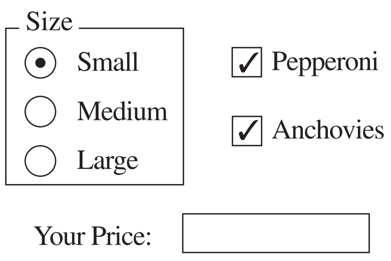
A graphical user interface is made up of components such as buttons and text fields. The Swing library uses containers and layout managers to arrange these components. This How To explains how to group components into containers and how to pick the right layout managers.

Step 1 Make a sketch of your desired component layout.

Draw all the buttons, labels, text fields, and borders on a sheet of paper. Graph paper works best.

Here is an example—a user interface for ordering pizza. The user interface contains

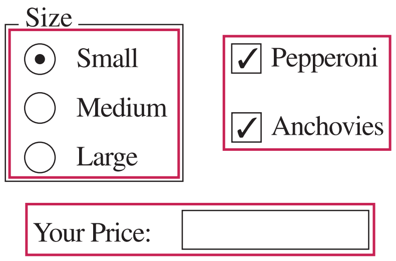
- Three radio buttons
- Two check boxes
- A label: "Your Price:"
- A text field
- A border



Step 2 Find groupings of adjacent components with the same layout.

Usually, the component arrangement is complex enough that you need to use several panels, each with its own layout manager. Start by looking at adjacent components that are arranged top to bottom or left to right. If several components are surrounded by a border, they should be grouped together.

Here are the groupings from the pizza user interface:



Step 3 Identify layouts for each group.

When components are arranged horizontally, choose a flow layout. When components are arranged vertically, use a grid layout with one column.

In the pizza user interface example, you would choose

- A (3, 1) grid layout for the radio buttons
- A (2, 1) grid layout for the check boxes
- A flow layout for the label and text field

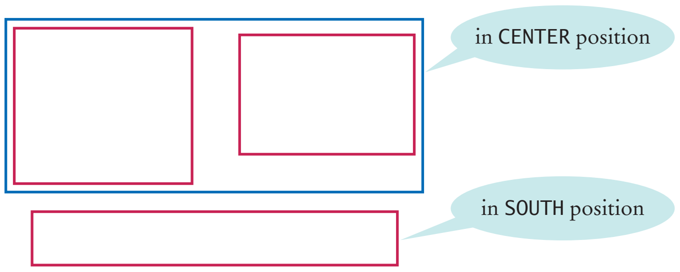
Step 4 Group the groups together.

Look at each group as one blob, and group the blobs together into larger groups, just as you grouped the components in the preceding step. If you note one large blob surrounded by smaller blobs, you can group them together in a border layout.

You may have to repeat the grouping again if you have a very complex user interface. You are done if you have arranged all groups in a single container.

For example, the three component groups of the pizza user interface can be arranged as:

- A group containing the first two component groups, placed in the center of a container with a border layout.
- The third component group, in the southern area of that container.



In this step, you may run into a couple of complications. The group "blobs" tend to vary in size more than the individual components. If you place them inside a grid layout, the grid layout forces them all to be the same size. Also, you occasionally would like a component from one group to line up with a component from another group, but there is no way for you to communicate that intent to the layout managers.

These problems can be overcome by using more sophisticated layout managers or implementing a custom layout manager. However, those techniques are beyond the scope of this book. Sometimes, you may want to start over with Step 1, using a component layout that is easier to manage. Or you can decide to live with minor imperfections of the layout. Don't worry about achieving the perfect layout—after all, you are learning programming, not user-interface design.

Step 5 Write the code to generate the layout.

This step is straightforward but potentially tedious, especially if you have a large number of components.

Start by constructing the components. Then construct a panel for each component group and set its layout manager if it is not a flow layout (the default for panels). Add a border to the panel if required. Finally, add the components to their panels. Continue in this fashion until you reach the outermost containers, which you add to the frame.

Here is an outline of the code required for the pizza user interface.

```
JPanel radioButtonPanel = new JPanel();
radioButtonPanel.setLayout(new GridLayout(3, 1));
radioButton.setBorder(new TitledBorder(new EtchedBorder(), "Size"));
radioButtonPanel.add(smallButton);
radioButtonPanel.add(mediumButton);
radioButtonPanel.add(largeButton);

JPanel checkBoxPanel = new JPanel();
checkBoxPanel.setLayout(new GridLayout(2, 1));
checkBoxPanel.add(pepperoniButton());
checkBoxPanel.add(anchoviesButton());

JPanel pricePanel = new JPanel(); // Uses FlowLayout by default
pricePanel.add(new JLabel("Your Price:"));
pricePanel.add(priceTextField);

JPanel centerPanel = new JPanel(); // Uses FlowLayout
centerPanel.add(radioButtonPanel);
centerPanel.add(checkBoxPanel);

// Frame uses BorderLayout by default
add(centerPanel, BorderLayout.CENTER);
add(pricePanel, BorderLayout.SOUTH);
```

Of course, you also need to add event handlers to the components. See How To 10.1.

Productivity Hint 18.1

Use a GUI Builder

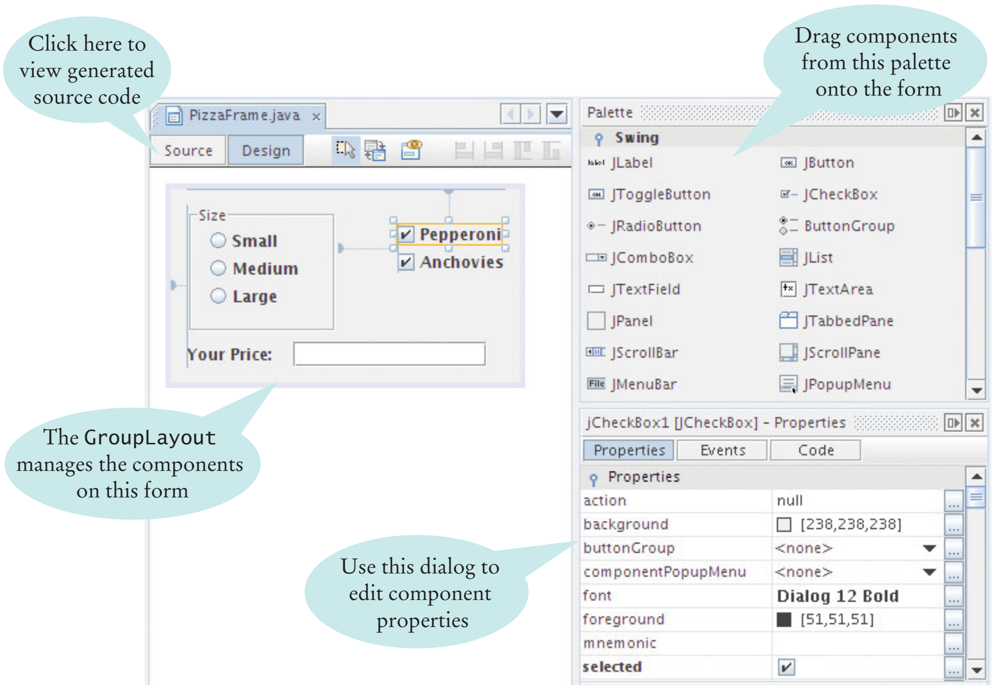
As you have seen, implementing even a simple graphical user interface in Java is quite tedious. You have to write a lot of code for constructing components, using layout managers, and providing event handlers. Most of the code is boring and repetitive.

A GUI builder takes away much of the tedium. Most GUI builders help you in three ways:

- You drag and drop components onto a panel. The GUI builder writes the layout management code for you.
- You customize components with a dialog box, setting properties such as fonts, colors, text, and so on. The GUI builder writes the customization code for you.
- You provide event handlers by picking the event to process and providing just the code snippet for the listener method. The GUI builder writes the boilerplate code for attaching a listener object.

Java 6 introduced `GroupLayout`, a powerful layout manager that was specifically designed to be used by GUI builders. The free NetBeans development environment, available from `http://netbeans.org`, makes use of this layout manager—see Figure 11.

If you need to build a complex user interface, you will find that learning to use a GUI builder is a very worthwhile investment. You will spend less time writing boring code, and you will have more fun designing your user interface and focusing on the functionality of your program.



Properties	
action	null
background	[238,238,238]
buttonGroup	<none>
componentPopupMenu	<none>
font	Dialog 12 Bold
foreground	[51,51,51]
mnemonic	
selected	✓

Figure 11 A GUI Builder

18.5 Menus

A frame contains a menu bar. The menu bar contains menus. A menu contains submenus and menu items.

Anyone who has ever used a graphical user interface is familiar with pull-down menus (see Figure 12). In Java it is easy to create these menus.

The container for the top-level menu items is called a *menu bar*. A *menu* is a collection of *menu items* and more menus (submenus). You add menu items and submenus with the add method:

```
JMenuItem fileExitItem = new JMenuItem("Exit");
fileMenu.add(fileExitItem);
```

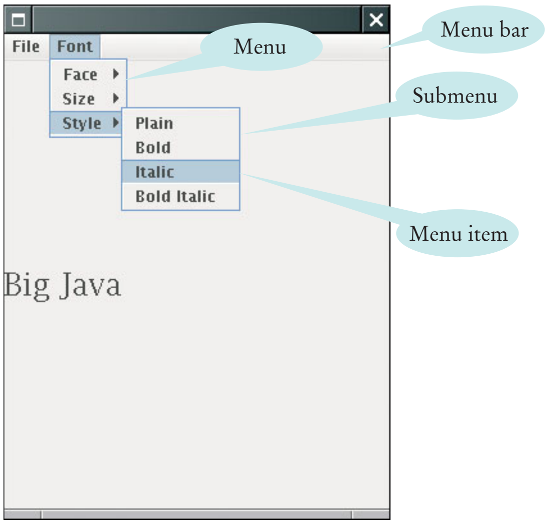
Menu items generate action events.

A menu item has no further submenus. When the user selects a menu item, the menu item sends an action event. Therefore, you want to add a listener to each menu item:

```
fileExitItem.addActionListener(listener);
```

You add action listeners only to menu items, not to menus or the menu bar. When the user clicks on a menu name and a submenu opens, no action event is sent.

Figure 12 Pull-Down Menus



The following program builds up a small but typical menu and traps the action events from the menu items. To keep the program readable, it is a good idea to use a separate method for each menu or set of related menus. Have a look at the `createFaceItem` method, which creates a menu item to change the font face. The same listener class takes care of three cases, with the `name` parameters varying for each menu item. The same strategy is used for the `createSizeItem` and `createStyleItem` methods.

ch18/menu/FontViewer2.java

```java
import javax.swing.JFrame;

/**
   This program uses a menu to display font effects.
*/
public class FontViewer2
{
   public static void main(String[] args)
   {
      JFrame frame = new FontViewer2Frame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

ch18/menu/FontViewer2Frame.java

```java
import java.awt.BorderLayout;
import java.awt.Font;
import java.awt.GridLayout;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.ButtonGroup;
import javax.swing.JButton;
import javax.swing.JCheckBox;
import javax.swing.JComboBox;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JMenu;
import javax.swing.JMenuBar;
import javax.swing.JMenuItem;
import javax.swing.JPanel;
import javax.swing.JRadioButton;
import javax.swing.border.EtchedBorder;
import javax.swing.border.TitledBorder;

/**
   This frame has a menu with commands to change the font
   of a text sample.
*/
public class FontViewer2Frame extends JFrame
{
   private static final int FRAME_WIDTH = 300;
   private static final int FRAME_HEIGHT = 400;

   private JLabel sampleField;
   private String facename;
   private int fontstyle;
   private int fontsize;

   /**
      Constructs the frame.
   */
   public FontViewer2Frame()
   {
      // Construct text sample
      sampleField = new JLabel("Big Java");
      add(sampleField, BorderLayout.CENTER);

      // Construct menu
      JMenuBar menuBar = new JMenuBar();
      setJMenuBar(menuBar);
      menuBar.add(createFileMenu());
      menuBar.add(createFontMenu());

      facename = "Serif";
      fontsize = 24;
      fontstyle = Font.PLAIN;

      setSampleFont();
      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }

   /**
      Creates the File menu.
      @return the menu
   */
   public JMenu createFileMenu()

   {
      JMenu menu = new JMenu("File");
      menu.add(createFileExitItem());
      return menu;
   }

   /**
      Creates the File->Exit menu item and sets its action listener.
      @return the menu item
   */
   public JMenuItem createFileExitItem()
   {
      JMenuItem item = new JMenuItem("Exit");
      class MenuItemListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            System.exit(0);
         }
      }
      ActionListener listener = new MenuItemListener();
      item.addActionListener(listener);
      return item;
   }

   /**
      Creates the Font submenu.
      @return the menu
   */
   public JMenu createFontMenu()
   {
      JMenu menu = new JMenu("Font");
      menu.add(createFaceMenu());
      menu.add(createSizeMenu());
      menu.add(createStyleMenu());
      return menu;
   }

   /**
      Creates the Face submenu.
      @return the menu
   */
   public JMenu createFaceMenu()
   {
      JMenu menu = new JMenu("Face");
      menu.add(createFaceItem("Serif"));
      menu.add(createFaceItem("SansSerif"));
      menu.add(createFaceItem("Monospaced"));
      return menu;
   }

    /**
      Creates the Size submenu.
      @return the menu
   */
   public JMenu createSizeMenu()
   {
      JMenu menu = new JMenu("Size");
      menu.add(createSizeItem("Smaller", -1));
      menu.add(createSizeItem("Larger", 1));
      return menu;
   }

   /**
      Creates the Style submenu.
      @return the menu
   */
   public JMenu createStyleMenu()
   {
      JMenu menu = new JMenu("Style");
      menu.add(createStyleItem("Plain", Font.PLAIN));
      menu.add(createStyleItem("Bold", Font.BOLD));
      menu.add(createStyleItem("Italic", Font.ITALIC));
      menu.add(createStyleItem("Bold Italic", Font.BOLD
            + Font.ITALIC));
      return menu;
   }

   /**
      Creates a menu item to change the font face and set its action listener.
      @param name the name of the font face
      @return the menu item
   */
   public JMenuItem createFaceItem(final String name)
   {
      JMenuItem item = new JMenuItem(name);
      class MenuItemListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            facename = name;
            setSampleFont();
         }
      }
      ActionListener listener = new MenuItemListener();
      item.addActionListener(listener);
      return item;
   }

   /**
      Creates a menu item to change the font size
      and set its action listener.
      @param name the name of the menu item
      @param ds the amount by which to change the size
      @return the menu item
   */
   public JMenuItem createSizeItem(String name, final int ds)
   {
      JMenuItem item = new JMenuItem(name);
      class MenuItemListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            fontsize = fontsize + ds;
            setSampleFont();
         }
      }
      ActionListener listener = new MenuItemListener();
      item.addActionListener(listener);
      return item;
   }

```

```java
   /**
      Creates a menu item to change the font style
      and set its action listener.
      @param name the name of the menu item
      @param style the new font style
      @return the menu item
   */
   public JMenuItem createStyleItem(String name, final int style)
   {
      JMenuItem item = new JMenuItem(name);
      class MenuItemListener implements ActionListener
      {
         public void actionPerformed(ActionEvent event)
         {
            fontstyle = style;
            setSampleFont();
         }
      }
      ActionListener listener = new MenuItemListener();
      item.addActionListener(listener);
      return item;
   }

   /**
      Sets the font of the text sample.
   */
   public void setSampleFont()
   {
      Font f = new Font(facename, fontstyle, fontsize);
      sampleField.setFont(f);
      sampleField.repaint();
   }
}
```

SELF CHECK

11. Why do `JMenu` objects not generate action events?

12. Why is the `name` parameter in the `createFaceItem` method declared as `final`?

How To 18.2 Implementing a Graphical User Interface (GUI)

A GUI program allows users to supply inputs and specify actions. The `textfield/Investment-Viewer3` program has only one input and one action. More sophisticated programs have more interesting user interactions, but the basic principles are the same.

Step 1 Enumerate the actions that your program needs to carry out.

For example, the investment viewer has a single action, to add interest. Other programs may have different actions, perhaps for making deposits, inserting coins, and so on.

Step 2 For each action, enumerate the inputs that you need.

For example, the investment viewer has a single input: the interest rate. Other programs may have different inputs, such as amounts of money, product quantities, and so on.

Step 3 For each action, enumerate the outputs that you need to show.

The investment viewer has a single output: the current balance. Other programs may show different quantities, messages, and so on.

Step 4 Supply the user-interface components.

Use buttons or menus for actions, text components for inputs, choice components to present finite sets of choices, and labels for outputs. Implement your own components to produce graphical output, such as charts or drawings.

Step 5 Use layout managers for layout.

Add the required components to a frame, using the techniques of How To 18.1.

Step 6 Supply event handler classes.

For each button, choice component, or menu item, you need to add an object of a listener class. The listener classes must implement the `ActionListener` interface. Supply a class for each action (or group of related actions), and put the instructions for the action in the `actionPerformed` method.

```
class Button1Listener implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      // button1 action goes here
      . . .
   }
}
```

Remember to declare any local variables accessed by the listener methods as `final`.

Step 7 Make listener objects and attach them to the event sources.

For action events, the event source is a button or other user-interface component, or a timer. You need to add a listener object to each event source, like this:

```
ActionListener listener1 = new Button1Listener();
button1.addActionListener(listener1);
```

18.6 Exploring the Swing Documentation

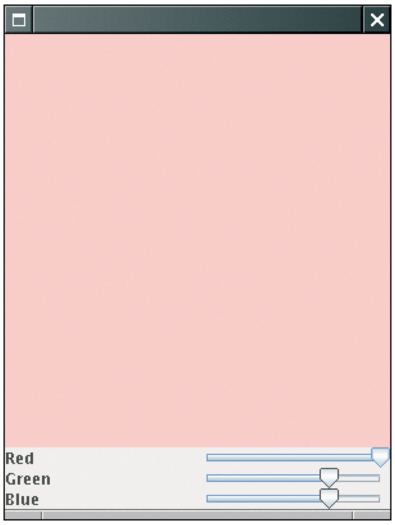
You should learn to navigate the API documentation to find out more about user-interface components.

In the preceding sections, you saw the basic properties of the most common user-interface components. We purposefully omitted many options and variations to simplify the discussion. You can go a long way by using only the simplest properties of these components. If you want to implement a more sophisticated effect, you can look inside the Swing documentation. You will probably find the documentation quite intimidating at first glance, though. The purpose of this section is to show you how you can use the documentation to your advantage without becoming overwhelmed.

As an example, consider a program for mixing colors by specifying the red, green, and blue values. How can you specify the colors? Of course, you could supply three text fields, but sliders would be more convenient for users of your program (see Figure 13).

The Swing user-interface toolkit has a large set of user-interface components. How do you know if there is a slider? You can buy a book that illustrates all Swing components. Or you can run the sample application included in the Java Development Kit that shows off all Swing components (see Figure 14). Or you can look at the names of all of the classes that start with `J` and decide that `JSlider` may be a good candidate.

Figure 13
A Color Viewer



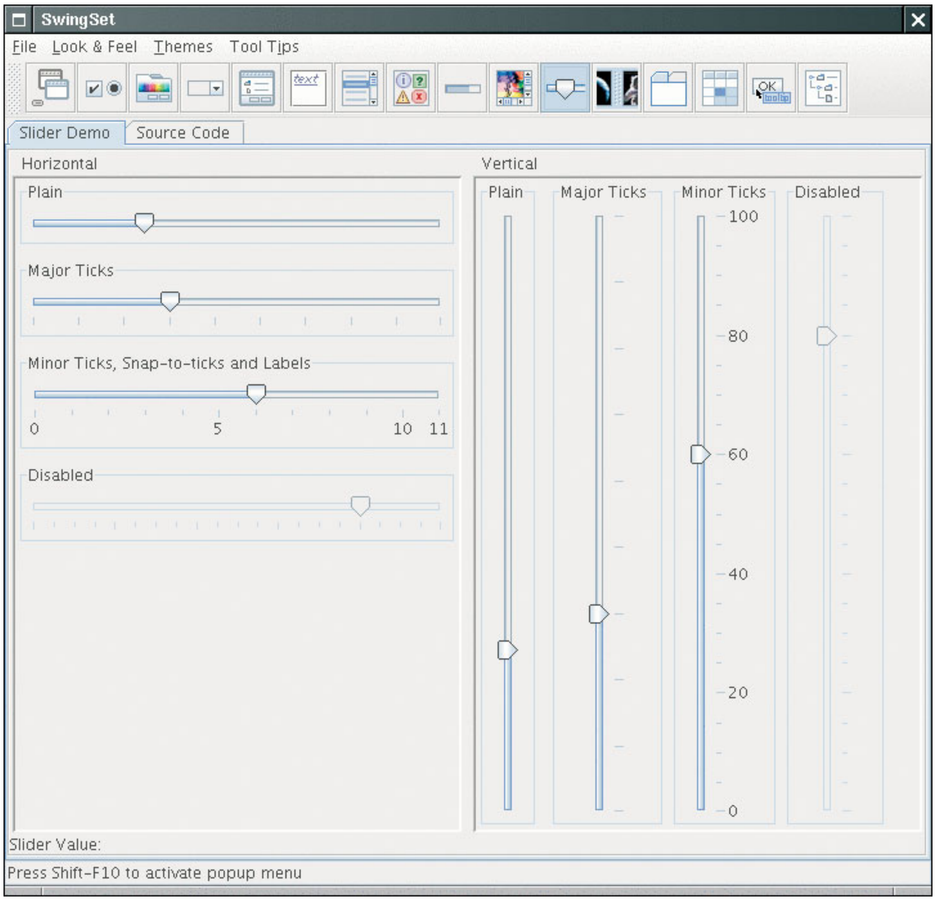


Figure 14 The SwingSet Demo

Next, you need to ask yourself a few questions:

- How do I construct a `JSlider`?
- How can I get notified when the user has moved it?
- How can I tell to which value the user has set it?

When you look at the documentation of the `JSlider` class, you will probably not be happy. There are over 50 methods in the `JSlider` class and over 250 inherited methods, and some of the method descriptions look downright scary, such as the one in Figure 15. Apparently some folks out there are concerned about the `valueIsAdjusting` property, whatever that may be, and the designers of this class felt it necessary to supply a method to tweak that property. Until you too feel that need, your best bet is to ignore this method. As the author of an introductory book, it pains me to tell you to ignore certain facts. But the truth of the matter is that the Java library is so large and complex that nobody understands it in its entirety, not even the designers of Java themselves. You need to develop the ability to separate fundamental concepts from ephemeral minutiae. For example, it is important that you understand the concept of event handling. Once you understand the concept, you can ask the question, "What event does the slider send when the user moves it?" But it is not important that you memorize how to set tick marks or that you know how to implement a slider with a custom look and feel.

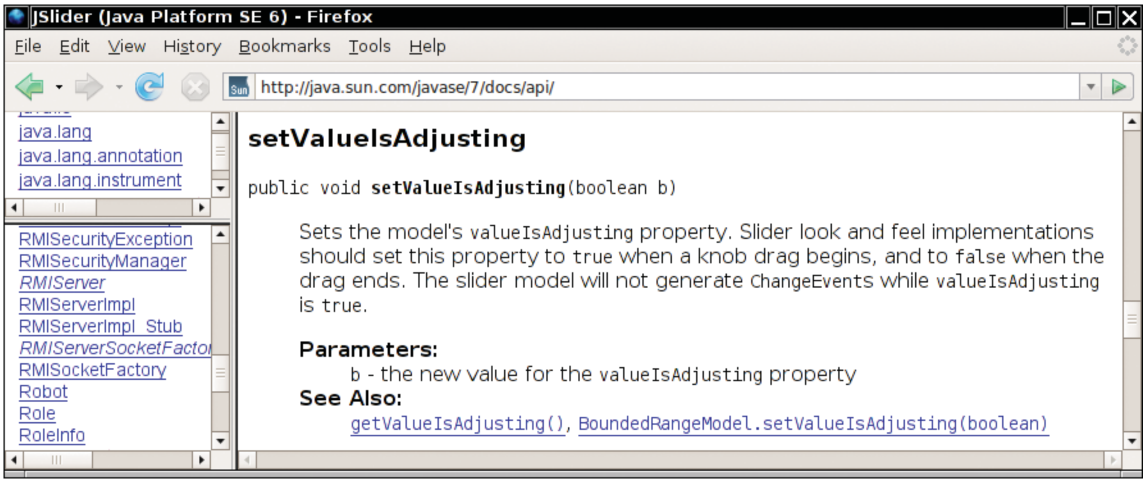
Let us go back to our fundamental questions. In Java 6, there are six constructors for the `JSlider` class. You want to learn about one or two of them. You must strike a balance somewhere between the trivial and the bizarre. Consider

`public JSlider()`
Creates a horizontal slider with the range 0 to 100 and an initial value of 50.

Maybe that is good enough for now, but what if you want another range or initial value? It seems too limited.

On the other side of the spectrum, there is

`public JSlider(BoundedRangeModel brm)`
Creates a horizontal slider using the specified `BoundedRangeModel`.



setValueIsAdjusting

`public void setValueIsAdjusting(boolean b)`

Sets the model's `valueIsAdjusting` property. Slider look and feel implementations should set this property to `true` when a knob drag begins, and to `false` when the drag ends. The slider model will not generate `ChangeEvent`s while `valueIsAdjusting` is `true`.

Parameters:
`b` - the new value for the `valueIsAdjusting` property
See Also:
`getValueIsAdjusting()`, `BoundedRangeModel.setValueIsAdjusting(boolean)`

Figure 15 A Mysterious Method Description from the API Documentation

Whoa! What is that? You can click on the `BoundedRangeModel` link to get a long explanation of this class. This appears to be some internal mechanism for the Swing implementors. Let's try to avoid this constructor if we can. Looking further, we find

```
public JSlider(int min, int max, int value)
```
Creates a horizontal slider using the specified `min`, `max`, and `value`.

This sounds general enough to be useful and simple enough to be usable. You might want to stash away the fact that you can have vertical sliders as well.

Next, you want to know what events a slider generates. There is no `addActionListener` method. That makes sense. Adjusting a slider seems different from clicking a button, and Swing uses a different event type for these events. There is a method

```
public void addChangeListener(ChangeListener l)
```

Click on the `ChangeListener` link to find out more about this interface. It has a single method

```
void stateChanged(ChangeEvent e)
```

Apparently, that method is called whenever the user moves the slider. What is a `ChangeEvent`? Once again, click on the link, to find out that this event class has *no* methods of its own, but it inherits the `getSource` method from its superclass `EventObject`. The `getSource` method tells us which component generated this event, but we don't need that information—we know that the event came from the slider.

Now let's make a plan: Add a change event listener to each slider. When the slider is changed, the `stateChanged` method is called. Find out the new value of the slider. Recompute the color value and repaint the color panel. That way, the color panel is continually repainted as the user moves one of the sliders.

To compute the color value, you will still need to get the current value of the slider. Look at all the methods that start with `get`. Sure enough, you find

```
public int getValue()
```
Returns the slider's value.

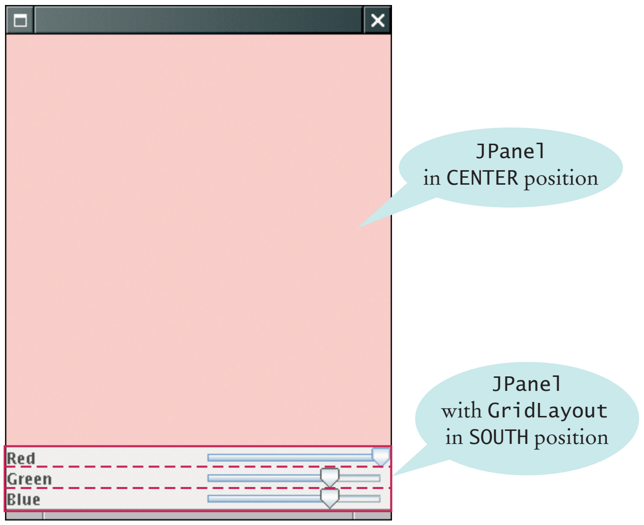
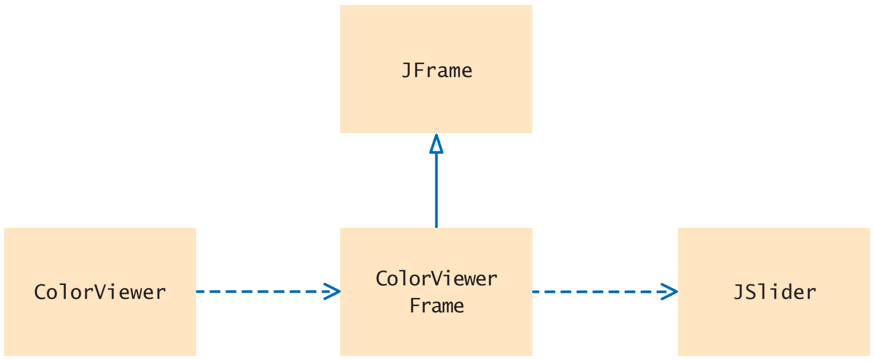

JPanel in CENTER position
JPanel with GridLayout in SOUTH position
Red
Green
Blue

Figure 16
The Components of the `ColorViewerFrame`

Figure 17 Classes of the Color Viewer Program



Now you know everything you need to write the program. The program uses one new Swing component and one event listener of a new type. After having mastered the basics, you may want to explore the capabilities of the component further, for example by adding tick marks—see Exercise P18.17.

Figure 16 shows how the components are arranged in the frame. Figure 17 shows the UML diagram.

ch18/slider/ColorViewer.java

```java
import javax.swing.JFrame;

public class ColorViewer
{
   public static void main(String[] args)
   {
      ColorViewerFrame frame = new ColorViewerFrame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

ch18/slider/ColorViewerFrame.java

```java
import java.awt.BorderLayout;
import java.awt.Color;
import java.awt.GridLayout;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JSlider;
import javax.swing.event.ChangeListener;
import javax.swing.event.ChangeEvent;

public class ColorViewerFrame extends JFrame
{
   private static final int FRAME_WIDTH = 300;
   private static final int FRAME_HEIGHT = 400;

   private JPanel colorPanel;
   private JSlider redSlider;
   private JSlider greenSlider;
   private JSlider blueSlider;

   public ColorViewerFrame()
   {
      colorPanel = new JPanel();

      add(colorPanel, BorderLayout.CENTER);
      createControlPanel();
      setSampleColor();
      setSize(FRAME_WIDTH, FRAME_HEIGHT);
   }

   public void createControlPanel()
   {
      class ColorListener implements ChangeListener
      {
         public void stateChanged(ChangeEvent event)
         {
            setSampleColor();
         }
      }

      ChangeListener listener = new ColorListener();

      redSlider = new JSlider(0, 255, 255);
      redSlider.addChangeListener(listener);

      greenSlider = new JSlider(0, 255, 175);
      greenSlider.addChangeListener(listener);

      blueSlider = new JSlider(0, 255, 175);
      blueSlider.addChangeListener(listener);

      JPanel controlPanel = new JPanel();
      controlPanel.setLayout(new GridLayout(3, 2));

      controlPanel.add(new JLabel("Red"));
      controlPanel.add(redSlider);

      controlPanel.add(new JLabel("Green"));
      controlPanel.add(greenSlider);

      controlPanel.add(new JLabel("Blue"));
      controlPanel.add(blueSlider);

      add(controlPanel, BorderLayout.SOUTH);
   }

   /**
      Reads the slider values and sets the panel to
      the selected color.
   */
   public void setSampleColor()
   {
      // Read slider values

      int red = redSlider.getValue();
      int green = greenSlider.getValue();
      int blue = blueSlider.getValue();

```

```
        // Set panel background to selected color

        colorPanel.setBackground(new Color(red, green, blue));
        colorPanel.repaint();
    }
}
```

SELF CHECK

13. Suppose you want to allow users to pick a color from a color dialog box. Which class would you use? Look in the API documentation.
14. Why does a slider emit change events and not action events?

Summary of Learning Objectives

Use text fields for reading text input.

- Use `JTextField` components to provide space for user input. Place a `JLabel` next to each text field.

Use text areas for reading and displaying multi-line text.

- Use a `JTextArea` to show multiple lines of text.
- You can add scroll bars to any component with a `JScrollPane`.

Learn how to arrange multiple components in a container.

- User-interface components are arranged by placing them inside containers. Containers can be placed inside larger containers.
- Each container has a layout manager that directs the arrangement of its components.
- When adding a component to a container with the border layout, specify the `NORTH`, `EAST`, `SOUTH`, `WEST`, or `CENTER` position.
- The content pane of a frame has a border layout by default. A panel has a flow layout by default.

Select among the Swing components for presenting choices to the user.

- For a small set of mutually exclusive choices, use a group of radio buttons or a combo box.
- Add radio buttons into a `ButtonGroup` so that only one button in the group is on at any time.
- You can place a border around a panel to group its contents visually.
- For a binary choice, use a check box.
- For a large set of choices, use a combo box.
- Radio buttons, check boxes, and combo boxes generate action events, just as buttons do.

Implement menus in a Swing program.

- A frame contains a menu bar. The menu bar contains menus. A menu contains submenus and menu items.
- Menu items generate action events.
- You should learn to navigate the API documentation to find out more about user-interface components.

Classes, Objects, and Methods Introduced in this Chapter

```
java.awt.BorderLayout
   CENTER
   EAST
   NORTH
   SOUTH
   WEST
java.awt.Container
   setLayout
java.awt.FlowLayout
java.awt.Font
java.awt.GridLayout
javax.swing.AbstractButton
   isSelected
   setSelected
javax.swing.ButtonGroup
   add
javax.swing.ImageIcon
javax.swing.JCheckBox
javax.swing.JComboBox
   addItem
   getSelectedItem
   isEditable
   setEditable
javax.swing.JComponent
   setBorder
   setFont
javax.swing.JFrame
   setJMenuBar
javax.swing.JMenu
   add
javax.swing.JMenuBar
   add
javax.swing.JMenuItem
javax.swing.JRadioButton
javax.swing.JScrollPane
javax.swing.JSlider
   addChangeListener
   getValue
javax.swing.JTextArea
   append
javax.swing.JTextField
javax.swing.border.EtchedBorder
javax.swing.border.TitledBorder
javax.swing.event.ChangeEvent
javax.swing.event.ChangeListener
   stateChanged
javax.swing.text.JTextComponent
   getText
   isEditable
   setEditable
   setText
```

Media Resources

WILEY PLUS

www.wiley.com/ college/ horstmann

- ● Lab Exercises
- ⊕ Practice Quiz
- ⊕ Code Completion Exercises

Review Exercises

★G **R18.1** What is the difference between a label, a text field, and a text area?

★★G **R18.2** Name a method that is declared in `JTextArea`, a method that `JTextArea` inherits from `JTextComponent`, and a method that `JTextArea` inherits from `JComponent`.

★G **R18.3** Can you use a flow layout for the components in a frame? If yes, how?

★G **R18.4** What is the advantage of a layout manager over telling the container "place this component at position (x, y)"?

★★G **R18.5** What happens when you place a single button into the `CENTER` area of a container that uses a border layout? Try it out, by writing a small sample program, if you aren't sure of the answer.

★★G **R18.6** What happens if you place multiple buttons directly into the `SOUTH` area, without using a panel? Try it out, by writing a small sample program, if you aren't sure of the answer.

★★G **R18.7** What happens when you add a button to a container that uses a border layout and omit the position? Try it out and explain.

★★G **R18.8** What happens when you try to add a button to another button? Try it out and explain.

★★G **R18.9** The `ColorViewerFrame` uses a grid layout manager. Explain a drawback of the grid that is apparent from Figure 16 on page 767. What could you do to overcome this drawback?

★★★G **R18.10** What is the difference between the grid layout and the grid bag layout?

★★★G **R18.11** Can you add icons to check boxes, radio buttons, and combo boxes? Browse the Java documentation to find out. Then write a small test program to verify your findings.

★G **R18.12** What is the difference between radio buttons and check boxes?

★G **R18.13** Why do you need a button group for radio buttons but not for check boxes?

★G **R18.14** What is the difference between a menu bar, a menu, and a menu item?

★G **R18.15** When browsing through the Java documentation for more information about sliders, we ignored the `JSlider` constructor with no parameters. Why? Would it have worked in our sample program?

★G **R18.16** How do you construct a vertical slider? Consult the Swing documentation for an answer.

★★G **R18.17** Why doesn't a `JComboBox` send out change events?

★★★G **R18.18** What component would you use to show a set of choices, just as in a combo box, but so that several items are visible at the same time? Run the Swing demo application or look at a book with Swing example programs to find the answer.

★★G **R18.19** How many Swing user-interface components are there? Look at the Java documentation to get an approximate answer.

★★G **R18.20** How many methods does the `JProgressBar` component have? Be sure to count inherited methods. Look at the Java documentation.

Programming Exercises

★G **P18.1** Write a graphical application front end for a bank account class. Supply text fields and buttons for depositing and withdrawing money, and for displaying the current balance in a label.

★G **P18.2** Write a graphical application front end for an `Earthquake` class. Supply a text field and button for entering the strength of the earthquake. Display the earthquake description in a label.

★G **P18.3** Write a graphical application front end for a `DataSet` class. Supply text fields and buttons for adding floating-point values, and display the current minimum, maximum, and average in a label.

★G **P18.4** Write an application with three labeled text fields, one each for the initial amount of a savings account, the annual interest rate, and the number of years. Add a button "Calculate" and a read-only text area to display the result, namely, the balance of the savings account after the end of each year.

★★G **P18.5** In the application from Exercise P18.4, replace the text area with a bar chart that shows the balance after the end of each year.

★★★G **P18.6** Write a program that contains a text field, a button "Add Value", and a component that draws a bar chart of the numbers that a user typed into the text field.

★★★G **P18.7** Write a program that draws a clock face with a time that the user enters in two text fields (one for the hours, one for the minutes).

Hint: You need to determine the angles of the hour hand and the minute hand. The angle of the minute hand is easy: The minute hand travels 360 degrees in 60 minutes. The angle of the hour hand is harder; it travels 360 degrees in 12×60 *minutes*.

★G **P18.8** Write an application with three buttons labeled "Red", "Green", and "Blue" that changes the background color of a panel in the center of the frame to red, green, or blue.

★★G **P18.9** Add icons to the buttons of Exercise P18.8.

★★G **P18.10** Write a calculator application. Use a grid layout to arrange buttons for the digits and for the $+ - \times \div$ operations. Add a text field to display the result.

★G **P18.11** Write an application with three radio buttons labeled "Red", "Green", and "Blue" that changes the background color of a panel in the center of the frame to red, green, or blue.

★G **P18.12** Write an application with three check boxes labeled “Red”, “Green”, and “Blue” that adds a red, green, or blue component to the background color of a panel in the center of the frame. This application can display a total of eight color combinations.

★G **P18.13** Write an application with a combo box containing three items labeled “Red”, “Green”, and “Blue” that changes the background color of a panel in the center of the frame to red, green, or blue.

★G **P18.14** Write an application with a Color menu and menu items labeled “Red”, “Green”, and “Blue” that changes the background color of a panel in the center of the frame to red, green, or blue.

★G **P18.15** Write a program that displays a number of rectangles at random positions. Supply buttons “Fewer” and “More” that generate fewer or more random rectangles. Each time the user clicks on “Fewer”, the count should be halved. Each time the user clicks on “More”, the count should be doubled.

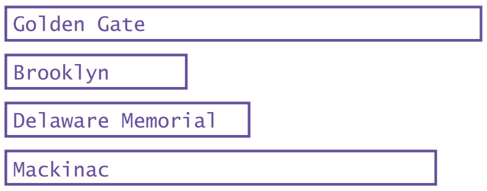
★★G **P18.16** Modify the program of Exercise P18.15 to replace the buttons with a slider to generate fewer or more random rectangles.

★★G **P18.17** In the slider test program, add a set of tick marks to each slider that show the exact slider position.

★★★G **P18.18** Enhance the font viewer program to allow the user to select different fonts. Research the API documentation to find out how to find the available fonts on the user’s system.

Programming Projects

Project 18.1 Write a program that lets users design charts such as the following:



Use appropriate components to ask for the length, label, and color, then apply them when the user clicks an “Add Item” button. Allow the user to switch between bar charts and pie charts.

Project 18.2 Write a program that displays a scrolling message in a panel. Use a timer for the scrolling effect. In the timer’s action listener, move the starting position of the message and repaint. When the message has left the window, reset the starting position to the other corner. Provide a user interface to customize the message text, font, foreground and background colors, and the scrolling speed and direction.

Answers to Self-Check Questions

1. Then the text field is not labeled, and the user will not know its purpose.
2. `Integer.parseInt(textField.getText())`
3. A text field holds a single line of text; a text area holds multiple lines.
4. The text area is intended to display the program output. It does not collect user input.
5. Don't construct a `JScrollPane` but add the `resultArea` object directly to the frame.
6. First add them to a panel, then add the panel to the north end of a frame.
7. Place them inside a panel with a `GridLayout` that has three rows and one column.
8. If you have many options, a set of radio buttons takes up a large area. A combo box can show many options without using up much space. But the user cannot see the options as easily.
9. When any of the component settings is changed, the program simply queries all of them and updates the label.
10. To keep it from growing too large. It would have grown to the same width and height as the two panels below it.
11. When you open a menu, you have not yet made a selection. Only `JMenuItem` objects correspond to selections.
12. The parameter variable is accessed in a method of an inner class.
13. `JColorChooser`.
14. Action events describe one-time changes, such as button clicks. Change events describe continuous changes.

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Appendix A

The Basic Latin and Latin-1 Subsets of Unicode

This appendix lists the Unicode characters that are most commonly used for processing Western European languages. A complete listing of Unicode characters can be found at `http://unicode.org`.

Table 1 Selected Control Characters

Character	Code	Decimal	Escape Sequence
Tab	`'\u0009'`	9	`'\t'`
Newline	`'\u000A'`	10	`'\n'`
Return	`'\u000D'`	13	`'\r'`
Space	`'\u0020'`	32	

Table 2 The Basic Latin (ASCII) Subset of Unicode

Char.	Code	Dec.	Char.	Code	Dec.	Char.	Code	Dec.
			@	'\u0040'	64	`	'\u0060'	96
!	'\u0021'	33	A	'\u0041'	65	a	'\u0061'	97
"	'\u0022'	34	B	'\u0042'	66	b	'\u0062'	98
#	'\u0023'	35	C	'\u0043'	67	c	'\u0063'	99
$	'\u0024'	36	D	'\u0044'	68	d	'\u0064'	100
%	'\u0025'	37	E	'\u0045'	69	e	'\u0065'	101
&	'\u0026'	38	F	'\u0046'	70	f	'\u0066'	102
'	'\u0027'	39	G	'\u0047'	71	g	'\u0067'	103
(	'\u0028'	40	H	'\u0048'	72	h	'\u0068'	104
)	'\u0029'	41	I	'\u0049'	73	i	'\u0069'	105
*	'\u002A'	42	J	'\u004A'	74	j	'\u006A'	106
+	'\u002B'	43	K	'\u004B'	75	k	'\u006B'	107
,	'\u002C'	44	L	'\u004C'	76	l	'\u006C'	108
-	'\u002D'	45	M	'\u004D'	77	m	'\u006D'	109
.	'\u002E'	46	N	'\u004E'	78	n	'\u006E'	110
/	'\u002F'	47	O	'\u004F'	79	o	'\u006F'	111
0	'\u0030'	48	P	'\u0050'	80	p	'\u0070'	112
1	'\u0031'	49	Q	'\u0051'	81	q	'\u0071'	113
2	'\u0032'	50	R	'\u0052'	82	r	'\u0072'	114
3	'\u0033'	51	S	'\u0053'	83	s	'\u0073'	115
4	'\u0034'	52	T	'\u0054'	84	t	'\u0074'	116
5	'\u0035'	53	U	'\u0055'	85	u	'\u0075'	117
6	'\u0036'	54	V	'\u0056'	86	v	'\u0076'	118
7	'\u0037'	55	W	'\u0057'	87	w	'\u0077'	119
8	'\u0038'	56	X	'\u0058'	88	x	'\u0078'	120
9	'\u0039'	57	Y	'\u0059'	89	y	'\u0079'	121
:	'\u003A'	58	Z	'\u005A'	90	z	'\u007A'	122
;	'\u003B'	59	[	'\u005B'	91	{	'\u007B'	123
<	'\u003C'	60	\	'\u005C'	92	|	'\u007C'	124
=	'\u003D'	61	]	'\u005D'	93	}	'\u007D'	125
>	'\u003E'	62	^	'\u005E'	94	~	'\u007E'	126
?	'\u003F'	63	_	'\u005F'	95			

Table 3 The Latin-1 Subset of Unicode

Char.	Code	Dec.	Char.	Code	Dec.	Char.	Code	Dec.
			À	'\u00C0'	192	à	'\u00E0'	224
¡	'\u00A1'	161	Á	'\u00C1'	193	á	'\u00E1'	225
¢	'\u00A2'	162	Â	'\u00C2'	194	â	'\u00E2'	226
£	'\u00A3'	163	Ã	'\u00C3'	195	ã	'\u00E3'	227
¤	'\u00A4'	164	Ä	'\u00C4'	196	ä	'\u00E4'	228
¥	'\u00A5'	165	Å	'\u00C5'	197	å	'\u00E5'	229
¦	'\u00A6'	166	Æ	'\u00C6'	198	æ	'\u00E6'	230
§	'\u00A7'	167	Ç	'\u00C7'	199	ç	'\u00E7'	231
¨	'\u00A8'	168	È	'\u00C8'	200	è	'\u00E8'	232
©	'\u00A9'	169	É	'\u00C9'	201	é	'\u00E9'	233
ª	'\u00AA'	170	Ê	'\u00CA'	202	ê	'\u00EA'	234
«	'\u00AB'	171	Ë	'\u00CB'	203	ë	'\u00EB'	235
¬	'\u00AC'	172	Ì	'\u00CC'	204	ì	'\u00EC'	236
-	'\u00AD'	173	Í	'\u00CD'	205	í	'\u00ED'	237
®	'\u00AE'	174	Î	'\u00CE'	206	î	'\u00EE'	238
¯	'\u00AF'	175	Ï	'\u00CF'	207	ï	'\u00EF'	239
°	'\u00B0'	176	Ð	'\u00D0'	208	ð	'\u00F0'	240
±	'\u00B1'	177	Ñ	'\u00D1'	209	ñ	'\u00F1'	241
²	'\u00B2'	178	Ò	'\u00D2'	210	ò	'\u00F2'	242
³	'\u00B3'	179	Ó	'\u00D3'	211	ó	'\u00F3'	243
´	'\u00B4'	180	Ô	'\u00D4'	212	ô	'\u00F4'	244
µ	'\u00B5'	181	Õ	'\u00D5'	213	õ	'\u00F5'	245
¶	'\u00B6'	182	Ö	'\u00D6'	214	ö	'\u00F6'	246
·	'\u00B7'	183	×	'\u00D7'	215	÷	'\u00F7'	247
¸	'\u00B8'	184	Ø	'\u00D8'	216	ø	'\u00F8'	248
¹	'\u00B9'	185	Ù	'\u00D9'	217	ù	'\u00F9'	249
º	'\u00BA'	186	Ú	'\u00DA'	218	ú	'\u00FA'	250
»	'\u00BB'	187	Û	'\u00DB'	219	û	'\u00FB'	251
¼	'\u00BC'	188	Ü	'\u00DC'	220	ü	'\u00FC'	252
½	'\u00BD'	189	Ý	'\u00DD'	221	ý	'\u00FD'	253
¾	'\u00BE'	190	Þ	'\u00DE'	222	þ	'\u00FE'	254
¿	'\u00BF'	191	ß	'\u00DF'	223	ÿ	'\u00FF'	255

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Appendix B

Java Operator Summary

The Java operators are listed in groups of decreasing precedence in the table below. The horizontal lines in the table indicate a change in operator precedence. For example, `z = x - y;` means `z = (x - y);` because `=` has lower precedence than `-`.

The prefix unary operators, conditional operator, and the assignment operators associate right-to-left. All other operators associate left-to-right.

Operator	Description	Associativity
`.`	Access class feature	Left to right
`[]`	Array subscript	
`()`	Function call	
`++`	Increment	Right to left
`--`	Decrement	
`!`	Boolean *not*	
`~`	Bitwise *not*	
`+` *(unary)*	(Has no effect)	
`-` *(unary)*	Negative	
(*TypeName*)	Cast	
`new`	Object allocation	
`*`	Multiplication	Left to right
`/`	Division or integer division	
`%`	Integer remainder	
`+`	Addition, string concatenation	Left to right
`-`	Subtraction	

Operator	Description	Associativity
`<<`	Shift left	Left to right
`>>`	Right shift with sign extension	
`>>>`	Right shift with zero extension	
`<`	Less than	Left to right
`<=`	Less than or equal	
`>`	Greater than	
`>=`	Greater than or equal	
`instanceof`	Tests whether an object's type is a given type or a subtype thereof	
`==`	Equal	Left to right
`!=`	Not equal	
`&`	Bitwise *and*	Left to right
`^`	Bitwise exclusive *or*	Left to right
`|`	Bitwise *or*	Left to right
`&&`	Boolean "short circuit" *and*	Left to right
`||`	Boolean "short circuit" *or*	Left to right
`? :`	Conditional	Right to left
`=`	Assignment	Right to left
op=	Assignment with binary operator (*op* is one of +, -, *, /, &, |, ^, <<, >>, >>>)	

Appendix C

Java Reserved Word Summary

Reserved Word	Description
`abstract`	An abstract class or method
`assert`	An assertion that a condition is fulfilled
`boolean`	The Boolean type
`break`	Breaks out of the current loop or labeled statement
`byte`	The 8-bit signed integer type
`case`	A label in a `switch` statement
`catch`	The handler for an exception in a `try` block
`char`	The 16-bit Unicode character type
`class`	Defines a class
`const`	Not used
`continue`	Skip the remainder of a loop body
`default`	The default label in a `switch` statement
`do`	A loop whose body is executed at least once
`double`	The 64-bit double-precision floating-point type
`else`	The alternative clause in an `if` statement
`enum`	An enumeration type
`extends`	Indicates that a class is a subclass of another class
`final`	A value that cannot be changed after it has been initialized, a method that cannot be overridden, or a class that cannot be extended
`finally`	A clause of a `try` block that is always executed
`float`	The 32-bit single-precision floating-point type
`for`	A loop with initialization, condition, and update expressions
`goto`	Not used

Reserved Word	Description
`if`	A conditional branch statement
`implements`	Indicates that a class realizes an interface
`import`	Allows the use of class names without the package name
`instanceof`	Tests whether an object's type is a given type or a subtype thereof
`int`	The 32-bit integer type
`interface`	An abstract type with only abstract methods and constants
`long`	The 64-bit integer type
`native`	A method implemented in non-Java code
`new`	Allocates an object
`package`	A collection of related classes
`private`	A feature that is accessible only by methods of the same class
`protected`	A feature that is accessible only by methods of the same class, a subclass, or another class in the same package
`public`	A feature that is accessible by all methods
`return`	Returns from a method
`short`	The 16-bit integer type
`static`	A feature that is defined for a class, not for individual instances
`strictfp`	Use strict rules for floating-point computations
`super`	Invoke the superclass constructor or a superclass method
`switch`	A selection statement
`synchronized`	A block of code that is accessible to only one thread at a time
`this`	The implicit parameter of a method; or invocation of another constructor of the same class
`throw`	Throws an exception
`throws`	The exceptions that a method may throw
`transient`	Instance variables that should not be serialized
`try`	A block of code with exception handlers or a `finally` handler
`void`	Tags a method that doesn't return a value
`volatile`	A variable that may be accessed by multiple threads without synchronization
`while`	A loop statement

Appendix D

The Java Library

This appendix lists all classes and methods from the standard Java library that are used in this book.

In the following inheritance hierarchy, superclasses that are not used in this book are shown in gray type. Some classes implement interfaces not covered in this book; they are omitted. Classes are sorted first by package, then alphabetically within a package.

```
java.awt.Shape
java.lang.Cloneable
java.lang.Object
   java.awt.BorderLayout
   java.awt.Color
   java.awt.Component
      java.awt.Container
         javax.swing.JComponent
            javax.swing.AbstractButton
               javax.swing.JButton
               javax.swing.JMenuItem
                  javax.swing.JMenu
               javax.swing.JToggleButton
                  javax.swing.JCheckBox
                  javax.swing.JRadioButton
            javax.swing.JComboBox
            javax.swing.JFileChooser
            javax.swing.JLabel
            javax.swing.JMenuBar
            javax.swing.JPanel
            javax.swing.JOptionPane
            javax.swing.JScrollPane
            javax.swing.JSlider
            javax.swing.text.JTextComponent
               javax.swing.JTextArea
               javax.swing.JTextField
         java.awt.Panel
            java.applet.Applet
               javax.swing.JApplet
      java.awt.Window
         java.awt.Frame
            javax.swing.JFrame
   java.awt.Dimension2D
      java.awt.Dimension implements Cloneable
   java.awt.FlowLayout
   java.awt.Font
java.awt.Graphics
   java.awt.Graphics2D;
java.awt.GridLayout
java.awt.event.MouseAdapter implements MouseListener
java.awt.geom.Line2D implements Cloneable, Shape
   java.awt.geom.Line2D.Double
java.awt.geom.Point2D implements Cloneable
   java.awt.geom.Point2D.Double
java.awt.geom.RectangularShape implements Cloneable, Shape
   java.awt.geom.Rectangle2D
      java.awt.Rectangle
   java.awt.geom.Ellipse2D
      java.awt.geom.Ellipse2D.Double
java.io.File implements Comparable<File>
java.io.InputStream
   java.io.FileInputStream
   java.io.ObjectInputStream
java.io.OutputStream
   java.io.FileOutputStream
   java.io.FilterOutputStream
      java.io.PrintStream
   java.io.ObjectOutputStream
java.io.RandomAccessFile
java.io.Writer
   java.io.PrintWriter
java.lang.Boolean implements Comparable<Boolean>
java.lang.Character implements Comparable<Character>
java.lang.Math
java.lang.Number
   java.math.BigDecimal implements Comparable<BigDecimal>
   java.math.BigInteger implements Comparable<BigInteger>
   java.lang.Double implements Comparable<Double>
   java.lang.Integer implements Comparable<Integer>
java.lang.String implements Comparable<String>
java.lang.System
java.lang.Throwable
  java.lang.Error
  java.lang.Exception
     java.lang.CloneNotSupportedException
     java.io.IOException
        java.io.EOFException
        java.io.FileNotFoundException
     java.lang.RuntimeException
        java.lang.IllegalArgumentException
           java.lang.NumberFormatException
        java.lang.IllegalStateException
        java.util.NoSuchElementException
           java.util.InputMismatchException
        java.lang.NullPointerException
java.net.URL
java.util.AbstractCollection<E>
   java.util.AbstractList<E>
      java.util.AbstractSequentialList<E>
         java.util.LinkedList<E> implements Cloneable, List<E>
      java.util.ArrayList<E> implements Cloneable, List<E>
   java.util.AbstractQueue<E>
      java.util.PriorityQueue<E>
      java.util.AbstractSet<E>
         java.util.HashSet<E> implements Cloneable, Set<E>
         java.util.TreeSet<E> implements Cloneable, SortedSet<E>
   java.util.AbstractMap<K, V>
      java.util.HashMap<K, V> implements Cloneable, Map<K, V>
      java.util.TreeMap<K, V> implements Cloneable, Map<K, V>
   java.util.Arrays
   java.util.Collections
   java.util.Calendar
      java.util.GregorianCalendar
   java.util.EventObject
      java.awt.AWTEvent
         java.awt.event.ActionEvent
         java.awt.event.ComponentEvent
            java.awt.event.InputEvent
               java.awt.event.MouseEvent
      javax.swing.event.ChangeEvent
   java.util.Random
   java.util.Scanner
   java.util.logging.Level
   java.util.logging.Logger
   javax.swing.ButtonGroup
   javax.swing.ImageIcon
   javax.swing.Timer
   javax.swing.border.AbstractBorder
      javax.swing.border.EtchedBorder
      javax.swing.border.TitledBorder
java.lang.Comparable<T>
java.util.Collection<E>
   java.util.List<E>
   java.util.Set<E>
      java.util.SortedSet<E>
java.util.Comparator<T>
java.util.EventListener
   java.awt.event.ActionListener
   java.awt.event.MouseListener
   javax.swing.event.ChangeListener
java.util.Iterator<E>
   java.util.ListIterator<E>
java.util.Map<K, V>
```

In the following descriptions, the phrase “this object” (“this component”, “this container”, and so forth) means the object (component, container, and so forth) on which the method is invoked (the implicit parameter, `this`).

Package java.applet

Class java.applet.Applet

- `void` **`destroy`**`()`
  This method is called when the applet is about to be terminated, after the last call to `stop`.
- `void` **`init`**`()`
  This method is called when the applet has been loaded, before the first call to `start`. Applets override this method to carry out applet-specific initialization and to read applet parameters.
- `void` **`start`**`()`
  This method is called after the `init` method and each time the applet is revisited.
- `void` **`stop`**`()`
  This method is called whenever the user has stopped watching this applet.

Package java.awt

Class java.awt.BorderLayout

- **`BorderLayout`**`()`
  This constructs a border layout. A border layout has five regions for adding components, called `"North"`, `"East"`, `"South"`, `"West"`, and `"Center"`.
- `static final int CENTER`
  This value identifies the center position of a border layout.
- `static final int EAST`
  This value identifies the east position of a border layout.
- `static final int NORTH`
  This value identifies the north position of a border layout.
- `static final int SOUTH`
  This value identifies the south position of a border layout.
- `static final int WEST`
  This value identifies the west position of a border layout.

Class java.awt.Color

- **`Color`**`(int red, int green, int blue)`
  This creates a color with the specified red, green, and blue values between `0` and 255.
  Parameters: `red` The red component
  `green` The green component
  `blue` The blue component

Class java.awt.Component

- `void` **`addMouseListener`**`(MouseListener listener)`
  This method adds a mouse listener to the component.
  Parameters: `listener` The mouse listener to be added
- `int` **`getHeight`**`()`
  This method gets the height of this component.
  Returns: The height in pixels.
- `int` **`getWidth`**`()`
  This method gets the width of this component.
  Returns: The width in pixels.
- `void` **`repaint`**`()`
  This method repaints this component by scheduling a call to the `paint` method.
- `void` **`setPreferredSize`**`(Dimension preferredSize)`
  This method sets the preferred size of this component.
- `void` **`setSize`**`(int width, int height)`
  This method sets the size of this component.
  Parameters: `width` the component width
  `height` the component height
- `void` **`setVisible`**`(boolean visible)`
  This method shows or hides the component.
  Parameters: `visible` `true` to show the component, or `false` to hide it

Class java.awt.Container

- `void` **`add`**`(Component c)`
- `void` **`add`**`(Component c, Object position)`
  These methods add a component to the end of this container. If a position is given, the layout manager is called to position the component.
  Parameters: `c` The component to be added
  `position` An object expressing position information for the layout manager
- `void` **`setLayout`**`(LayoutManager manager)`
  This method sets the layout manager for this container.
  Parameters: `manager` A layout manager

Class java.awt.Dimension

- **`Dimension`**`(int width, int height)`
  This constructs a `Dimension` object with the given width and height.
  Parameters: `width` The width
  `height` The height

Class java.awt.FlowLayout

- **`FlowLayout`**`()`
  This constructs a new flow layout. A flow layout places as many components as possible in a row, without changing their size, and starts new rows when necessary.

Class java.awt.Font

- `Font(String name, int style, int size)`

  This constructs a font object from the specified name, style, and point size.

  Parameters: `name` The font name, either a font face name or a logical font name, which must be one of `"Dialog"`, `"DialogInput"`, `"Monospaced"`, `"Serif"`, or `"SansSerif"`

  `style` One of `Font.PLAIN`, `Font.ITALIC`, `Font.BOLD`, or `Font.ITALIC+Font.BOLD`

  `size` The point size of the font

Class java.awt.Frame

- `void setTitle(String title)`

  This method sets the frame title.

  Parameters: `title` The title to be displayed in the border of the frame

Class java.awt.Graphics

- `void setColor(Color c)`

  This method sets the current color. From now on, all graphics operations use this color.

  Parameters: `c` The new drawing color

Class java.awt.Graphics2D

- `void draw(Shape s)`

  This method draws the outline of the given shape. Many classes—among them `Rectangle` and `Line2D.Double`—implement the `Shape` interface.

  Parameters: `s` The shape to be drawn

- `void drawString(String s, int x, int y)`
- `void drawString(String s, float x, float y)`

  These methods draw a string in the current font.

  Parameters: `s` The string to draw

  `x,y` The basepoint of the first character in the string

- `void fill(Shape s)`

  This method draws the given shape and fills it with the current color.

  Parameters: `s` The shape to be filled

Class java.awt.GridLayout

- `GridLayout(int rows, int cols)`

  This constructor creates a grid layout with the specified number of rows and columns. The components in a grid layout are arranged in a grid with equal widths and heights. One, but not both, of `rows` and `cols` can be zero, in which case any number of objects can be placed in a row or in a column, respectively.

  Parameters: `rows` The number of rows in the grid

  `cols` The number of columns in the grid

Class java.awt.Rectangle

- `Rectangle()`

  This constructs a rectangle with a top-left corner at (`0`, `0`) and width and height set to `0`.

- `Rectangle(int x, int y, int width, int height)`
  This constructs a rectangle with given top-left corner and size.
  Parameters: `x,y` The top-left corner
  `width` The width
  `height` The height
- `double getHeight()`
- `double getWidth()`
  These methods get the height and width of the rectangle.
- `double getX()`
- `double getY()`
  These methods get the *x*- and *y*-coordinates of the top-left corner of the rectangle.
- `void grow(int dw, int dh)`
  This method adjusts the width and height of this rectangle.
  Parameters: `dw` The amount to add to the width (can be negative)
  `dh` The amount to add to the height (can be negative)
- `Rectangle intersection(Rectangle other)`
  This method computes the intersection of this rectangle with the specified rectangle.
  Parameters: `other` A rectangle
  Returns: The largest rectangle contained in both `this` and `other`
- `void setLocation(int x, int y)`
  This method moves this rectangle to a new location.
  Parameters: `x,y` The new top-left corner
- `void setSize(int width, int height)`
  This method sets the width and height of this rectangle to new values.
  Parameters: `width` The new width
  `height` The new height
- `void translate(int dx, int dy)`
  This method moves this rectangle.
  Parameters: `dx` The distance to move along the *x*-axis
  `dy` The distance to move along the *y*-axis
- `Rectangle union(Rectangle other)`
  This method computes the union of this rectangle with the specified rectangle. This is not the set-theoretic union but the smallest rectangle that contains both `this` and `other`.
  Parameters: `other` A rectangle
  Returns: The smallest rectangle containing both `this` and `other`

Interface java.awt.Shape

The `Shape` interface describes shapes that can be drawn and filled by a `Graphics2D` object.

Package java.awt.event

Interface java.awt.event.ActionListener

- `void actionPerformed(ActionEvent e)`
  The event source calls this method when an action occurs.

Class `java.awt.event.MouseEvent`

- `int` **`getX`**`()`

  This method returns the horizontal position of the mouse as of the time the event occurred.

  Returns: The *x*-position of the mouse
- `int` **`getY`**`()`

  This method returns the vertical position of the mouse as of the time the event occurred.

  Returns: The *y*-position of the mouse

Interface `java.awt.event.MouseListener`

- `void` **`mouseClicked`**`(MouseEvent e)`

  This method is called when the mouse has been clicked (that is, pressed and released in quick succession).
- `void` **`mouseEntered`**`(MouseEvent e)`

  This method is called when the mouse has entered the component to which this listener was added.
- `void` **`mouseExited`**`(MouseEvent e)`

  This method is called when the mouse has exited the component to which this listener was added.
- `void` **`mousePressed`**`(MouseEvent e)`

  This method is called when a mouse button has been pressed.
- `void` **`mouseReleased`**`(MouseEvent e)`

  This method is called when a mouse button has been released.

Package `java.awt.geom`

Class `java.awt.geom.Ellipse2D.Double`

- **`Ellipse2D.Double`**`(double x, double y, double w, double h)`

  This constructs an ellipse from the specified coordinates.

  Parameters: `x, y` The top-left corner of the bounding rectangle

  `w` The width of the bounding rectangle

  `h` The height of the bounding rectangle

Class `java.awt.geom.Line2D`

- `double` **`getX1`**`()`
- `double` **`getX2`**`()`
- `double` **`getY1`**`()`
- `double` **`getY2`**`()`

  These methods get the requested coordinate of an endpoint of this line.

  Returns: The *x*- or *y*-coordinate of the first or second endpoint
- `void` **`setLine`**`(double x1, double y1, double x2, double y2)`

  This methods sets the endpoints of this line.

  Parameters: `x1, y1` A new endpoint of this line

  `x2, y2` The other new endpoint

Class `java.awt.geom.Line2D.Double`

- `Line2D.Double(double x1, double y1, double x2, double y2)`

  This constructs a line from the specified coordinates.

  Parameters: `x1, y1` One endpoint of the line
  `x2, y2` The other endpoint
- `Line2D.Double(Point2D p1, Point2D p2)`

  This constructs a line from the two endpoints.

  Parameters: `p1, p2` The endpoints of the line

Class `java.awt.geom.Point2D`

- `double getX()`
- `double getY()`

  These methods get the requested coordinates of this point.

  Returns: The *x*- or *y*-coordinate of this point
- `void setLocation(double x, double y)`

  This method sets the *x*- and *y*-coordinates of this point.

  Parameters: `x, y` The new location of this point

Class `java.awt.geom.Point2D.Double`

- `Point2D.Double(double x, double y)`

  This constructs a point with the specified coordinates.

  Parameters: `x, y` The coordinates of the point

Class `java.awt.geom.RectangularShape`

- `int getHeight()`
- `int getWidth()`

  These methods get the height or width of the bounding rectangle of this rectangular shape.

  Returns: The height or width, respectively
- `double getCenterX()`
- `double getCenterY()`
- `double getMaxX()`
- `double getMaxY()`
- `double getMinX()`
- `double getMinY()`

  These methods get the requested coordinate value of the corners or center of the bounding rectangle of this shape.

  Returns: The center, maximum, or minimum *x*- and *y*-coordinates

Package java.io

Class java.io.EOFException

- **EOFException**(String message)
  This constructs an "end of file" exception object.
  Parameters: message The detail message

Class java.io.File

- **File**(String name)
  This constructs a File object that describes a file (which may or may not exist) with the given name.
  Parameters: name The name of the file
- static final String pathSeparator
  The sytem-dependent separator between path names. A colon (:) in Linux or Mac OS X; a semicolon (;) in Windows.

Class java.io.FileInputStream

- **FileInputStream**(File f)
  This constructs a file input stream and opens the chosen file. If the file cannot be opened for reading, a FileNotFoundException is thrown.
  Parameters: f The file to be opened for reading
- **FileInputStream**(String name)
  This constructs a file input stream and opens the named file. If the file cannot be opened for reading, a FileNotFoundException is thrown.
  Parameters: name The name of the file to be opened for reading

Class java.io.FileNotFoundException

This exception is thrown when a file could not be opened.

Class java.io.FileOutputStream

- **FileOutputStream**(File f)
  This constructs a file output stream and opens the chosen file. If the file cannot be opened for writing, a FileNotFoundException is thrown.
  Parameters: f The file to be opened for writing
- **FileOutputStream**(String name)
  This constructs a file output stream and opens the named file. If the file cannot be opened for writing, a FileNotFoundException is thrown.
  Parameters: name The name of the file to be opened for writing

Class java.io.InputStream

- void **close**()
  This method closes this input stream (such as a FileInputStream) and releases any system resources associated with the stream.

- `int` **`read`**`()`
  This method reads the next byte of data from this input stream.
  Returns: The next byte of data, or -1 if the end of the stream is reached.

Class java.io.InputStreamReader

- **`InputStreamReader`**`(InputStream in)`
  This constructs a reader from a specified input stream.
  Parameters: `in` The stream to read from

Class java.io.IOException

This type of exception is thrown when an input/output error is encountered.

Class java.io.ObjectInputStream

- **`ObjectInputStream`**`(InputStream in)`
  This constructs an object input stream.
  Parameters: `in` The stream to read from
- `Object` **`readObject`**`()`
  This method reads the next object from this object input stream.
  Returns: The next object

Class java.io.ObjectOutputStream

- **`ObjectOutputStream`**`(OutputStream out)`
  This constructs an object output stream.
  Parameters: `out` The stream to write to
- `Object` **`writeObject`**`(Object obj)`
  This method writes the next object to this object output stream.
  Parameters: `obj` The object to write

Class java.io.OutputStream

- `void` **`close`**`()`
  This method closes this output stream (such as a `FileOutputStream`) and releases any system resources associated with this stream. A closed stream cannot perform output operations and cannot be reopened.
- `void` **`write`**`(int b)`
  This method writes the lowest byte of `b` to this output stream.
  Parameters: `b` The integer whose lowest byte is written

Class java.io.PrintStream/Class java.io.PrintWriter

- **`PrintStream`**`(String name)`
- **`PrintWriter`**`(String name)`
  This constructs a `PrintStream` or `PrintWriter` and opens the named file. If the file cannot be opened for writing, a `FileNotFoundException` is thrown.
  Parameters: `name` The name of the file to be opened for writing
- `void` **`close`**`()`
  This method closes this stream or writer and releases any associated system resources.

- `void` **`print`**`(int x)`
- `void` **`print`**`(double x)`
- `void` **`print`**`(Object x)`
- `void` **`print`**`(String x)`
- `void` **`println`**`()`
- `void` **`println`**`(int x)`
- `void` **`println`**`(double x)`
- `void` **`println`**`(Object x)`
- `void` **`println`**`(String x)`

  These methods print a value to this `PrintStream` or `PrintWriter`. The `println` methods print a newline after the value. Objects are printed by converting them to strings with their `toString` methods.

  Parameters: `x` The value to be printed

- `PrintStream` **`printf`**`(Sting format, Object... values)`
- `Printwriter` **`printf`**`(Sting format, Object... values)`

  This method prints the format string to this `PrintStream` or `PrintWriter`, substituting the given values for placeholders that start with `%`.

  Parameters: `format` The format string
  `values` The values to be printed. You can supply any number of values

  Returns: The implicit parameter

Class java.io.RandomAccessFile

- **`RandomAccessFile`**`(String name, String mode)`

  This method opens a named random access file for reading or read/write access.

  Parameters: `name` The file name
  `mode` `"r"` for reading or `"rw"` for read/write access

- `long` **`getFilePointer`**`()`

  This method gets the current position in this file.

  Returns: The current position for reading and writing

- `long` **`length`**`()`

  This method gets the length of this file.

  Returns: The file length

- `char` **`readChar`**`()`
- `double` **`readDouble`**`()`
- `int` **`readInt`**`()`

  These methods read a value from the current position in this file.

  Returns: The value that was read from the file

- `void` **`seek`**`(long position)`

  This method sets the position for reading and writing in this file.

  Parameters: `position` The new position

- `void` **`writeChar`**`(int x)`
- `void` **`writeChars`**`(String x)`
- `void` **`writeDouble`**`(double x)`
- `void` **`writeInt`**`(int x)`

  These methods write a value to the current position in this file.

  Parameters: `x` The value to be written

Package java.lang

Class java.lang.Boolean

- `Boolean(boolean value)`
  This constructs a wrapper object for a `boolean` value.
  Parameters: `value` The value to store in this object
- `boolean booleanValue()`
  This method returns the `boolean` value stored in this `Boolean` object.
  Returns: The Boolean value of this object

Class java.lang.Character

- `static boolean isDigit(ch)`
  This method tests whether a given character is a Unicode digit.
  Parameters: `ch` The character to test
  Returns: `true` if the character is a digit
- `static boolean isLetter(ch)`
  This method tests whether a given character is a Unicode letter.
  Parameters: `ch` The character to test
  Returns: `true` if the character is a letter
- `static boolean isLowerCase(ch)`
  This method tests whether a given character is a lowercase Unicode letter.
  Parameters: `ch` The character to test
  Returns: `true` if the character is a lowercase letter
- `static boolean isUpperCase(ch)`
  This method tests whether a given character is an uppercase Unicode letter.
  Parameters: `ch` The character to test
  Returns: `true` if the character is an uppercase letter

Interface java.lang.Cloneable

A class implements this interface to indicate that the `Object.clone` method is allowed to make a shallow copy of its instance variables.

Class java.lang.CloneNotSupportedException

This exception is thrown when a program tries to use `Object.clone` to make a shallow copy of an object of a class that does not implement the `Cloneable` interface.

Interface java.lang.Comparable<T>

- `int compareTo(T other)`
  This method compares this object with the `other` object.
  Parameters: `other` The object to be compared
  Returns: A negative integer if this object is less than the other, zero if they are equal, or a positive integer otherwise

Class java.lang.Double

- **Double**(double value)
  This constructs a wrapper object for a double-precision floating-point number.
  Parameters: value The value to store in this object
- double **doubleValue**()
  This method returns the floating-point value stored in this Double wrapper object.
  Returns: The value stored in the object
- static double **parseDouble**(String s)
  This method returns the floating-point number that the string represents. If the string cannot be interpreted as a number, a NumberFormatException is thrown.
  Parameters: s The string to be parsed
  Returns: The value represented by the string parameter

Class java.lang.Error

This is the superclass for all unchecked system errors.

Class java.lang.IllegalArgumentException

- **IllegalArgumentException**()
  This constructs an IllegalArgumentException with no detail message.

Class java.lang.IllegalStateException

This exception is thrown if the state of an object indicates that a method cannot currently be applied.

Class java.lang.Integer

- **Integer**(int value)
  This constructs a wrapper object for an integer.
  Parameters: value The value to store in this object
- int **intValue**()
  This method returns the integer value stored in this wrapper object.
  Returns: The value stored in the object
- static int **parseInt**(String s)
  This method returns the integer that the string represents. If the string cannot be interpreted as an integer, a NumberFormatException is thrown.
  Parameters: s The string to be parsed
  Returns: The value represented by the string parameter
- static Integer **parseInt**(String s, int base)
  This method returns the integer value that the string represents in a given number system. If the string cannot be interpreted as an integer, a NumberFormatException is thrown.
  Parameters: s The string to be parsed
  base The base of the number system (such as 2 or 16)
  Returns: The value represented by the string parameter

- `static String` **`toString`**`(int i)`
- `static String` **`toString`**`(int i, int base)`

  This method creates a string representation of an integer in a given number system. If no base is given, a decimal representation is created.

  Parameters: `i` An integer number
  `base` The base of the number system (such as 2 or 16)

  Returns: A string representation of the number parameter in the specified number system
- `static final int MAX_VALUE`

  This constant is the largest value of type `int`.
- `static final int MIN_VALUE`

  This constant is the smallest (negative) value of type `int`.

Class `java.lang.Math`

- `static double` **`abs`**`(double x)`

  This method returns the absolute value $|x|$.

  Parameters: `x` A floating-point value

  Returns: The absolute value of the parameter
- `static double` **`acos`**`(double x)`

  This method returns the angle with the given cosine, $\cos^{-1} x \in [0, \pi]$.

  Parameters: `x` A floating-point value between –1 and 1

  Returns: The arc cosine of the parameter, in radians
- `static double` **`asin`**`(double x)`

  This method returns the angle with the given sine, $\sin^{-1} x \in [-\pi/2, \pi/2]$.

  Parameters: `x` A floating-point value between –1 and 1

  Returns: The arc sine of the parameter, in radians
- `static double` **`atan`**`(double x)`

  This method returns the angle with the given tangent, $\tan^{-1} x\ (-\pi/2, \pi/2)$.

  Parameters: `x` A floating-point value

  Returns: The arc tangent of the parameter, in radians
- `static double` **`atan2`**`(double y, double x)`

  This method returns the arc tangent, $\tan^{-1}(y/x) \in (-\pi, \pi)$. If x can equal zero, or if it is necessary to distinguish "northwest" from "southeast" and "northeast" from "southwest", use this method instead of `atan(y/x)`.

  Parameters: `y,x` Two floating-point values

  Returns: The angle, in radians, between the points (0,0) and (x,y)
- `static double` **`ceil`**`(double x)`

  This method returns the smallest integer $\geq x$ (as a `double`).

  Parameters: `x` A floating-point value

  Returns: The "ceiling integer" of the parameter
- `static double` **`cos`**`(double radians)`

  This method returns the cosine of an angle given in radians.

  Parameters: `radians` An angle, in radians

  Returns: The cosine of the parameter
- `static double` **`exp`**`(double x)`

  This method returns the value e^x, where e is the base of the natural logarithms.

  Parameters: `x` A floating-point value

  Returns: e^x

- `static double` **`floor`**`(double x)`
  This method returns the largest integer $\leq x$ (as a `double`).
  Parameters: `x` A floating-point value
  Returns: The "floor integer" of the parameter
- `static double` **`log`**`(double x)`
- `static double` **`log10`**`(double x)`
  This method returns the natural (base e) or decimal (base 10) logarithm of x, $\ln x$.
  Parameters: `x` A number greater than 0.0
  Returns: The natural logarithm of the parameter
- `static int` **`max`**`(int x, int y)`
- `static double` **`max`**`(double x, double y)`
  These methods return the larger of the given parameter values.
  Parameters: `x, y` Two integers or floating-point values
  Returns: The maximum of the parameter values
- `static int` **`min`**`(int x, int y)`
- `static double` **`min`**`(double x, double y)`
  These methods return the smaller of the given parameter values.
  Parameters: `x, y` Two integers or floating-point values
  Returns: The minimum of the parameter values
- `static double` **`pow`**`(double x, double y)`
  This method returns the value x^y ($x > 0$, or $x = 0$ and $y > 0$, or $x < 0$ and y is an integer).
  Parameters: `x, y` Two floating-point values
  Returns: The value of the first parameter raised to the power of the second parameter
- `static long` **`round`**`(double x)`
  This method returns the closest `long` integer to the parameter.
  Parameters: `x` A floating-point value
  Returns: The value of the parameter rounded to the nearest `long` value
- `static double` **`sin`**`(double radians)`
  This method returns the sine of an angle given in radians.
  Parameters: `radians` An angle, in radians
  Returns: The sine of the parameter
- `static double` **`sqrt`**`(double x)`
  This method returns the square root of x, $\sqrt{x}$.
  Parameters: `x` A nonnegative floating-point value
  Returns: The square root of the parameter
- `static double` **`tan`**`(double radians)`
  This method returns the tangent of an angle given in radians.
  Parameters: `radians` An angle, in radians
  Returns: The tangent of the parameter
- `static double` **`toDegrees`**`(double radian)`
  This method converts radians to degrees.
  Parameters: `radians` An angle, in radians
  Returns: The angle in degrees
- `static double` **`toRadians`**`(double degrees)`
  This methods converts degrees to radians.
  Parameters: `degrees` An angle, in degrees
  Returns: The angle in radians

- `static final double E`
  This constant is the value of *e*, the base of the natural logarithms.
- `static final double PI`
  This constant is the value of π.

Class java.lang.NullPointerException

This exception is thrown when a program tries to use an object through a `null` reference.

Class java.lang.NumberFormatException

This exception is thrown when a program tries to parse the numerical value of a string that is not a number.

Class java.lang.Object

- `protected Object` **`clone`**`()`
  This constructs and returns a shallow copy of this object whose instance variables are copies of the instance variables of this object. If an instance variable of the object is an object reference itself, only the reference is copied, not the object itself. However, if the class does not implement the `Cloneable` interface, a `CloneNotSupportedException` is thrown. Subclasses should redefine this method to make a deep copy.
  Returns: A copy of this object
- `boolean` **`equals`**`(Object other)`
  This method tests whether `this` and the other object are equal. This method tests only whether the object references are to the same object. Subclasses should redefine this method to compare the instance variables.
  Parameters: `other` The object with which to compare
  Returns: `true` if the objects are equal, `false` otherwise
- `void` **`notify`**`()`
  This method notifies one of the threads that is currently on the wait list for the lock of this object.
- `void` **`notifyAll`**`()`
  This method notifies all of the threads that are currently on the wait list for the lock of this object.
- `String` **`toString`**`()`
  This method returns a string representation of this object. This method produces only the class name and locations of the objects. Subclasses should redefine this method to print the instance variables.
  Returns: A string describing this object
- `void` **`wait`**`()`
  This method blocks the currently executing thread and puts it on the wait list for the lock of this object.

Class java.lang.RuntimeException

This is the superclass for all unchecked exceptions.

Class `java.lang.String`

- `int` **`compareTo`**`(String other)`

  This method compares this string and the other string lexicographically.

  Parameters: `other` The other string to be compared

  Returns: A value less than `0` if this string is lexicographically less than the other, `0` if the strings are equal, and a value greater than `0` otherwise.

- `boolean` **`equals`**`(String other)`
- `boolean` **`equalsIgnoreCase`**`(String other)`

  These methods test whether two strings are equal, or whether they are equal when letter case is ignored.

  Parameters: `other` The other string to be compared

  Returns: `true` if the strings are equal

- `static String` **`format`**`(String format, Object... values)`

  This method formats the given string by substituting placeholders that start with `%` with the given values.

  Parameters: `format` The string with the placeholders
  `values` The values to be substituted for the placeholders

  Returns: The formatted string, with the placeholders replaced by the given values

- `int` **`length`**`()`

  This method returns the length of this string.

  Returns: The count of characters in this string

- `String` **`replace`**`(String match, String replacement)`

  This method replaces matching substrings with a given replacement.

  Parameters: `match` The string whose matches are to be replaced
  `replacement` The string with which matching substrings are replaced

  Returns: A string that is identical to this string, with all matching substrings replaced by the given replacement

- `String` **`substring`**`(int begin)`
- `String` **`substring`**`(int begin, int pastEnd)`

  These methods return a new string that is a substring of this string, made up of all characters starting at position `begin` and up to either position `pastEnd - 1`, if it is given, or the end of the string.

  Parameters: `begin` The beginning index, inclusive
  `pastEnd` The ending index, exclusive

  Returns: The specified substring

- `String` **`toLowerCase`**`()`

  This method returns a new string that consists of all characters in this string converted to lowercase.

  Returns: A string with all characters in this string converted to lowercase

- `String` **`toUpperCase`**`()`

  This method returns a new string that consists of all characters in this string converted to uppercase.

  Returns: A string with all characters in this string converted to uppercase

Class `java.lang.System`

- `static void` **`arraycopy`**`(`
  `Object from, int fromStart, Object to, int toStart, int count)`

  This method copies values from one array to the other. (The array parameters are of type `Object` because you can convert an array of numbers to an `Object` but not to an `Object[]`.)

  Parameters: `from` The source array
  `fromStart` Start position in the source array
  `to` The destination array
  `toStart` Start position in the destination data
  `count` The number of array elements to be copied

- `static long` **`currentTimeMillis`**`()`

  This method returns the difference, measured in milliseconds, between the current time and midnight, Universal Time, January 1, 1970.

  Returns: The current time in milliseconds

- `static void` **`exit`**`(int status)`

  This method terminates the program.

  Parameters: `status` Exit status. A nonzero status code indicates abnormal termination

- `static final InputStream in`

  This object is the "standard input" stream. Reading from this stream typically reads keyboard input.

- `static final PrintStream out`

  This object is the "standard output" stream. Printing to this stream typically sends output to the console window.

Class `java.lang.Throwable`

This is the superclass of exceptions and errors.

- **`Throwable`**`()`

  This constructs a `Throwable` with no detail message.

- `String` **`getMessage`**`()`

  This method gets the message that describes the exception or error.

  Returns: The message

- `void` **`printStackTrace`**`()`

  This method prints a stack trace to the "standard error" stream. The stack trace contains a printout of this object and of all calls that were pending at the time it was created.

Package `java.math`

Class `java.math.BigDecimal`

- **`BigDecimal`**`(String value)`

  This constructs an arbitrary-precision floating-point number from the digits in the given string.

  Parameters: `value` A string representing the floating-point number

- `BigDecimal` **`add`**`(BigDecimal other)`
- `BigDecimal` **`multiply`**`(BigDecimal other)`
- `BigDecimal` **`subtract`**`(BigDecimal other)`

  These methods return a `BigDecimal` whose value is the sum, difference, product, or quotient of this number and the other.

  Parameters: `other` The other number

  Returns: The result of the arithmetic operation

Class java.math.BigInteger

- **`BigInteger`**`(String value)`

  This constructs an arbitrary-precision integer from the digits in the given string.

  Parameters: `value` A string representing an arbitrary-precision integer
- `BigInteger` **`add`**`(BigInteger other)`
- `BigInteger` **`divide`**`(BigInteger other)`
- `BigInteger` **`mod`**`(BigInteger other)`
- `BigInteger` **`multiply`**`(BigInteger other)`
- `BigInteger` **`subtract`**`(BigInteger other)`

  These methods return a `BigInteger` whose value is the sum, difference, product, quotient, or remainder of this number and the other.

  Parameters: `other` The other number

  Returns: The result of the arithmetic operation

Package java.net

Class java.net.URL

- **`URL`**`(String s)`

  This constructs an `URL` object from a string containing the URL.

  Parameters: `s` The URL string, such as `"http://java.sun.com/index.html"`
- `InputStream` **`openStream`**`()`

  This method gets the input stream through which the client can read the information that the server sends.

  Returns: The input stream associated with this URL

Package java.util

Class java.util.ArrayList<E>

- **`ArrayList`**`()`

  This constructs an empty array list.
- `boolean` **`add`**`(E element)`

  This method appends an element to the end of this array list.

  Parameters: `element` The element to add

  Returns: `true` (This method returns a value because it overrides a method in the `List` interface.)

- `void` **`add`**`(int index, E element)`
  This method inserts an element into this array list.
  Parameters: `index` Insert position
  `element` The element to insert
- `E` **`get`**`(int index)`
  This method gets the element at the specified position in this array list.
  Parameters: `index` Position of the element to return
  Returns: The requested element
- `E` **`remove`**`(int index)`
  This method removes the element at the specified position in this array list and returns it.
  Parameters: `index` Position of the element to remove
  Returns: The removed element
- `E` **`set`**`(int index, E element)`
  This method replaces the element at a specified position in this array list.
  Parameters: `index` Position of element to replace
  `element` Element to be stored at the specified position
  Returns: The element previously at the specified position
- `int` **`size`**`()`
  This method returns the number of elements in this array list.
  Returns: The number of elements in this array list

Class java.util.Arrays

- `static int` **`binarySearch`**`(Object[] a, Object key)`
  This method searches the specified array for the specified object using the binary search algorithm. The array elements must implement the `Comparable` interface. The array must be sorted in ascending order.
  Parameters: `a` The array to be searched
  `key` The value to be searched for
  Returns: The position of the search key, if it is contained in the array; otherwise, $-index - 1$, where *index* is the position where the element may be inserted
- `static` *`T`*`[]` **`copyOf`**`(`*`T`*`[] a, int newLength)`
  This method copies the elements of the array `a`, or the first `newLength` elements if `a.length < newLength`, into an array of length `newLength` and returns that array. *T* can be a primitive type, class, or interface type.
  Parameters: `a` The array to be copied
  `key` The value to be searched for
  Returns: The position of the search key, if it is contained in the array; otherwise, $-index - 1$, where *index* is the position where the element may be inserted
- `static void` **`sort`**`(Object[] a)`
  This method sorts the specified array of objects into ascending order. Its elements must implement the `Comparable` interface.
  Parameters: `a` The array to be sorted
- `static String` **`toString`**`(`*`T`*`[] a)`
  This method creates and returns a string containing the array elements. *T* can be a primitive type, class, or interface type.
  Parameters: `a` An array
  Returns: A string containing a comma-separated list of string representations of the array elements, surrounded by brackets.

Class java.util.Calendar

- `int` **`get`**`(int field)`
  This method returns the value of the given field.
  Parameters: One of `Calendar.YEAR`, `Calendar.MONTH`, `Calendar.DAY_OF_MONTH`, `Calendar.HOUR`, `Calendar.MINUTE`, `Calendar.SECOND`, or `Calendar.MILLISECOND`

Interface java.util.Collection<E>

- `boolean` **`add`**`(E element)`
  This method adds an element to this collection.
  Parameters: `element` The element to add
  Returns: `true` if adding the element changes the collection
- `boolean` **`contains`**`(E element)`
  This method tests whether an element is present in this collection.
  Parameters: `element` The element to find
  Returns: `true` if the element is contained in the collection
- `Iterator` **`iterator`**`()`
  This method returns an iterator that can be used to traverse the elements of this collection.
  Returns: An object of a class implementing the `Iterator` interface
- `boolean` **`remove`**`(E element)`
  This method removes an element from this collection.
  Parameters: `element` The element to remove
  Returns: `true` if removing the element changes the collection
- `int` **`size`**`()`
  This method returns the number of elements in this collection.
  Returns: The number of elements in this collection

Class java.util.Collections

- `static <T> int` **`binarySearch`**`(List<T> a, T key)`
  This method searches the specified list for the specified object using the binary search algorithm. The list elements must implement the `Comparable` interface. The list must be sorted in ascending order.
  Parameters: `a` The list to be searched
  `key` The value to be searched for
  Returns: The position of the search key, if it is contained in the list; otherwise, –*index* – 1, where *index* is the position where the element may be inserted
- `static <T> void` **`sort`**`(T[] a)`
  This method sorts the specified list of objects into ascending order. Its elements must implement the `Comparable` interface.
  Parameters: `a` The list to be sorted

Interface java.util.Comparator<T>

- `int compare(T first, T second)`

  This method compares the given objects.

  Parameters: `first`, `second` The objects to be compared

  Returns: A negative integer if the first object is less than the second, zero if they are equal, or a positive integer otherwise

Class java.util.EventObject

- `Object getSource()`

  This method returns a reference to the object on which this event initially occurred.

  Returns: The source of this event

Class java.util.GregorianCalendar

- `GregorianCalendar()`

  This constructs a calendar object that represents the current date and time.

- `GregorianCalendar(int year, int month, int day)`

  This constructs a calendar object that represents the start of the given date.

  Parameters: `year`, `month`, `day` The given date

Class java.util.HashMap<K, V>

- `HashMap<K, V>()`

  This constructs an empty hash map.

Class java.util.HashSet<E>

- `HashSet<E>()`

  This constructs an empty hash set.

Class java.util.InputMismatchException

This exception is thrown if the next available input item does not match the type of the requested item.

Interface java.util.Iterator<E>

- `boolean hasNext()`

  This method checks whether the iterator is past the end of the list.

  Returns: `true` if the iterator is not yet past the end of the list

- `E next()`

  This method moves the iterator over the next element in the linked list. This method throws an exception if the iterator is past the end of the list.

  Returns: The object that was just skipped over

- `void remove()`

  This method removes the element that was returned by the last call to `next` or `previous`. This method throws an exception if there was an `add` or `remove` operation after the last call to `next` or `previous`.

Class `java.util.LinkedList<E>`

- `void` **`addFirst`**`(E element)`
- `void` **`addLast`**`(E element)`

  These methods add an element before the first or after the last element in this list.

  Parameters: `element` The element to be added
- `E` **`getFirst`**`()`
- `E` **`getLast`**`()`

  These methods return a reference to the specified element from this list.

  Returns: The first or last element
- `E` **`removeFirst`**`()`
- `E` **`removeLast`**`()`

  These methods remove the specified element from this list.

  Returns: A reference to the removed element

Interface `java.util.List<E>`

- `ListIterator<E>` **`listIterator`**`()`

  This method gets an iterator to visit the elements in this list.

  Returns: An iterator that points before the first element in this list

Interface `java.util.ListIterator<E>`

Objects implementing this interface are created by the `listIterator` methods of list classes.

- `void` **`add`**`(E element)`

  This method adds an element after the iterator position and moves the iterator after the new element.

  Parameters: `element` The element to be added
- `boolean` **`hasPrevious`**`()`

  This method checks whether the iterator is before the first element of the list.

  Returns: `true` if the iterator is not before the first element of the list
- `E` **`previous`**`()`

  This method moves the iterator over the previous element in the linked list. This method throws an exception if the iterator is before the first element of the list.

  Returns: The object that was just skipped over
- `void` **`set`**`(E element)`

  This method replaces the element that was returned by the last call to `next` or `previous`. This method throws an exception if there was an add or remove operation after the last call to `next` or `previous`.

  Parameters: `element` The element that replaces the old list element

Interface `java.util.Map<K, V>`

- `V` **`get`**`(K key)`

  Gets the value associated with a key in this map.

  Parameters: `key` The key for which to find the associated value

  Returns: The value associated with the key, or `null` if the key is not present in the table
- `Set<K>` **`keySet`**`()`

  This method returns all keys in the table of this map.

  Returns: A set of all keys in the table of this map

- V **put**(K key, V value)
  This method associates a value with a key in this map.
  Parameters: key The lookup key
  value The value to associate with the key
  Returns: The value previously associated with the key, or null if the key was not present in the table
- V **remove**(K key)
  This method removes a key and its associated value from this map.
  Parameters: key The lookup key
  Returns: The value previously associated with the key, or null if the key was not present in the table

Class java.util.NoSuchElementException

This exception is thrown if an attempt is made to retrieve a value that does not exist.

Class java.util.PriorityQueue<E>

- **PriorityQueue**<E>()
  This constructs an empty priority queue. The element type E must implement the Comparable interface.
- E **remove**()
  This method removes the smallest element in the priority queue.
  Returns: The removed value

Class java.util.Random

- **Random**()
  This constructs a new random number generator.
- double **nextDouble**()
  This method returns the next pseudorandom, uniformly distributed floating-point number between 0.0 (inclusive) and 1.0 (exclusive) from this random number generator's sequence.
  Returns: The next pseudorandom floating-point number
- int **nextInt**(int n)
  This method returns the next pseudorandom, uniformly distributed integer between 0 (inclusive) and the specified value (exclusive) drawn from this random number generator's sequence.
  Parameters: n Number of values to draw from
  Returns: The next pseudorandom integer

Class java.util.Scanner

- **Scanner**(File in)
- **Scanner**(InputStream in)
- **Scanner**(Reader in)
  These construct a scanner that reads from the given file, input stream, or reader.
  Parameters: in The file, input stream, or reader from which to read
- void **close**()
  This method closes this scanner and releases any associated system resources.

- `boolean` **`hasNext`**`()`
- `boolean` **`hasNextDouble`**`()`
- `boolean` **`hasNextInt`**`()`
- `boolean` **`hasNextLine`**`()`

  These methods test whether it is possible to read any non-empty string, a floating-point value, an integer, or a line, as the next item.

  Returns: `true` if it is possible to read an item of the requested type, `false` otherwise (either because the end of the file has been reached, or because a number type was tested and the next item is not a number)
- `String` **`next`**`()`
- `double` **`nextDouble`**`()`
- `int` **`nextInt`**`()`
- `String` **`nextLine`**`()`

  These methods read the next whitespace-delimited string, floating-point value, integer, or line.

  Returns: The value that was read
- `Scanner` **`useDelimiter`**`(String pattern)`

  Sets the pattern for the delimiters between input tokens.

  Parameters: `pattern` A regular expression for the delimiter pattern

  Returns: This scanner

Interface java.util.Set<E>

This interface describes a collection that contains no duplicate elements.

Class java.util.TreeMap<K, V>

- **`TreeMap`**`<K, V>()`

  This constructs an empty tree map. The `TreeMap` iterator visits the entries in sorted order.

Class java.util.TreeSet<E>

- **`TreeSet`**`<E>()`

  This constructs an empty tree set.

Package java.util.logging

Class java.util.logging.Level

- `static final int ALL`

  This value indicates logging of all messages.
- `static final int INFO`

  This value indicates informational logging.
- `static final int NONE`

  This value indicates logging of no messages.

Class java.util.logging.Logger

- `static Logger` **`getGlobal`**`()`

  This method gets the global logger. For Java 5 and 6, use `getLogger("global")` instead.

  Returns: The global logger that, by default, displays messages with level *`INFO`* or a higher severity on the console.

- `void` **`info`**`(String message)`
  This method logs an informational message.
  Parameters: `message` The message to log
- `void` **`setLevel`**`(Level aLevel)`
  This method sets the logging level. Logging messages with a lesser severity than the current level are ignored.
  Parameters: `aLevel` The minimum level for logging messages

Package javax.swing

Class javax.swing.AbstractButton

- `void` **`addActionListener`**`(ActionListener listener)`
  This method adds an action listener to the button.
  Parameters: `listener` The action listener to be added
- `boolean` **`isSelected`**`()`
  This method returns the selection state of the button.
  Returns: `true` if the button is selected
- `void` **`setSelected`**`(boolean state)`
  This method sets the selection state of the button. This method updates the button but does not trigger an action event.
  Parameters: `state` `true` to select, `false` to deselect

Class javax.swing.ButtonGroup

- `void` **`add`**`(AbstractButton button)`
  This method adds the button to the group.
  Parameters: `button` The button to add

Class javax.swing.ImageIcon

- **`ImageIcon`**`(String filename)`
  This constructs an image icon from the specified graphics file.
  Parameters: `filename` A string specifying a file name

Class javax.swing.JButton

- **`JButton`**`(String label)`
  This constructs a button with the given label.
  Parameters: `label` The button label

Class javax.swing.JCheckBox

- **`JCheckBox`**`(String text)`
  This constructs a check box, having the given text, initially deselected. (Use the `setSelected()` method to make the box selected; see the `javax.swing.AbstractButton` class.)
  Parameters: `text` The text displayed next to the check box

Class `javax.swing.JComboBox`

- `JComboBox()`
  This constructs a combo box with no items.
- `void addItem(Object item)`
  This method adds an item to the item list of this combo box.
  Parameters: `item` The item to add
- `Object getSelectedItem()`
  This method gets the currently selected item of this combo box.
  Returns: The currently selected item
- `boolean isEditable()`
  This method checks whether the combo box is editable. An editable combo box allows the user to type into the text field of the combo box.
  Returns: `true` if the combo box is editable
- `void setEditable(boolean state)`
  This method is used to make the combo box editable or not.
  Parameters: `state` `true` to make editable, `false` to disable editing

Class `javax.swing.JComponent`

- `protected void paintComponent(Graphics g)`
  Override this method to paint the surface of a component. Your method needs to call `super.paintComponent(g)`.
  Parameters: `g` The graphics context used for drawing
- `void setBorder(Border b)`
  This method sets the border of this component.
  Parameters: `b` The border to surround this component
- `void setFont(Font f)`
  Sets the font used for the text in this component.
  Parameters: `f` A font

Class `javax.swing.JFileChooser`

- `JFileChooser()`
  This constructs a file chooser.
- `File getSelectedFile()`
  This method gets the selected file from this file chooser.
  Returns: The selected file
- `int showOpenDialog(Component parent)`
  This method displays an “Open File” file chooser dialog box.
  Parameters: `parent` The parent component or `null`
  Returns: The return state of this file chooser after it has been closed by the user: either `APPROVE_OPTION` or `CANCEL_OPTION`. If `APPROVE_OPTION` is returned, call `getSelectedFile()` on this file chooser to get the file
- `int showSaveDialog(Component parent)`
  This method displays a “Save File” file chooser dialog box.
  Parameters: `parent` The parent component or `null`
  Returns: The return state of the file chooser after it has been closed by the user: either `APPROVE_OPTION` or `CANCEL_OPTION`

Class javax.swing.JFrame

- `void` **`setDefaultCloseOperation`**`(int operation)`
  This method sets the default action for closing the frame.
  Parameters: `operation` The desired close operation. Choose among `DO_NOTHING_ON_CLOSE`, `HIDE_ON_CLOSE` (the default), `DISPOSE_ON_CLOSE`, or `EXIT_ON_CLOSE`
- `void` **`setJMenuBar`**`(JMenuBar mb)`
  This method sets the menu bar for this frame.
  Parameters: `mb` The menu bar. If `mb` is `null`, then the current menu bar is removed
- `static final int EXIT_ON_CLOSE`
  This value indicates that when the user closes this frame, the application is to exit.

Class javax.swing.JLabel

- **`JLabel`**`(String text)`
- **`JLabel`**`(String text, int alignment)`
  These containers create a `JLabel` instance with the specified text and horizontal alignment.
  Parameters: `text` The label text to be displayed by the label
  `alignment` One of `SwingConstants.LEFT`, `SwingConstants.CENTER`, or `SwingConstants.RIGHT`

Class javax.swing.JMenu

- **`JMenu`**`()`
  This constructs a menu with no items.
- `JMenuItem` **`add`**`(JMenuItem menuItem)`
  This method appends a menu item to the end of this menu.
  Parameters: `menuItem` The menu item to be added
  Returns: The menu item that was added

Class javax.swing.JMenuBar

- **`JMenuBar`**`()`
  This constructs a menu bar with no menus.
- `JMenu` **`add`**`(JMenu menu)`
  This method appends a menu to the end of this menu bar.
  Parameters: `menu` The menu to be added
  Returns: The menu that was added

Class javax.swing.JMenuItem

- **`JMenuItem`**`(String text)`
  This constructs a menu item.
  Parameters: `text` The text to appear in the menu item

Class javax.swing.JOptionPane

- `static String` **`showInputDialog`**`(Object prompt)`
  This method brings up a modal input dialog box, which displays a prompt and waits for the user to enter an input in a text field, preventing the user from doing anything else in this program.
  Parameters: `prompt` The prompt to display
  Returns: The string that the user typed
- `static void` **`showMessageDialog`**`(Component parent, Object message)`
  This method brings up a confirmation dialog box that displays a message and waits for the user to confirm it.
  Parameters: `parent` The parent component or `null`
  `message` The message to display

Class javax.swing.JPanel

This class is a component without decorations. It can be used as an invisible container for other components.

Class javax.swing.JRadioButton

- **`JRadioButton`**`(String text)`
  This constructs a radio button having the given text that is initially deselected. (Use the `setSelected()` method to select it; see the `javax.swing.AbstractButton` class.)
  Parameters: `text` The string displayed next to the radio button

Class javax.swing.JScrollPane

- **`JScrollPane`**`(Component c)`
  This constructs a scroll pane around the given component.
  Parameters: `c` The component that is decorated with scroll bars

Class javax.swing.JSlider

- **`JSlider`**`(int min, int max, int value)`
  This constructor creates a horizontal slider using the specified minimum, maximum, and value.
  Parameters: `min` The smallest possible slider value
  `max` The largest possible slider value
  `value` The initial value of the slider
- `void` **`addChangeListener`**`(ChangeListener listener)`
  This method adds a change listener to the slider.
  Parameters: `listener` The change listener to add
- `int` **`getValue`**`()`
  This method returns the slider's value.
  Returns: The current value of the slider

Class javax.swing.JTextArea

- **JTextArea**()
  This constructs an empty text area.
- **JTextArea**(int rows, int columns)
  This constructs an empty text area with the specified number of rows and columns.
  Parameters: `rows` The number of rows
  `columns` The number of columns
- void **append**(String text)
  This method appends text to this text area.
  Parameters: `text` The text to append

Class javax.swing.JTextField

- **JTextField**()
  This constructs an empty text field.
- **JTextField**(int columns)
  This constructs an empty text field with the specified number of columns.
  Parameters: `columns` The number of columns

Class javax.swing.Timer

- **Timer**(int millis, ActionListener listener)
  This constructs a timer that notifies an action listener whenever a time interval has elapsed.
  Parameters: `millis` The number of milliseconds between timer notifications
  `listener` The object to be notified when the time interval has elapsed
- void **start**()
  This method starts the timer. Once the timer has started, it begins notifying its listener.
- void **stop**()
  This method stops the timer. Once the timer has stopped, it no longer notifies its listener.

Package javax.swing.border

Class javax.swing.border.EtchedBorder

- **EtchedBorder**()
  This constructor creates a lowered etched border.

Class javax.swing.border.TitledBorder

- **TitledBorder**(Border b, String title)
  This constructor creates a titled border that adds a title to a given border.
  Parameters: `b` The border to which the title is added
  `title` The title the border should display

Package javax.swing.event

Class javax.swing.event.ChangeEvent

Components such as sliders emit change events when they are manipulated by the user.

Interface javax.swing.event.ChangeListener

- `void` **`stateChanged`**`(ChangeEvent e)`
  This event is called when the event source has changed its state.
  Parameters: `e` A change event

Package javax.swing.text

Class javax.swing.text.JTextComponent

- `String` **`getText`**`()`
  This method returns the text contained in this text component.
  Returns: The text
- `boolean` **`isEditable`**`()`
  This method checks whether this text component is editable.
  Returns: `true` if the component is editable
- `void` **`setEditable`**`(boolean state)`
  This method is used to make this text component editable or not.
  Parameters: `state` `true` to make editable, `false` to disable editing
- `void` **`setText`**`(String text)`
  This method sets the text of this text component to the specified text. If the text is empty, the old text is deleted.
  Parameters: `text` The new text to be set
  This method sets the validation mode for all document builders that are generated from this factory.
  Parameters: `b` `true` if documents should be validated during parsing

Appendix E

Java Syntax Summary

In this syntax summary, we use a monospaced font for actual Java reserved words and tokens such as `while`. An italic font denotes language constructs such as *condition* or *variable*. Items enclosed in brackets `[ ]` are optional. Items separated by vertical bars | are alternatives. Do not include the brackets or vertical bars in your code!

The summary reflects the parts of the Java language that were covered in this book. For a full overview of the Java syntax, see `http://java.sun.com/docs/books/jls/`.

As always, please be careful to distinguish an ellipsis . . . from the ... token. The latter appears twice in this appendix in the "variable parameters" discussion in the "Methods" section.

Types

A type is a primitive type or a reference type. The primitive types are

- The numeric types `int`, `long`, `short`, `char`, `byte`, `float`, `double`
- The `boolean` type

The reference types are

- Classes such as `String` or `Employee`
- Enumeration types such as `enum Sex { FEMALE, MALE }`
- Interfaces such as `Comparable`
- Array types such as `Employee[]` or `int[][]`

Variables

Local variable declarations have the form

`[final]` *Type variableName* `[=` *initializer*`];`

Examples:

```
int n;
double x = 0;
String harry = "Harry Handsome";
Rectangle box = new Rectangle(5, 10, 20, 30);
int[] a = { 1, 4, 9, 16, 25 };
```

The variable name consists only of letters, numbers, and underscores. It must begin with a letter or underscore. Names are case-sensitive: `totalscore`, `TOTALSCORE`, and `totalScore` are three different variables.

The scope of a local variable extends from the point of its definition to the end of the enclosing block.

A variable that is declared as `final` can have its value set only once.

Instance variables will be discussed under "Classes".

Expressions

An *expression* is a variable, a method call, or a combination of subexpressions joined by operators. Examples are:

```
x
Math.sin(x)
x + Math.sin(x)
x * (1 + Math.sin(x))
x++
x == y
x == y && (z > 0 || w > 0)
p.x
e.getSalary()
v[i]
```

Operators can be *unary*, *binary*, or *ternary*. A unary operator acts on a single expression, such as `x++`. A binary operator combines two expressions, such as `x + y`. A ternary operator combines three expressions. Java has one ternary operator, `? :` (see Special Topic 5.1).

Unary operators can be *prefix* or *postfix*. A prefix operator is written before the expression on which it operates, as in `-x`. A postfix operator is written after the expression on which it operates, such as `x++`.

Operators are ranked by *precedence* levels. Operators with a higher precedence bind more strongly than operators with a lower precedence. For example, `*` has a higher precedence than `+`, so `x + y * z` is the same as `x + (y * z)`, even though the `+` comes first.

Most operators are *left-associative*. That is, operators of the same precedence are evaluated from the left to the right. For example, `x - y + z` is interpreted as `(x - y) + z`, not `x - (y + z)`. The exceptions are the unary prefix operators and the assignment operator which are right-associative. For example, `z = y = Math.sin(x)` means the same as `z = (y = Math.sin(x))`.

Appendix B has a list of all Java operators.

Classes

The syntax for a *class* is

```
[public] [abstract|final] class ClassName
      [extends SuperClassName]
      [implements InterfaceName₁, InterfaceName₂, . . .]
{
   feature₁
   feature₂
   . . .
}
```

Each *feature* is either a declaration of the form

```
modifiers constructor|method|instance variable|class
```

or an initialization block

```
[static] { body }
```

See the section "Constructors" for more information about initialization blocks.

Potential *modifiers* include `public`, `private`, `protected`, `static`, and `final`.

An *instance variable* declaration has the form

```
Type variableName [= initializer];
```

A *constructor* has the form

```
ClassName(parameter₁, parameter₂, . . .)
      [throws ExceptionType₁, ExceptionType₂, . . .]
{
   body
}
```

A *method* has the form

```
Type methodName(parameter₁, parameter₂, . . .)
      [throws ExceptionType₁, ExceptionType₂, . . .]
{
   body
}
```

An *abstract method* has the form

```
abstract Type methodName(parameter₁, parameter₂, . . .);
```

Here is an example:

```
public class Point
{
   private double x;
   private double y;

   public Point()
   {
      x = 0; y = 0;
   }

   public Point(double xx, double yy)
   {
      x = xx; y = yy;
   }

   public double getX()
   {
      return x;
   }

   public double getY()
   {
      return y;
   }
}
```

A class can have both instance variables and `static` variables. Each object of the class has a separate copy of the instance variables. There is only a one per-class copy of the `static` variables.

A class that is declared as `abstract` cannot be instantiated. That is, you cannot construct objects of that class.

A class that is declared as `final` cannot be extended.

Interfaces

The syntax for an interface is

```
[public] interface InterfaceName
      [extends InterfaceName_1, InterfaceName_2, . . .]
{
   feature_1
   feature_2
   . . .
}
```

Each feature has the form

modifiers method|instance variable

Potential modifiers are `public`, `static`, `final`. However, modifiers are never necessary because methods are automatically `public` and instance variables are automatically `public static final`.

An instance variable declaration has the form

Type variableName = *initializer*;

A method declaration has the form

Type methodName(*parameter*$_1$, *parameter*$_2$, . . .);

Here is an example:

```
public interface Measurable
{
   int CM_PER_INCH = 2.54;

   int getMeasure();
}
```

Enumeration Types

The syntax for an enumeration type is

```
[public] enum EnumerationTypeName
{
   constant_1, constant_2, . . .;
   feature_1
   feature_2
   . . .
}
```

Each constant is a constant name, followed by optional construction parameters.

constantName[(*parameter*$_1$, *parameter*$_2$, . . .)]

The semicolon after the constants is only required if the enumeration declares additional features. An enumeration can have the same features as a class. Each feature has the form

modifiers method|instance variable

Potential modifiers are `public`, `static`, `final`.

Here are two examples:

```
public enum Suit { HEARTS, DIAMONDS, SPADES, CLUBS };
public enum Card
{
   TWO(2), THREE(3), FOUR(4), FIVE(5), SIX(6),
         SEVEN(7), EIGHT(8), NINE(9), TEN(10),
         JACK(10), QUEEN(10), KING(10), ACE(11);
   private int value;

   public void Card(int aValue) { value = aValue; }
   public int getValue() { return value; }
}
```

Methods

A method definition has the form

modifiers Type methodName(*parameter*$_1$, *parameter*$_2$, . . ., *parameter*$_n$)
    [`throws` *ExceptionType*$_1$, *ExceptionType*$_2$, . . .]
{
   body
}

The return type *Type* is any Java type, or the special type `void` to indicate that the method returns no value.

Each *parameter* has the form

[`final`] *Type parameterName*

A method has *variable parameters* if the last parameter has the special form

Type... *parameterName*

Such a method can be called with a sequence of values of the given type of any length. The parameter variable with the given name is an array of the given type that holds the parameter values. For example, the method

```
public static double sum(double... values)
{
   double s = 0;
   for (double v : values) s = s + v;
   return s;
}
```

can be called as

```
double result = sum(1, -2.5, 3.14);
```

In Java, all parameters are passed by *value*. Each parameter is a local variable whose scope extends to the end of the method body. It is initialized with a copy of the value supplied in the call. That value may be a primitive type or a reference type. If it is a reference type, invoking a mutator on the reference will modify the object whose reference has been passed to the method.

Changing the value of the parameter variable has no effect outside the method. Tagging the parameter as `final` disallows such a change altogether. This is commonly done to allow access of the parameter from an inner class declared in the method.

Java distinguishes between *instance* methods and *static* methods. Instance methods have a special parameter, the *implicit* parameter, supplied in the method call with the syntax

implicitParameterValue.*methodName*(*parameterValue*$_1$, *parameterValue*$_2$, . . .)

Example:

```
harry.setSalary(30000)
```

The type of the implicit parameter must be the same as the type of the class containing the method definition. A static method does not have an implicit parameter.

In the method body, the `this` variable is initialized with a copy of the implicit parameter value. Using an instance variable name without qualification means to access the instance variable of the implicit parameter. For example,

```
public void setSalary(double s)
{
   salary = s; // i.e., this.salary = s
}
```

By default, Java uses *dynamic method lookup*. The virtual machine determines the class to which the implicit parameter object belongs and invokes the method declared in that class. However, if a method is invoked on the special variable `super`, then the method declared in the superclass is invoked on `this`. For example,

```
public class MyPanel extends JPanel
{
   . . .
   public void paintComponent(Graphics g)
   {
      super.paintComponent(g);
      // Calls JPanel.paintComponent
      . . .
   }
   . . .
}
```

The `return` statement causes a method to exit immediately. If the method type is not `void`, you must return a value. The syntax is

`return` [*value*];

For example,

```
public double getSalary()
{
   return salary;
}
```

A method can call itself. Such a method is called *recursive:*

```
public static int factorial(int n)
{
   if (n <= 1) return 1;
      return n * factorial(n - 1);
}
```

Constructors

A constructor definition has the form

```
modifiers ClassName(parameter1, parameter2, . . .)
      [throws ExceptionType1, ExceptionType2, . . .]
{
   body
}
```

You invoke a constructor to allocate and construct a new object with a `new` expression

```
new ClassName(parameterValue1, parameterValue2, . . .)
```

A constructor can call the body of another constructor of the same class with the syntax

```
this(parameterValue1, parameterValue2, . . .)
```

For example,

```
public Employee()
{
   this("", 0);
}
```

It can call a constructor of its superclass with the syntax

```
super(parameterValue1, parameterValue2, . . .)
```

The call to `this` or `super` must be the first statement in the constructor.

Arrays are constructed with the syntax

```
new ArrayType [ = { initializer1, initializer2, . . . }]
```

For example,

```
new int[] = { 1, 4, 9, 16, 25 }
```

When an object is constructed, the following actions take place:

- All instance variables are initialized with `0`, `false`, or `null`.
- The initializers and initialization blocks are executed in the order in which they are declared.
- The body of the constructor is invoked.

When a class is loaded, the following actions take place:

- All static variables are initialized with `0`, `false`, or `null`.
- The initializers of static variables and static initialization blocks are executed in the order in which they are declared.

Statements

A *statement* is one of the following:

- An expression followed by a semicolon
- A branch or loop statement
- A `return` statement
- A `throw` statement
- A block, that is, a group of variable declarations and statements enclosed in braces `{. . .}`
- A `try` block

Java has two branch statements (`if` and `switch`), three loop statements (`while`, `for`, and `do`), and two mechanisms for nonlinear control flow (`break` and `continue`).

The `if` statement has the form

```
if (condition) statement1 [else statement2]
```

If the *condition* is true, then the first *statement* is executed. Otherwise, the second *statement* is executed.

The `switch` statement has the form

```
switch (expression)
{
   group1:
   group2:
   . . .
     [default:
      statement1
      statement2
      . . .]
}
```

Where each group has the form

```
case constant1
case constant2
. . .
   statement1
   statement2
   . . .
```

The *expression* must be an integer or an enumeration type. Depending on its value, control is transferred to the first statement following the matching `case` label, or to the first statement following the `default` label if none of the `case` labels match. Execution continues with the next statement until a `break` or `return` statement is encountered, an exception is thrown, or the end of the `switch` is reached. Execution skips over any `case` labels.

The `while` loop has the form

```
while (condition) statement
```

The *statement* is executed while the *condition* is true.

The `for` loop has the form

```
for (initExpression|variableDeclaration;
      condition;
      updateExpression1, updateExpression2, . . .)
   statement
```

The initialization expression or the variable declaration are executed once. While the *condition* remains true, the loop *statement* and the *updateExpressions* are executed. Examples:

```
for (i = 0; i < 10; i++)
   sum = sum + i;
for (int i = 0, j = 9; i < 10; i++, j--)
   a[j] = b[i];
```

The enhanced `for` loop or "for each" loop has the form

```
for (Type variable : array|iterableObject)
   statement
```

When this loop traverses an array, it is equivalent to

```
for (int i = 0; i < array.length; i++)
{
   Type variable = array[i];
   statement
}
```

Otherwise, the *iterableObject* must belong to a class that implements the `Iterable` interface. Then the loop is equivalent to

```
Iterator i = iterableObject.iterator();
while (i.hasNext())
{
   Type variable = i.next();
   statement
}
```

The `do` loop has the form

```
do statement while (condition);
```

The *statement* is repeatedly executed until the *condition* is no longer true. In contrast to a `while` loop, the statement of a `do` loop is executed at least once.

The `break` statement exits the innermost enclosing `while`, `do`, `for`, or `switch` statement (not counting `if` or block statements).

Any statement (including `if` and block statements) can be tagged with a label:

label: *statement*

The labeled `break` statement

```
break label;
```

exits the labeled statement.

The `continue` statement skips past the end of the *statement* part of a `while`, `do`, or `for` loop. In the case of the `while` or `do` loop, the loop *condition* is executed next. In the case of the `for` loop, the *updateExpressions* are executed next.

The labeled `continue` statement

```
continue label;
```

skips past the end of the *statement* part of a `while`, `do`, or `for` loop with the matching label.

Exceptions

The `throw` statement

```
throw expression;
```

abruptly terminates the current method and resumes control inside the innermost matching `catch` clause of a surrounding `try` block. The *expression* must evaluate to a reference to an object of a subclass of `Throwable`.

The `try` statement has the form

```
try tryBlock
[catch (ExceptionType1 exceptionVariable1) catchBlock1
catch (ExceptionType2 exceptionVariable2) catchBlock2
. . .]
[finally finallyBlock]
```

- The `try` statement must have at least one `catch` or `finally` clause.
- All blocks are block statements in the usual sense, that is, `{ . . . }`-delimited statement sequences.

The statements in the *tryBlock* are executed. If one of them throws an exception object whose type is a subtype of one of the types in the `catch` clauses, then its *catchBlock* is executed. As soon as the catch block is entered, that exception is handled.

If the *tryBlock* exits for any reason at all (because all of its statements executed completely; because one of its statements was a `break`, `continue`, or `return` statement; or because an exception was thrown), then the *finallyBlock* is executed.

If the *finallyBlock* was entered because an exception was thrown and it itself throws another exception, then that exception masks the prior exception.

Packages

A class can be placed in a package by putting the package declaration

```
package packageName;
```

as the first non-`import` declaration of the source file.

A package name has the form

```
identifier1.identifier2. . . .
```

For example,

```
java.util
com.horstmann.bigjava
```

A fully qualified name of a class is

```
packageName.ClassName
```

Classes can always be referenced by their fully qualified class names. However, this can be inconvenient. For that reason, you can reference imported classes by just their *ClassName*. All classes in the package `java.lang` and in the package of the current source file are always imported. To import additional classes, use an `import` directive

```
import packageName.ClassName;
```

or

```
import packageName.*;
```

The second version imports all classes in the package.

Generic Types and Methods

A generic type is declared with one or more *type parameters*, placed after the type name:

```
modifiers class|interface TypeName<typeParameter1, typeParameter2, . . .>
```

Similarly, a generic method is declared with one or more type parameters, placed *before* the method's return type:

```
modifiers <typeParameter1, typeParameter2, . . .> returnType methodName
```

Each type parameter has the form

```
typeParameterName [extends bound1 & bound2 & . . .]
```

For example,

```
public class BinarySearchTree<T extends Comparable>
public interface Comparator<T>
public <T extends Comparable & Cloneable> T cloneMin(T[] values)
```

Type parameters can be used in the definition of the generic type or method as if they were regular types. They can be replaced with any types that match the bounds. For example, the `BinarySearchTree<String>` type substitutes the `String` type for the type parameter `T`.

Type parameters can also be replaced with *wildcard types*. A wildcard type has the form

```
? [super|extends Type]
```

It denotes a specific type that is unknown at the time that is declared. For example, `Comparable<? super Rectangle>` is a type `Comparable<S>` for a specific type `S`, which can be `Rectangle` or a supertype such as `RectangularShape` or `Shape`.

Comments

There are three kinds of comments:

```
/* comment */
// one-line-comment
/** documentationComment */
```

The one-line comment extends to the end of the line. The other comments can span multiple lines and extend to the `*/` delimiter.

Documentation comments are further explained in Appendix H.

Appendix F

HTML Summary

A Brief Introduction to HTML

A web page is written in a language called HTML (Hypertext Markup Language). Like Java code, HTML code is made up of text that follows certain strict rules. When a browser reads a web page, the browser *interprets* the code and *renders* the page, displaying characters, fonts, paragraphs, tables, and images.

HTML files are made up of text and *tags* that tell the browser how to render the text. Nowadays, there are dozens of HTML tags—see Table 1 for a summary of the most important tags. Fortunately, you need only a few to get started. Most HTML tags come in pairs consisting of an opening tag and a closing tag, and each pair applies to the text between the two tags. Here is a typical example of a tag pair:

```
Java is an <i>object-oriented</i> programming language.
```

The tag pair `<i> </i>` directs the browser to display the text inside the tags in *italics*:

Java is an *object-oriented* programming language.

The closing tag is just like the opening tag, but it is prefixed by a slash (/). For example, bold-faced text is delimited by `<b> </b>`, and a paragraph is delimited by the tag pair `<p> </p>`.

```
<p><b>Java</b> is an <i>object-oriented</i> programming language.</p>
```

The result is the paragraph

Java is an *object-oriented* programming language.

Another common construct is a bulleted list. For example:

Java is

- object-oriented
- safe
- platform-independent

Here is the HTML code to display it:

```
<p>Java is</p>
<ul><li>object-oriented</li>
<li>safe</li>
<li>platform-independent</li></ul>
```

Each item in the list is delimited by `<li> </li>` (for "list item"), and the whole list is surrounded by `<ul> </ul>` (for "unnumbered list").

Table 1 Selected HTML Tags

Tag	Meaning	Children	Commonly Used Attributes
html	HTML document	head, body	
head	Head of an HTML document	title	
title	Title of an HTML document		
body	Body of an HTML document		
h1 . . . h6	Heading level 1 . . . 6		
p	Paragraph		
ul	Unnumbered list	li	
ol	Ordered list	li	
dl	Definition list	dt, dd	
li	List item		
dt	Term to be defined		
dd	Definition data		
table	Table	tr	
tr	Table row	th, td	
th	Table header cell		
td	Table cell data		
a	Anchor		href, name
img	Image		src, width, height
applet	Applet		code, width, height
pre	Preformatted text		
hr	Horizontal rule		
br	Line break		
i or em	Italic		
b or strong	Bold		
tt or code	Typewriter or code font		
s or strike	Strike through		
u	Underline		
super	Superscript		

Table 1 Selected HTML Tags, continued

Tag	Meaning	Children	Commonly Used Attributes
`sub`	Subscript		
`form`	Form		`action, method`
`input`	Input field		`type, name, value, size, checked`
`select`	Combo box style selector	`option`	`name`
`option`	Option for selection		
`textarea`	Multiline text area		`name, rows, cols`

As in Java code, you can freely use white space (spaces and line breaks) in HTML code to make it easier to read. For example, you can lay out the code for a list as follows:

```
<p>Java is</p>
<ul>
<li>object-oriented</li>
<li>safe</li>
<li>platform-independent</li>
</ul>
```

The browser ignores the white space.

If you omit a tag (such as a `</li>`), most browsers will try to guess the missing tags—sometimes with differing results. It is always best to include all tags.

You can include images in your web pages with the `img` tag. In its simplest form, an image tag has the form

```
<img src="hamster.jpeg"/>
```

This code tells the browser to load and display the image that is stored in the file `hamster.jpeg`. This is a slightly different type of tag. Rather than text inside a tag pair `<img> </img>`, the `img` tag uses an attribute to specify a file name. Attributes have names and values. For example, the `src` attribute has the value `"hamster.jpeg"`. Table 2 contains commonly used attributes.

It is considered polite to use several additional attributes with the `img` tag, namely the *image size* and an *alternate description*:

```
<img src="hamster.jpeg" width="640" height="480"
alt="A photo of Harry, the Horrible Hamster"/>
```

These additional attributes help the browser lay out the page and display a temporary description while gathering the data for the image (or if the browser cannot display images, such as a voice browser for blind users). Users with slow network connections really appreciate this extra effort.

Because there is no closing `</img>` tag, we put a slash `/` before the closing `>`. This is not a requirement of HTML, but it is a requirement of the emerging XHTML standard, the XML-based successor to HTML. See `www.w3c.org/TR/xhtml1` for more information on XHTML.

Table 2 Selected HTML Attributes

Attribute	Description	Commonly Contained in Element
`name`	Name of form element or anchor	`input, select, textarea, a`
`href`	Hyperlink reference	`a`
`src`	Source (as of an image)	`img`
`code`	Applet code	`applet`
`width, height`	Width, height of image or applet	`img, applet`
`rows, cols`	Rows, columns of text area	`textarea`
`type`	Type of input field, such as `text`, `password`, `checkbox`, `radio`, `submit`, `hidden`	`input`
`value`	Value of input field, or label of submit button	`input`
`size`	Size of text field	`input`
`checked`	Check radio button or checkbox	`input`
`action`	URL of form action	`form`
`method`	`GET` or `POST`	`form`

The most important tag in web pages is the `<a> </a>` tag pair, which makes the enclosed text into a *link* to another file. The links between web pages are what makes the Web into, well, a web. The browser displays a link in a special way (for example, underlined text in blue color). Here is the code for a typical link:

```
<a href="http://java.sun.com">Java</a> is an object-oriented
programming language.
```

When the viewer of the web page clicks on the word Java, the browser loads the web page located at `java.sun.com`. (The value of the `href` attribute is a *Universal Resource Locator* (URL), which tells the browser where to go. The prefix `http:`, for *Hypertext Transfer Protocol*, tells the browser to fetch the file as a web page. Other protocols allow different actions, such as `ftp:` to download a file, `mailto:` to send e-mail to a user, and `file:` to view a local HTML file.)

Finally, the `applet` tag includes an applet in a web page. To display an applet, you need first to write and compile a Java file to generate the applet code—see Special Topic 2.2. Then you tell the browser how to find the code for the applet and how much screen space to reserve for the applet. Here is an example:

```
<applet code="HamsterApplet.class" width="400" height="300">An
animation of Harry, the Horrible Hamster</applet>
```

The text between the `<applet>` and `</applet>` tags is only displayed in lieu of the actual applet by browsers that can't run Java applets.

Table 3 Selected HTML Entities

Entity	Description	Appearance
`&lt;`	Less than	<
`&gt;`	Greater than	>
`&amp;`	Ampersand	&
`&quot;`	Quotation mark	"
`&nbsp;`	Nonbreaking space	
`&copy;`	Copyright symbol	©

You have noticed that tags are enclosed in angle brackets (less-than and greater-than signs). What if you want to show an angle bracket on a web page? HTML provides the notations `&lt;` and `&gt;` to produce the `<` and `>` symbols, respectively. Other codes of this kind produce symbols such as accented letters. The `&` (ampersand) symbol introduces these codes; to get that symbol itself, use `&amp;`. See Table 3 for a summary.

You may already have created web pages with a web editor that works like a word processor, giving you a WYSIWYG (what you see is what you get) view of your web page. But the tags are still there, and you can see them when you load the HTML file into a text editor. If you are comfortable using a WYSIWYG web editor, and if your editor can insert applet tags, you don't need to memorize HTML tags at all. But many programmers and professional web designers prefer to work directly with the tags at least some of the time, because it gives them more control over their pages.

Appendix G Tool Summary

In this summary, we use a monospaced font for actual commands such as `javac`. An italic font denotes descriptions of tool command components such as *options*. Items enclosed in brackets [. . .] are optional. Items separated by vertical bars | are alternatives. Do not include the brackets or vertical bars when typing the commands.

The Java Compiler

`javac` [*options*] *sourceFile*$_1$|@*fileList*$_1$ *sourceFile*$_2$|@*fileList*$_2$ . . .

A file list is a text file that contains one file name per line. For example,

File Greeting.list

```
Greeting.java
GreetingTest.java
```

Then you can compile all files with the command

```
javac @Greeting.list
```

The Java compiler options are summarized in Table 1.

Table 1 Common Compiler Options

Option	Description
`-classpath` *locations* or `-cp` *locations*	The compiler is to look for classes on this path, overriding the `CLASSPATH` environment variable. If neither is specified, the current directory is used. Each *location* is a directory, JAR file, or ZIP file. Locations are separated by a platform-dependent separator (: on Unix, ; on Windows).
`-sourcepath` *locations*	The compiler is to look for source files on this path. If not specified, source files are searched in the class path.
`-d` *directory*	The compiler places files into the specified directory.
`-g`	Generate debugging information.
`-verbose`	Include information about all classes that are being compiled (useful for troubleshooting).
`-deprecation`	Give detailed information about the usage of deprecated messages.
`-Xlint:`*errorType*	Carry out additional error checking. If you get warnings about unchecked conversions, compile with the `-Xlint:unchecked` option.

The Java Virtual Machine Launcher

The following command loads the given class and starts its `main` method, passing it an array containing the provided command line arguments.

```
java [options] ClassName [argument1 argument2 . . . ]
```

The following command loads the main class of the given JAR file and starts its `main` method, passing it an array containing the provided command line arguments.

```
java [options] -jar jarFileName [argument1 argument2 . . . ]
```

The Java virtual machine options are summarized in Table 2.

Table 2 Common Virtual Machine Launcher Options

Option	Description
`-classpath` *locations* or `-cp` *locations*	Look for classes on this path, overriding the `CLASSPATH` environment variable. If neither is specified, the current directory is used. Each *location* is a directory, JAR file, or ZIP file. Locations are separated by a platform-dependent separator (`:` on Unix, `;` on Windows).
`-verbose`	Trace class loading
`-D`*property*`=`*value*	Set a system property that you can retrieve with the `System.getProperties` method.

The Applet Viewer

```
appletviewer url1 url2 . . .
```

The *urls* are searched for applets, and each applet is displayed in a separate window.
An applet should be specified as an HTML tag of the form

```
<applet
   code=appletClassFile
   width=pixels
   height=pixels
   [codebase=relativeURL]>
   <param name=parameterName1 value=parameterValue1>
   <param name=parameterName2 value=parameterValue2>
   . . .
</applet>
```

The `codebase` parameter is an URL that is relative to the URL of the HTML file containing the `applet` or `object` tag.

The JAR Tool

To combine one or more files into a JAR (Java Archive) file, use the command

`jar cvf` *jarFile* *file*$_1$ *file*$_2$ . . .

The resulting JAR file can be included in a class path.

To build a program that can be launched with `java -jar`, you must create a *manifest file,* such as

File myprog.mf

```
Main-Class: com/horstmann/MyProg
```

The manifest must specify the path name of the class file that launches the application, but with the `.class` extension removed. Then build the JAR file as

`jar cvfm` *jarFile* *manifestFile* *file*$_1$ *file*$_2$ . . .

You can also use JAR as a replacement for a ZIP utility, simply to compress and bundle a set of files for any purpose. Then you may want to suppress the generation of the JAR manifest, with the command

`jar cvfM` *jarFile* *file*$_1$ *file*$_2$ . . .

To extract the contents of a JAR file into the current directory, use

`jar xvf` *jarFile*

To see the files contained in a JAR file without extracting the files, use

`jar tvf` *jarFile*

Appendix H

javadoc Summary

Setting Documentation Comments in Source

A documentation comment is delimited by `/**` and `*/`. You can comment

- Classes
- Methods
- Instance variables

Each comment is placed *immediately above* the feature it documents.

Each `/** . . . */` documentation comment contains introductory text followed by tagged documentation. A tag starts with an `@` character, such as `@author` or `@param`. Tags are summarized in Table 1. The *first sentence* of the introductory text should be a summary statement. The `javadoc` utility automatically generates summary pages that extract these sentences.

Table 1 Common javadoc Tags

Tag	Description
`@param` *parameter explanation*	A parameter of a method. Use a separate tag for each parameter.
`@return` *explanation*	The return value of a method.
`@throws` *exceptionType explanation*	An exception that a method may throw. Use a separate tag for each exception.
`@deprecated`	A feature that remains for compatibility but that should not be used for new code.
`@see` *packageName.ClassName* `@see` *packageName.ClassName* *#methodName*$(Type_1, Type_2, \ldots)$ `@see` *packageName.ClassName#variableName*	A reference to a related documentation entry.
`@author`	The author of a class or interface. Use a separate tag for each author.
`@version`	The version of a class or interface.

You can use HTML tags such as `em` for emphasis, `code` for a monospaced font, `img` for images, `ul` for bulleted lists, and so on.

Here is a typical example. The summary sentence (in color) will be included with the method summary.

```
/**
   Withdraws money from the bank account. Increments the
   transaction count.
   @param amount the amount to withdraw
   @return the balance after the withdrawal
   @throws IllegalArgumentException if the balance is not sufficient
*/
public double withdraw(double amount)
{
   if (balance - amount < minimumBalance)
      throw new IllegalArgumentException();
   balance = balance - amount;
   transactions++;
   return balance;
}
```

Generating Documentation from Commented Source

To extract the comments, run the `javadoc` program:

`javadoc` [*options*] *sourceFile*$_1$| *packageName*$_1$| @*fileList*$_1$
      sourceFile$_2$| *packageName*$_2$| @*fileList*$_2$ . . .

See the documentation of the `javac` command in Appendix F for an explanation of file lists. Commonly used options are summarized in Table 2.

To document all files in the current directory, use (all on one line)

```
javadoc -link http://java.sun.com/javase/7/docs/api
      -d docdir *.java
```

Table 2 Common javadoc Command Line Options

Option	Description
`-link` *URL*	Link to another set of Javadoc files. You should include a link to the standard library documentation, either locally or at `http://java.sun.com/javase/7/docs/api`.
`-d` *directory*	Store the output in *directory*. This is a useful option, because it keeps your current directory from being cluttered up with `javadoc` files.
`-classpath` *locations*	Look for classes on the specified paths, overriding the `CLASSPATH` environment variable. If neither is specified, the current directory is used. Each *location* is a directory, JAR file, or ZIP file. Locations are separated by a platform-dependent separator (: Unix, ; Windows).
`-sourcepath` *locations*	Look for source files on the specified paths. If not specified, source files are searched in the class path.
`-author, -version`	Include author, version information in the documentation. This information is omitted by default.

Appendix

Number Systems

Binary Numbers

Decimal notation represents numbers as powers of 10, for example

$$1729_{\text{decimal}} = 1 \times 10^3 + 7 \times 10^2 + 2 \times 10^1 + 9 \times 10^0$$

There is no particular reason for the choice of 10, except that several historical number systems were derived from people's counting with their fingers. Other number systems, using a base of 12, 20, or 60, have been used by various cultures throughout human history. However, computers use a number system with base 2 because it is far easier to build electronic components that work with two values, which can be represented by a current being either off or on, than it would be to represent 10 different values of electrical signals. A number written in base 2 is also called a *binary* number.

For example,

$$1101_{\text{binary}} = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 = 8 + 4 + 1 = 13$$

For digits after the "decimal" point, use negative powers of 2.

$$\begin{aligned} 1.101_{\text{binary}} &= 1 \times 2^0 + 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3} \\ &= 1 + \frac{1}{2} + \frac{1}{8} \\ &= 1 + 0.5 + 0.125 = 1.625 \end{aligned}$$

In general, to convert a binary number into its decimal equivalent, simply evaluate the powers of 2 corresponding to digits with value 1, and add them up. Table 1 shows the first powers of 2.

To convert a decimal integer into its binary equivalent, keep dividing the integer by 2, keeping track of the remainders. Stop when the number is 0. Then write the remainders as a binary number, starting with the *last* one.

For example,

$$\begin{aligned}
100 \div 2 &= 50 \text{ remainder } 0\\
50 \div 2 &= 25 \text{ remainder } 0\\
25 \div 2 &= 12 \text{ remainder } 1\\
12 \div 2 &= 6 \text{ remainder } 0\\
6 \div 2 &= 3 \text{ remainder } 0\\
3 \div 2 &= 1 \text{ remainder } 1\\
1 \div 2 &= 0 \text{ remainder } 1
\end{aligned}$$

Therefore, $100_{\text{decimal}} = 1100100_{\text{binary}}$.

Conversely, to convert a fractional number less than 1 to its binary format, keep multiplying by 2. If the result is greater than 1, subtract 1. Stop when the number is 0. Then use the digits before the decimal points as the binary digits of the fractional part, starting with the *first* one. For example,

$$\begin{aligned}
0.35 \cdot 2 &= 0.7\\
0.7 \cdot 2 &= 1.4\\
0.4 \cdot 2 &= 0.8\\
0.8 \cdot 2 &= 1.6\\
0.6 \cdot 2 &= 1.2\\
0.2 \cdot 2 &= 0.4
\end{aligned}$$

Here the pattern repeats. That is, the binary representation of 0.35 is 0.01 0110 0110 0110 . . .

To convert any floating-point number into binary, convert the whole part and the fractional part separately.

Table 1 Powers of Two

Power	Decimal Value
2^0	1
2^1	2
2^2	4
2^3	8
2^4	16
2^5	32
2^6	64
2^7	128
2^8	256
2^9	512
2^{10}	1,024
2^{11}	2,048
2^{12}	4,096
2^{13}	8,192
2^{14}	16,384
2^{15}	32,768
2^{16}	65,536

Two's Complement Integers

To represent negative integers, there are two common representations, called "signed magnitude" and "two's complement". Signed magnitude notation is simple: use the leftmost bit for the sign (0 = positive, 1 = negative). For example, when using 8-bit numbers,

$$-13 = 10001101_{\text{signed magnitude}}$$

However, building circuitry for adding numbers gets a bit more complicated when one has to take a sign bit into account. The two's complement representation solves this problem.

To form the two's complement of a number,

- Flip all bits.
- Then add 1.

For example, to compute –13 as an 8-bit value, first flip all bits of 00001101 to get 11110010. Then add 1:

$$-13 = 11110011_{\text{two's complement}}$$

Now no special circuitry is required for adding two numbers. Simply follow the normal rule for addition, with a carry to the next position if the sum of the digits and the prior carry is 2 or 3. For example,

```
          1 1111 111
+13         0000 1101
-13         1111 0011
          -----------
          1 0000 0000
```

But only the last 8 bits count, so +13 and –13 add up to 0, as they should.

In particular, –1 has two's complement representation 1111 . . . 1111, with all bits set.

The leftmost bit of a two's complement number is 0 if the number is positive or zero, 1 if it is negative.

Two's complement notation with a given number of bits can represent one more negative number than positive numbers. For example, the 8-bit two's complement numbers range from –128 to +127.

This phenomenon is an occasional cause for a programming error. For example, consider the following code:

```
byte b = . . .;
if (b < 0) b = (byte) -b;
```

This code does not guarantee that `b` is nonnegative afterwards. If `b` happens to be –128, then computing its negative again yields –128. (Try it out—take 10000000, flip all bits, and add 1.)

IEEE Floating-Point Numbers

The Institute for Electrical and Electronics Engineering (IEEE) defines standards for floating-point representations in the IEEE-754 standard. Figure 1 shows how single-precision (`float`) and double-precision (`double`) values are decomposed into

- A sign bit
- An exponent
- A mantissa

Floating-point numbers use scientific notation, in which a number is represented as

$$b_0.b_1b_2b_3\ldots \times 2^e$$

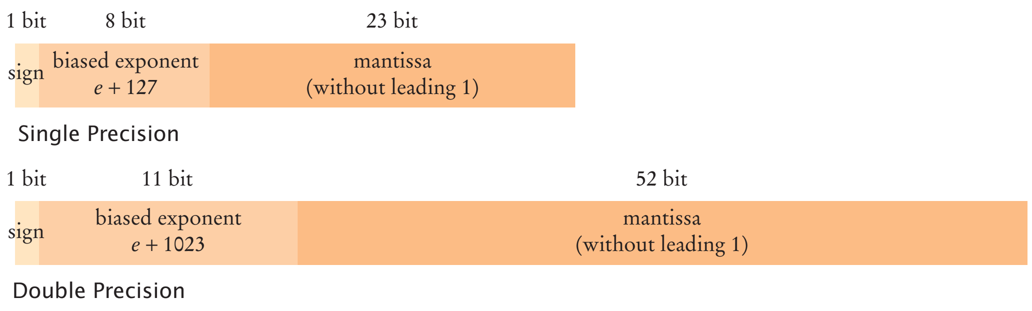

Figure 1 IEEE Floating-Point Representation

In this representation, e is the exponent, and the digits $b_0.b_1b_2b_3\ldots$ form the mantissa. The *normalized* representation is the one where $b_0 \neq 0$. For example,

$$100_{\text{decimal}} = 1100100_{\text{binary}} = 1.100100_{\text{binary}} \times 2^6$$

Because in the binary number system the first bit of a normalized representation must be 1, it is not actually stored in the mantissa. Therefore, you always need to add it on to represent the actual value. For example, the mantissa 1.100100 is stored as 100100.

The exponent part of the IEEE representation uses neither signed magnitude nor two's complement representation. Instead, a bias is added to the actual exponent. The bias is 127 for single-precision numbers, 1023 for double-precision numbers. For example, the exponent $e = 6$ would be stored as 133 in a single-precision number.

Thus,

$$100_{\text{decimal}} = 0\ 10000101\ 10010000000000000000000_{\text{single-precision IEEE}}$$

In addition, there are several special values. Among them are:

- *Zero:* biased exponent = 0, mantissa = 0.
- *Infinity:* biased exponent = 11. . .1, mantissa = ±0.
- *NaN* (not a number): biased exponent = 11. . .1, mantissa ≠ ±0.

Hexadecimal Numbers

Because binary numbers can be hard to read for humans, programmers often use the hexadecimal number system, with base 16. The digits are denoted as 0, 1, . . . , 9, A, B, C, D, E, F (see Table 2).

Four binary digits correspond to one hexadecimal digit. That makes it easy to convert between binary and hexadecimal values. For example,

$$11\,|\,1011\,|\,0001_{\text{binary}} = 3B1_{\text{hexadecimal}}$$

In Java, hexadecimal numbers are used for Unicode character values, such as `\u03B1` (the Greek lowercase letter alpha). Hexadecimal integers are denoted with a `0x` prefix, such as `0x3B1`.

Table 2 Hexadecimal Digits

Hexadecimal	Decimal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111

Appendix J

Bit and Shift Operations

There are four bit operations in Java: the unary negation (~) and the binary and (&), or (|), and exclusive or (^), often called xor.

Tables 1 and 2 show the truth tables for the bit operations in Java. When a bit operation is applied to integer values, the operation is carried out on corresponding bits.

Table 1 The Unary Negation Operation

a	~a
0	1
1	0

Table 2 The Binary And, Or, and Xor Operations

a	b	a & b	a | b	a ^ b
0	0	0	0	0
0	1	0	1	1
1	0	0	1	1
1	1	1	1	0

For example, suppose we want to compute `46 & 13`. First convert both values to binary. $46_{decimal} = 101110_{binary}$ (actually 00000000000000000000000000101110 as a 32-bit integer), and $13_{decimal} = 1101_{binary}$. Now combine corresponding bits:

```
  0.....0101110
& 0.....0001101
---------------
  0.....0001100
```

The answer is $1100_{binary} = 12_{decimal}$.

You sometimes see the `|` operator being used to combine two bit patterns. For example, `Font.BOLD` is the value 1, `Font.ITALIC` is 2. The binary or combination `Font.BOLD | Font.ITALIC` has both the bold and the italic bit set:

```
  0.....0000001
| 0.....0000010
---------------
  0.....0000011
```

Don't confuse the `&` and `|` bit operators with the `&&` and `||` operators. The latter work only on `boolean` values, not on bits of numbers.

Besides the operations that work on individual bits, there are three *shift* operations that take the bit pattern of a number and shift it to the left or right by a given number of positions. There are three shift operations: shift left (<<), right shift with sign extension (>>), and right shift with zero extension (>>>).

The left shift moves all bits to the left, filling in zeroes in the least significant bits. Shifting to the left by n bits yields the same result as multiplication by 2^n. The right shift with sign extension moves all bits to the right, propagating the sign bit. Therefore, the result is the same as integer division by 2^n, both for positive and negative values. Finally, the right shift with zero extension moves all bits to the right, filling in zeroes in the most significant bits. (See Figure 1.)

Note that the right-hand-side value of the shift operators is reduced modulo 32 (for `int` values) or 64 (for `long` values) to determine the actual number of bits to shift.

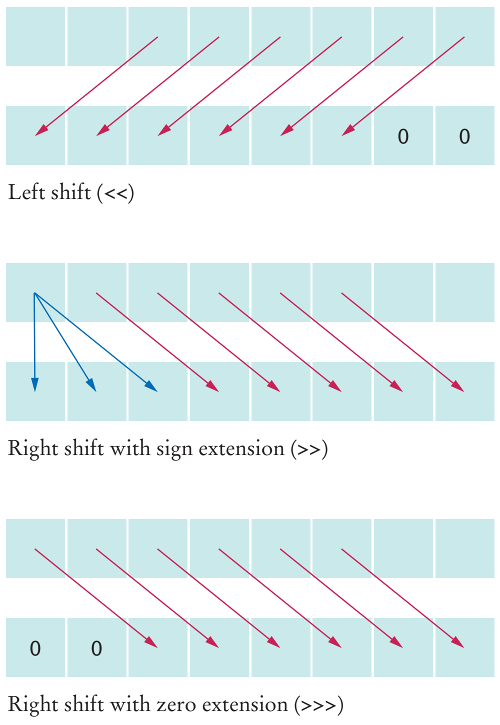
0
0
Left shift (<<)
Right shift with sign extension (>>)
0
0
Right shift with zero extension (>>>)

Figure 1 The Shift Operations

For example, `1 << 35` is the same as `1 << 3`. Actually shifting 1 by 35 bits to the left would make no sense—the result would be `0`.

The expression

```
1 << n
```

yields a bit pattern in which the `n`th bit is set (where the `0` bit is the least significant bit).

To set the `n`th bit of a number, carry out the operation

```
x = x | 1 << n
```

To check whether the `n`th bit is set, execute the test

```
if ((x & 1 << n) != 0) . . .
```

Note that the parentheses around the `&` are required—the `&` operator has a lower precedence than the relational operators.

Appendix K

UML Summary

In this book, we use a very restricted subset of the UML notation. This appendix lists the components of the subset.

For a complete discussion of the UML notation, see *The Unified Modeling Language User Guide,* Grady Booch, James Rumbaugh, and Ivar Jacobson (Addison-Wesley, 2005, 1999).

CRC Cards

CRC cards are used to describe in an informal fashion the responsibilities and collaborators for a class. Figure 1 shows a typical CRC card.

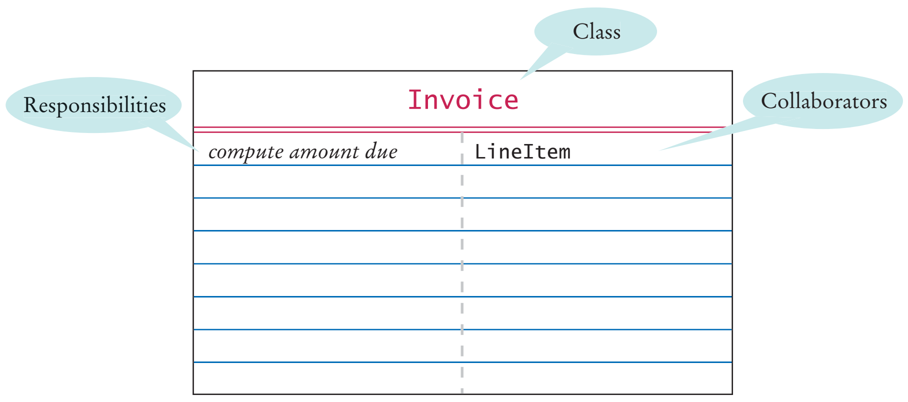

Figure 1 Typical CRC Card

UML Diagrams

Figure 2 shows the UML notation for classes and interfaces. You can optionally supply attributes and methods in a class diagram, as in Figure 3.

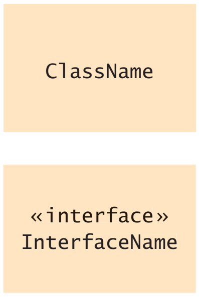

Figure 2
UML Symbols for Classes and Interfaces

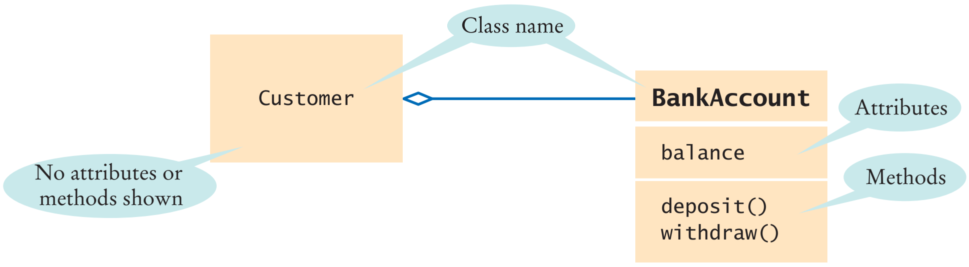

Figure 3 Attributes and Methods in a Class Diagram

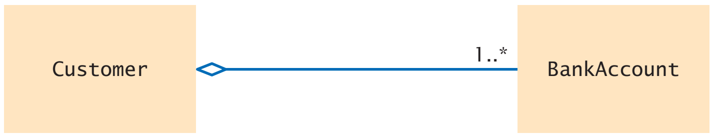

Figure 4 An Aggregation Relationship with Multiplicities

Table 1 shows the arrows used to indicate relationships between classes. Multiplicity can be indicated in a diagram, as in Figure 4.

Table 1 UML Relationship Symbols

Relationship	Symbol	Line Style	Arrow Tip
Inheritance	———▷	Solid	Triangle
Interface Implementation	- - - - - ▷	Dotted	Triangle
Aggregation	◇———	Solid	Diamond
Dependency	- - - - - >	Dotted	Open

Dependencies between objects are described by a dependency diagram. Figure 5 is a typical example.

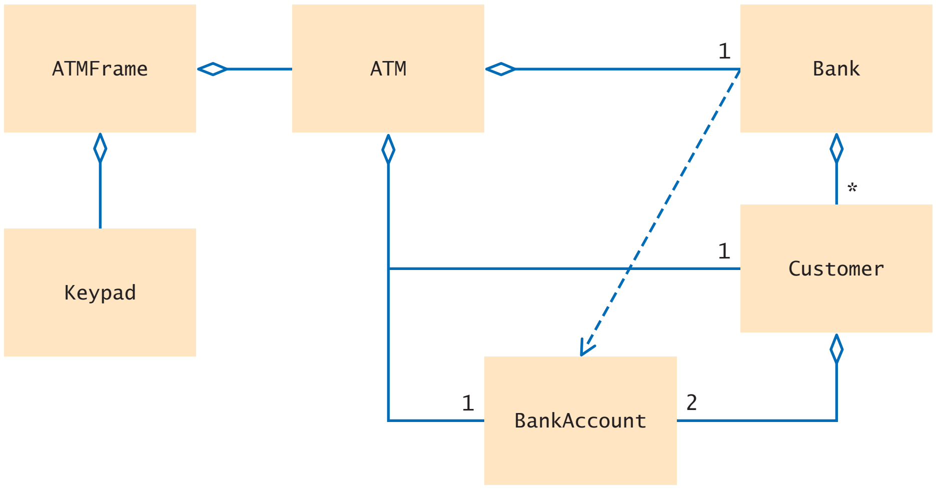

Figure 5 UML Class Diagram for the ATM Simulation

State diagrams are used when an object goes through a discrete set of states that affects its behavior (see Figure 6).

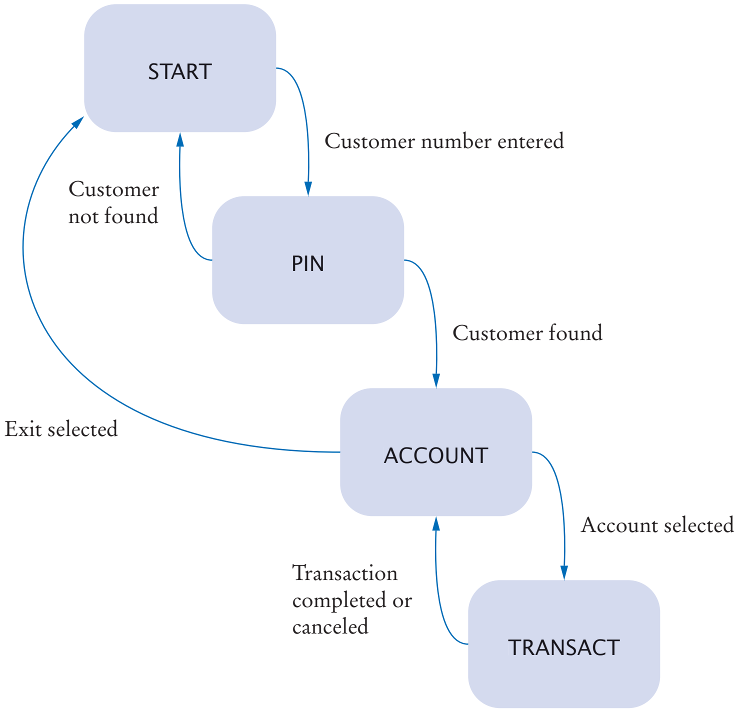

Figure 6 UML State Diagram for the ATM Class

Appendix L

Java Language Coding Guidelines

Introduction

This coding style guide is a simplified version of one that has been used with good success both in industrial practice and for college courses.

A style guide is a set of mandatory requirements for layout and formatting. Uniform style makes it easier for you to read code from your instructor and classmates. You will really appreciate that if you do a team project. It is also easier for your instructor and your grader to grasp the essence of your programs quickly.

A style guide makes you a more productive programmer because it *reduces gratuitous choice.* If you don't have to make choices about trivial matters, you can spend your energy on the solution of real problems.

In these guidelines, several constructs are plainly outlawed. That doesn't mean that programmers using them are evil or incompetent. It does mean that the constructs are not essential and can be expressed just as well or even better with other language constructs.

If you already have programming experience, in Java or another language, you may be initially uncomfortable at giving up some fond habits. However, it is a sign of professionalism to set aside personal preferences in minor matters and to compromise for the benefit of your group.

These guidelines are necessarily somewhat dull. They also mention features that you may not yet have seen in class. Here are the most important highlights:

- Tabs are set every three spaces.
- Variable and method names are lowercase, with occasional upperCase characters in the middle.
- Class names start with an Uppercase letter.
- Constant names are UPPERCASE, with an occasional UNDER_SCORE.
- There are spaces after keywords and surrounding binary operators.
- Braces must line up horizontally or vertically.
- No magic numbers may be used.
- Every method, except for `main` and overridden methods, must have a comment.
- At most 30 lines of code may be used per method.
- No `continue` or `break` is allowed.
- All non-`final` variables must be private.

Note to the instructor: Of course, many programmers and organizations have strong feelings about coding style. If this style guide is incompatible with your own preferences or with local custom, please feel free to modify it. For that purpose, this coding style guide is available in electronic form at `www.wiley.com/college/horstmann` and in the WileyPLUS course for this book.

Source Files

Each Java program is a collection of one or more source files. The executable program is obtained by compiling these files. Organize the material in each file as follows:

- `package` statement, if appropriate
- `import` statements
- A comment explaining the purpose of this file
- A `public` class
- Other classes, if appropriate

The comment explaining the purpose of this file should be in the format recognized by the `javadoc` utility. Start with a `/**`, and use the `@author` and `@version` tags:

```
/**
   COPYRIGHT (C) 2010 Harry Morgan. All Rights Reserved.
   Classes to manipulate widgets.
   Solves CS101 homework assignment #3
   @author Harry Morgan
   @version 1.01 2010-02-15
*/
```

Classes

Each class should be preceded by a class comment explaining the purpose of the class.

First list all public features, then all private features.

Within the public and private sections, use the following order:

1. Instance variables
2. Static variables
3. Constructors
4. Instance methods
5. Static methods
6. Inner classes

Leave a blank line after every method.

All non-`final` variables must be private. (However, instance variables of a private inner class may be public.) Methods and final variables can be either public or private, as appropriate.

All features must be tagged `public` or `private`. Do not use the default visibility (that is, package visibility) or the `protected` attribute.

Avoid static variables (except `final` ones) whenever possible. In the rare instance that you need static variables, you are permitted one static variable per class.

Methods

Every method (except for `main`) starts with a comment in `javadoc` format.

```
/**
   Convert calendar date into Julian day.
   Note: This algorithm is from Press et al., Numerical Recipes
   in C, 2nd ed., Cambridge University Press, 1992.
   @param day day of the date to be converted
   @param month month of the date to be converted
   @param year year of the date to be converted
   @return the Julian day number that begins at noon of the
   given calendar date.
*/
public static int getJulianDayNumber(int day, int month, int year)
{
   . . .
}
```

Parameter names must be explicit, especially if they are integers or Boolean:

```
public Employee remove(int d, double s)
   // Huh?
public Employee remove(int department, double severancePay)
   // OK
```

Methods must have at most 30 lines of code. The method signature, comments, blank lines, and lines containing only braces are not included in this count. This rule forces you to break up complex computations into separate methods.

Variables and Constants

Do not define all variables at the beginning of a block:

```
{
   double xold; // Don't
   double xnew;
   boolean done;
   . . .
}
```

Define each variable just before it is used for the first time:

```
{
   . . .
   double xold = Integer.parseInt(input);
   boolean done = false;
   while (!done)
   {
      double xnew = (xold + a / xold) / 2;
      . . .
   }
   . . .
}
```

Do not define two variables on the same line:

```
int dimes = 0, nickels = 0; // Don’t
```

Instead, use two separate definitions:

```
int dimes = 0; // OK
int nickels = 0;
```

In Java, constants must be defined with the keyword `final`. If the constant is used by multiple methods, declare it as `static final`. It is a good idea to define static final variables as `private` if no other class has an interest in them.

Do not use *magic numbers!* A magic number is a numeric constant embedded in code, without a constant definition. Any number except −1, 0, 1, and 2 is considered magic:

```
if (p.getX() < 300) // Don’t
```

Use `final` variables instead:

```
final double WINDOW_WIDTH = 300;
. . .
if (p.getX() < WINDOW_WIDTH) // OK
```

Even the most reasonable cosmic constant is going to change one day. You think there are 365 days per year? Your customers on Mars are going to be pretty unhappy about your silly prejudice. Make a constant

```
public static final int DAYS_PER_YEAR = 365;
```

so that you can easily produce a Martian version without trying to find all the 365s, 364s, 366s, 367s, and so on, in your code.

When declaring array variables, group the `[]` with the type, not the variable.

```
int[] values; // OK
int values[]; // Ugh—this is an ugly holdover from C
```

When using collections, use type parameters and not “raw” types.

```
ArrayList<String> names = new ArrayList<String>(); // OK
ArrayList names = new ArrayList(); // Not OK
```

Control Flow

The `if` Statement

Avoid the “`if . . . if . . . else`” trap. The code

```
if ( . . . )
   if ( . . . ) . . .;
else . . .;
```

will not do what the indentation level suggests, and it can take hours to find such a bug. Always use an extra pair of `{ . . . }` when dealing with “`if . . . if . . . else`”:

```
if ( . . . )
{
   if ( . . . ) . . .;
} // { . . . } are necessary
else . . .;
```

```
if ( . . . )
{
   if ( . . . ) . . .;
   else . . .;
} // { . . . } not necessary, but they keep you out of trouble
```

The for Statement

Use `for` loops only when a variable runs from somewhere to somewhere with some constant increment/decrement:

```
for (int i = 0; i < a.length; i++)
   System.out.println(a[i]);
```

Or, even better, use the "for each" loop:

```
for (int e : a)
   System.out.println(e);
```

Do not use the `for` loop for weird constructs such as

```
for (a = a / 2; count < ITERATIONS; System.out.println(xnew))
   // Don't
```

Make such a loop into a `while` loop. That way, the sequence of instructions is much clearer.

```
a = a / 2;
while (count < ITERATIONS) // OK
{
   . . .
   System.out.println(xnew);
}
```

Nonlinear Control Flow

Avoid the `switch` statement, because it is easy to fall through accidentally to an unwanted case. Use `if/else` instead.

Avoid the `break` or `continue` statements. Use another `boolean` variable to control the execution flow.

Exceptions

Do not tag a method with an overly general exception specification:

```
Widget readWidget(Reader in) throws Exception // Bad
```

Instead, specifically declare any checked exceptions that your method may throw:

```
Widget readWidget(Reader in)
      throws IOException, MalformedWidgetException // Good
```

Do not "squelch" exceptions:

```
try
{
   double price = in.readDouble();
}
catch (Exception e)
{ } // Bad
```

Beginners often make this mistake “to keep the compiler happy”. If the current method is not appropriate for handling the exception, simply use a `throws` specification and let one of its callers handle it.

Lexical Issues

Naming Conventions

The following rules specify when to use upper- and lowercase letters in identifier names.

- All variable and method names are in lowercase (maybe with an occasional upperCase in the middle); for example, `firstPlayer`.
- All constants are in uppercase (maybe with an occasional UNDER_SCORE); for example, `CLOCK_RADIUS`.
- All class and interface names start with uppercase and are followed by lowercase letters (maybe with an occasional UpperCase letter); for example, `BankTeller`.
- Generic type variables are in uppercase, usually a single letter.

Names must be reasonably long and descriptive. Use `firstPlayer` instead of `fp`. No drppng f vwls. Local variables that are fairly routine can be short (`ch`, `i`) as long as they are really just boring holders for an input character, a loop counter, and so on. Also, do not use `ctr`, `c`, `cntr`, `cnt`, `c2` for variables in your method. Surely these variables all have specific purposes and can be named to remind the reader of them (for example, `current`, `next`, `previous`, `result`, . . .). However, it is customary to use single-letter names, such as `T` or `E` for generic types.

Indentation and White Space

Use tab stops every three columns. That means you will need to change the tab stop setting in your editor!

Use blank lines freely to separate parts of a method that are logically distinct.

Use a blank space around every binary operator:

```
x1 = (-b - Math.sqrt(b * b - 4 * a * c)) / (2 * a);
// Good

x1=(-b-Math.sqrt(b*b-4*a*c))/(2*a);
// Bad
```

Leave a blank space after (and not before) each comma or semicolon. Do not leave a space before or after a parenthesis or bracket in an expression. Leave spaces around the `( . . . )` part of an `if`, `while`, `for`, or `catch` statement.

```
if (x == 0) y = 0;

f(a, b[i]);
```

Every line must fit in 80 columns. If you must break a statement, add an indentation level for the continuation:

```
a[n] = ..................................................
      + .................;
```

Start the indented line with an operator (if possible).

If the condition in an `if` or `while` statement must be broken, be sure to brace the body in, even if it consists of only one statement:

```
if ( .................................................
      && .................
      || .......... )
{
   . . .
}
```

If it weren't for the braces, it would be hard to separate the continuation of the condition visually from the statement to be executed.

Braces

Opening and closing braces must line up, either horizontally or vertically:

```
while (i < n) { System.out.println(a[i]); i++; }

while (i < n)
{
   System.out.println(a[i]);
   i++;
}
```

Some programmers don't line up vertical braces but place the `{` behind the keyword:

```
while (i < n) { // DON'T
   System.out.println(a[i]);
   i++;
}
```

Doing so makes it hard to check that the braces match.

Unstable Layout

Some programmers take great pride in lining up certain columns in their code:

```
firstRecord = other.firstRecord;
lastRecord  = other.lastRecord;
cutoff      = other.cutoff;
```

This is undeniably neat, but the layout is not stable under change. A new variable name that is longer than the preallotted number of columns requires that you move all entries around:

```
firstRecord = other.firstRecord;
lastRecord  = other.lastRecord;
cutoff      = other.cutoff;
marginalFudgeFactor = other.marginalFudgeFactor;
```

This is just the kind of trap that makes you decide to use a short variable name like `mff` instead. Use a simple layout that is easy to maintain as your programs change.

GLOSSARY

Abstract array An ordered sequence of items that can be efficiently accessed at random through an integer index.

Abstract class A class that cannot be instantiated.

Abstract list An ordered sequence of items that can be traversed sequentially and that allows for efficient insertion and removal of elements at any position.

Abstract method A method with a name, parameter types, and return type but without an implementation.

Abstraction The process of finding the essential feature set for a building block of a program such as a class.

Access specifier A reserved word that indicates the accessibility of a feature, such as `private` or `public`.

Accessor method A method that accesses an object but does not change it.

Actual parameter The expression supplied for a formal parameter of a method by the caller.

ADT (Abstract Data Type) A specification of the fundamental operations that characterize a data type, without supplying an implementation.

Aggregation The *has-a* relationship between classes.

Algorithm An unambiguous, executable, and terminating specification of a way to solve a problem.

Anonymous class A class that does not have a name.

Anonymous object An object that is not stored in a named variable.

API (Application Programming Interface) A code library for building programs.

API Documentation Information about each class in the Java library.

Applet A graphical Java program that executes inside a web browser or applet viewer.

Argument An actual parameter in a method call, or one of the values combined by an operator.

Array A collection of values of the same type stored in contiguous memory locations, each of which can be accessed by an integer index.

Array list A Java class that implements a dynamically-growable array of objects.

Assertion A claim that a certain condition holds in a particular program location.

Assignment Placing a new value into a variable.

Association A relationship between classes in which one can navigate from objects of one class to objects of the other class, usually by following object references.

Asymmetric bounds Bounds that include the starting index but not the ending index.

Attribute A named property that an object is responsible for maintaining.

Auto-boxing Automatically converting a primitive type value into a wrapper type object.

Balanced tree A tree in which each subtree has the property that the number of descendants to the left is approximately the same as the number of descendants to the right.

Big-Oh notation The notation $g(n) = O(f(n))$, which denotes that the function g grows at a rate that is bounded by the growth rate of the function f with respect to n. For example, $10n^2 + 100n - 1000 = O(n^2)$.

Binary file A file in which values are stored in their binary representation and cannot be read as text.

Binary operator An operator that takes two arguments, for example + in $x + y$.

Binary search A fast algorithm for finding a value in a sorted array. It narrows the search down to half of the array in every step.

Binary search tree A binary tree in which *each* subtree has the property that all left descendants are smaller than the value stored in the root, and all right descendants are larger.

Binary tree A tree in which each node has at most two child nodes.

Bit Binary digit; the smallest unit of information, having two possible values: `0` and 1. A data element consisting of n bits has 2^n possible values.

Black-box testing Testing a method without knowing its implementation.

Block A group of statements bracketed by `{}`.

Boolean operator See **Logical operator**

Boolean type A type with two possible values: `true` and `false`.

Border layout A layout management scheme in which components are placed into the center or one of the four borders of their container.

Boundary test case A test case involving values that are at the outer boundary of the set of legal values. For example, if a function is expected to work for all nonnegative integers, then `0` is a boundary test case.

Bounds error Trying to access an array element that is outside the legal range.

Breakpoint A point in a program, specified in a debugger, at which the debugger stops executing the program and lets the user inspect the program state.

`break` statement A statement that terminates a loop or `switch` statement.

Bucket In a hash table, a set of values with the same hash code.

Buffer A temporary storage location for holding values that have been produced (for example, characters typed by the user) and are waiting to be consumed (for example, read a line at a time).

Buffered input Input that is gathered in batches, for example, a line at a time.

Bug A programming error.

Byte A number made up of eight bits. Essentially all currently manufactured computers use a byte as the smallest unit of storage in memory.

Bytecode Instructions for the Java virtual machine.

Callback A mechanism for specifying a block of code so it can be executed at a later time.

Call by reference A method call mechanism in which the method receives the memory location of a variable supplied as an actual parameter. Call by reference enables a method to change the contents of the original variable so that the change remains in effect after the method returns.

Call by value A method call mechanism in which the method receives a copy of the contents of a variable supplied as an actual parameter. Java uses only call by value. If a parameter variable's type is a class, its value is an object reference, so the method can alter that object but cannot make the parameter variable refer to a different object.

Call stack The ordered set of all methods that currently have been called but not yet terminated, starting with the current method and ending with `main`.

Case sensitive Distinguishing upper- and lowercase characters.

Cast Explicitly converting a value from one type to a different type. For example, the cast from a floating-point number `x` to an integer is expressed in Java by the cast notation `(int) x`.

`catch` clause A part of a `try` block that is executed when a matching exception is thrown by any statement in the `try` block.

Central processing unit (CPU) The part of a computer that executes the machine instructions.

Character A single letter, digit, or symbol.

Check box A user-interface component that can be used for a binary selection.

Checked exception An exception that the compiler checks. All checked exceptions must be declared or caught.

Class A programmer-defined data type.

Class method See **Static method**

Class path The set of directories and archives that the virtual machine searches for class files.

Client A computer program or system that issues requests to a server and processes the server responses.

Cloning Making a copy of an object so the copy's state can be modified independently of the original object.

Code coverage A measure of the amount of source code that has been executed during testing.

Cohesion A class is cohesive if its features support a single abstraction.

Collaborator A class on which another class depends.

Combo box A user-interface component that combines a text field with a drop-down list of selections.

Command line The line the user types to start a program in DOS or UNIX or a command window in Windows. It consists of the program name followed by any necessary arguments.

Comment An explanation to help the human reader understand a section of a program; ignored by the compiler.

Compiler A program that translates code in a high-level language (such as Java) to machine instructions (such as bytecode for the Java virtual machine).

Compile-time error An error that is detected when a program is compiled.

Component See **User-interface component**

Compound statement A statement such as `if` or `while` that is made up of several parts such as a condition and a body.

Concatenation Placing one string after another to form a new string.

Concrete class A class that can be instantiated.

Console program A Java program that does not have a graphical window. A console program reads input from the keyboard and writes output to the terminal screen.

Constant A value that cannot be changed by a program. In Java, constants are defined with the reserved word `final`.

Construction Setting a newly allocated object to an initial state.

Constructor A method that initializes a newly instantiated object.

Container A user-interface component that can hold other components and present them together to the user. Also, a data structure, such as a list, that can hold a collection of objects and present them individually to a program.

Content pane The part of a Swing frame that holds the user-interface components of the frame.

Coupling The degree to which classes are related to each other by dependency.

CRC card An index card representing a class that lists its responsibilities and collaborating classes.

De Morgan's Law A law about logical operations that describes how to negate expressions formed with *and* and *or* operations.

Debugger A program that lets a user run another program one or a few steps at a time, stop execution, and inspect the variables in order to analyze it for bugs.

Default constructor A constructor that is invoked with no parameters.

Dependency The *uses* relationship between classes, in which one class needs services provided by another class.

Dictionary ordering See **Lexicographic ordering**

Directory A structure on a disk that can hold files or other directories; also called a folder.

Documentation comment A comment in a source file that can be automatically extracted into the program documentation by a program such as `javadoc`.

Dot notation The notation *object*`.`*method*`(`*parameters*`)` or *object*`.`*variable* used to invoke a method or access a variable.

Doubly linked list A linked list in which each link has a reference to both its predecessor and successor links.

Dynamic method lookup Selecting a method to be invoked at run time. In Java, dynamic method lookup considers the class of the implicit parameter object to select the appropriate method.

Editor A program for writing and modifying text files.

Embedded system The processor, software, and supporting circuitry that is included in a device other than a computer.

Encapsulation The hiding of implementation details.

End of file The condition that is true when all characters of a file have been read. Note that there is no special "end of file character". When composing a file on the keyboard, you may need to type a special character to tell the operating system to end the file, but that character is not part of the file.

Enumeration type A type with a finite number of values, each of which has its own symbolic name.

Escape character A character in text that is not taken literally but has a special meaning when combined with the character or characters that follow it. The \ character is an escape character in Java strings.

Event See **User-interface event**

Event class A class that contains information about an event, such as its source.

Event adapter A class that implements an event listener interface by defining all methods to do nothing.

Event handler A method that is executed when an event occurs.

Event listener An object that is notified by an event source when an event occurs.

Event source An object that can notify other classes of events.

Exception A class that signals a condition that prevents the program from continuing normally. When such a condition occurs, an object of the exception class is thrown.

Exception handler A sequence of statements that is given control when an exception of a particular type has been thrown and caught.

Explicit parameter A parameter of a method other than the object on which the method is invoked.

Expression A syntactical construct that is made up of constants, variables, method calls, and operators combining them.

Extension The last part of a file name, which specifies the file type. For example, the extension `.java` denotes a Java file.

Extreme Programming A development methodology that strives for simplicity, by removing formal structure and focusing on best practices.

Fibonacci numbers The sequence of numbers 1, 1, 2, 3, 5, 8, 13, . . ., in which every term is the sum of its two predecessors.

File A sequence of bytes that is stored on disk.

File pointer The position within a random-access file of the next byte to be read or written. It can be moved so as to access any byte in the file.

`finally` clause A part of a `try` block that is executed no matter how the `try` block is exited.

Flag See **Boolean type**

Floating-point number A number that can have a fractional part.

Flow layout A layout management scheme in which components are laid out left to right.

Flushing a stream Sending all characters that are still held in a buffer to its destination.

Folder See **Directory**

Font A set of character shapes in a particular style and size.

Formal parameter A variable in a method definition; it is initialized with an actual parameter value when the method is called.

Frame A window with a border and a title bar.

Garbage collection Automatic reclamation of memory occupied by objects that are no longer referenced.

Generic class A class with one or more type parameters.

Generic method A method with one or more type parameters.

Generic programming Providing program components that can be reused in a wide variety of situations.

`goto` statement A statement that transfers control to some other statement, which is tagged with a label. Java does not have a `goto` statement.

Graphics context A class through which a programmer can cause shapes to appear on a window or off-screen bitmap.

`grep` The "global regular expression print" search program, useful for finding all strings matching a pattern in a set of files.

Grid layout A layout management scheme in which components are placed into a two-dimensional grid.

GUI (Graphical User Interface) A user interface in which the user supplies inputs through graphical components such as buttons, menus, and text fields.

Hash code A value that is computed by a hash function.

Hash collision Two different objects for which a hash function computes identical values.

Hash function A function that computes an integer value from an object in such a way that different objects are likely to yield different values.

Hash table A data structure in which elements are mapped to array positions according to their hash function values.

Hashing Applying a hash function to a set of objects.

Heap A balanced binary tree that is used for implementing sorting algorithms and priority queues.

Heapsort algorithm A sorting algorithm that inserts the values to be sorted into a heap.

HTML (Hypertext Markup Language) The language in which web pages are described.

IDE (Integrated Development Environment) A programming environment that includes an editor, compiler, and debugger.

Immutable class A class without a mutator method.

Implementing an interface Implementing a class that defines all methods specified in the interface.

Implicit parameter The object on which a method is invoked. For example, in the call `x.f(y)`, the object `x` is the implicit parameter of the method `f`.

Importing a class or package Indicating the intention of referring to a class, or all classes in a package, by the simple name rather than the qualified name.

Inheritance The *is-a* relationship between a more general superclass and a more specialized subclass.

Initialization Setting a variable to a well-defined value when it is created.

Inner class A class that is defined inside another class.

Instance method A method with an implicit parameter; that is, a method that is invoked on an instance of a class.

Instance of a class An object whose type is that class.

Instance variable A variable defined in a class for which every object of the class has its own value.

Instantiation of a class Construction of an object of that class.

Integer A number that cannot have a fractional part.

Integer division Taking the quotient of two integers and discarding the remainder. In Java the / symbol denotes integer division if both arguments are integers. For example, `11/4` is `2`, not `2.75`.

Interface A type with no instance variables, only abstract methods and constants.

Internet A worldwide collection of networks, routing equipment, and computers using a common set of protocols that define how participants interact with each other.

Interpreter A program that reads a set of codes and carries out the commands specified by them.

Iterator An object that can inspect all elements in a container such as a linked list.

`javadoc` The documentation generator in the Java SDK. It extracts documentation comments from Java source files and produces a set of linked HTML files.

JDK The Java software development kit that contains the Java compiler and related development tools.

JVM The Java Virtual Machine.

Layout manager A class that arranges user-interface components inside a container.

Lazy evaluation Deferring the computation of a value until it is needed, thereby avoiding the computation if the value is never needed.

Legacy code Software that has existed for a long time and that continues to operate.

Lexicographic ordering Ordering strings in the same order as in a dictionary, by skipping all matching characters and comparing the first non matching characters of both strings. For example, “orbit” comes before “orchid” in lexicographic ordering. Note that in Java, unlike a dictionary, the ordering is case-sensitive: `Z` comes before `a`.

Library A set of precompiled classes that can be included in programs.

Linear search Searching a container (such as an array or list) for an object by inspecting each element in turn.

Linked list A data structure that can hold an arbitrary number of objects, each of which is stored in a link object, which contains a pointer to the next link.

Local variable A variable whose scope is a block.

Logging Sending messages that trace the progress of a program to a file or window.

Logical operator An operator that can be applied to Boolean values. Java has three logical operators: `&&`, `||`, and `!`.

Logic error An error in a syntactically correct program that causes it to act differently from its specification. (A form of run-time error.)

Loop A sequence of instructions that is executed repeatedly.

Loop and a half A loop whose termination decision is neither at the beginning nor at the end.

Loop invariant A statement about the program state that is preserved when the statements in the loop are executed once.

Machine code Instructions that can be executed directly by the CPU.

Magic number A number that appears in a program without explanation.

`main` method The method that is first called when a Java application executes.

Map A data structure that keeps associations between key and value objects.

Markup Information about data that is added as humanly readable instructions. An example is the tagging of HTML documents with elements such as `<h1>` or `<b>`.

Memory location A value that specifies the location of data in computer memory.

Merge sort A sorting algorithm that first sorts two halves of a data structure and then merges the sorted subarrays together.

Meta data Data that describe properties of a data set.

Method A sequence of statements that has a name, may have formal parameters, and may return a value. A method can be invoked any number of times, with different values for its parameters.

Method signature The name of a method and the types of its parameters.

Mock object An object that is used during program testing, replacing another object and providing similar behavior. Usually, the mock object is simpler to implement or provides better support for testing.

Mutator method A method that changes the state of an object.

Mutual recursion Cooperating methods that call each other.

Name clash Accidentally using the same name to denote two program features in a way that cannot be resolved by the compiler.

Negative test case A test case that is expected to fail. For example, when testing a root-finding program, an attempt to compute the square root of –1 is a negative test case.

Nested block A block that is contained inside another block.

Nested loop A loop that is contained in another loop.

`new` operator An operator that allocates new objects.

Newline The `'\n'` character, which indicates the end of a line.

Null reference A reference that does not refer to any object.

Number literal A constant value in a program this is explicitly written as a number, such as –2 or 6.02214115E23.

Object A value of a class type.

Object-oriented design Designing a program by discovering objects, their properties, and their relationships.

Object reference A value that denotes the location of an object in memory. In Java, a variable whose type is a class contains a reference to an object of that class.

Off-by-one error A common programming error in which a value is one larger or smaller than it should be.

Opening a file Preparing a file for reading or writing.

Operating system The software that launches application programs and provides services (such as a file system) for those programs.

Operator A symbol denoting a mathematical or logical operation, such as `+` or `&&`.

Operator associativity The rule that governs in which order operators of the same precedence are executed. For example, in Java the `-` operator is left-associative because `a - b - c` is interpreted as `(a - b) - c`, and `=` is right-associative because `a = b = c` is interpreted as `a = (b = c)`.

Operator precedence The rule that governs which operator is evaluated first. For example, in Java the `&&` operator has a higher precedence than the `||` operator. Hence `a || b && c` is interpreted as `a || (b && c)`. (See Appendix B.)

Oracle A program that predicts how another program should behave.

Overloading Giving more than one meaning to a method name.

Overriding Redefining a method in a subclass.

Package A collection of related classes. The `import` statement is used to access one or more classes in a package.

Package access Accessibility by methods of classes in the same package.

Panel A user-interface component with no visual appearance. It can be used to group other components.

Parallel arrays Arrays of the same length, in which corresponding elements are logically related.

Parameter An item of information that is specified to a method when the method is called. For example, in the call `System.out.println("Hello, World!")`, the parameters are the implicit parameter `System.out` and the explicit parameter `"Hello, World!"`.

Parameter passing Specifying expressions to be actual parameter values for a method when it is called.

Parameter variable A variable of a method that is initialized with a parameter value when the method is called.

Partially filled array An array that is not filled to capacity, together with a companion variable that indicates the number of elements actually stored.

Permutation A rearrangement of a set of values.

Polymorphism Selecting a method among several methods that have the same name on the basis of the actual types of the implicit parameters.

Positive test case A test case that a method is expected to handle correctly.

Postcondition A condition that is true after a method has been called.

Postfix operator A unary operator that is written after its argument.

Precondition A condition that must be true when a method is called if the method is to work correctly.

Predicate method A method that returns a Boolean value.

Prefix operator A unary operator that is written before its argument.

Primitive type In Java, a number type or `boolean`.

Priority queue An abstract data type that enables efficient insertion of elements and efficient removal of the smallest element.

Private feature A feature that is accessible only by methods of the same class or an inner class.

Project A collection of source files and their dependencies.

Prompt A string that tells the user to provide input.

Protected feature A feature that is accessible by a class, its inner classes, its subclasses, and the other classes in the same package.

Pseudocode A high-level description of the actions of a program or algorithm, using a mixture of English and informal programming language syntax.

Pseudorandom number A number that appears to be random but is generated by a mathematical formula.

Public feature A feature that is accessible by all classes.

Public interface The features (methods, variables, and nested types) of a class that are accessible to all clients.

Qualified name A name that is made unambiguous because it starts with the package name.

Queue A collection of items with "first in, first out" retrieval.

Quicksort A generally fast sorting algorithm that picks an element, called the pivot, partitions the sequence into the elements smaller than the pivot and those larger than the pivot, and then recursively sorts the subsequences.

Radio button A user-interface component that can be used for selecting one of several options.

RAM (random-access memory) Electronic circuits in a computer that can store code and data of running programs.

Random access The ability to access any value directly without having to read the values preceding it.

Reader In the Java input/output library, a class from which to read characters.

Recursion A method for computing a result by decomposing the inputs into simpler values and applying the same method to them.

Recursive method A method that can call itself with simpler values. It must handle the simplest values without calling itself.

Redirection Linking the input or output of a program to a file instead of the keyboard or display.

Reference See **Object reference**

Regression testing Keeping old test cases and testing every revision of a program against them.

Regular expression A string that defines a set of matching strings according to their content. Each part of a regular expression can be a specific required character; one of a set of permitted characters such as `[abc]`, which can be a range such as `[a-z]`; any character not in a set of forbidden characters, such as `[^0-9]`; a repetition of one or more matches, such as `[0-9]+`, or zero or more, such as `[ACGT]`; one of a set of alternatives, such as `and|et|und`; or various other possibilities. For example, `"[A-Za-z][0-9]+"` matches `"Cloud9"` or `"007"` but not `"Jack"`.

Relational operator An operator that compares two values, yielding a Boolean result.

Reserved word A word that has a special meaning in a programming language and therefore cannot be used as a name by the programmer.

Return value The value returned by a method through a `return` statement.

Reverse Polish notation A style of writing expressions in which the operators are written following the operands, such as `2 3 4  +` for `2 + 3  4`.

Roundoff error An error introduced by the fact that the computer can store only a finite number of digits of a floating-point number.

Run-time error An error in a syntactically correct program that causes it to act differently from its specification.

Run-time stack The data structure that stores the local variables of all called methods as a program runs.

Scope The part of a program in which a variable is defined.

Scripting language A programming language that favors rapid development over execution speed and code maintainability.

Selection sort A sorting algorithm in which the smallest element is repeatedly found and removed until no elements remain.

Sentinel A value in input that is not to be used as an actual input value but to signal the end of input.

Sequential access Accessing values one after another without skipping over any of them.

Sequential search See **Linear search**

Serialization The process of saving an object, and all the objects that it references, to a stream.

Server A computer program or system that receives requests from a client, obtains or computes the requested information, and sends it to the client.

Set An unordered collection that allows efficient addition, location, and removal of elements.

Shadowing Hiding a variable by defining another one with the same name.

Shallow copy Copying only the reference to an object.

Shell script A file that contains commands for running programs and manipulating files. Typing the name of the shell script file on the command line causes those commands to be executed.

Shell window A window for interacting with an operating system through textual commands.

Short circuit evaluation Evaluating only a part of an expression if the remainder cannot change the result.

Side effect An effect of a method other than returning a value.

Sign bit The bit of a binary number that indicates whether the number is positive or negative.

Signature See **Method signature**

Simple statement A statement consisting of a single expression.

Single-stepping Executing a program in the debugger one statement at a time.

Software life cycle All activities related to the creation and maintenance of the software from initial analysis until obsolescence.

Source code Instructions in a programming language that need to be translated before execution on a computer.

Source file A file containing instructions in a programming language such as Java.

Spiral model An iterative process model of software development in which design and implementation are repeated.

Stack A data structure with "last in, first out" retrieval. Elements can be added and removed only at one position, called the top of the stack.

Stack trace A printout of the call stack, listing all currently pending method calls.

State The current value of an object, which is determined by the cumulative action of all methods that were invoked on it.

State diagram A diagram that depicts state transitions and their causes.

Statement A syntactical unit in a program. In Java a statement is either a simple statement, a compound statement, or a block.

Static method A method with no implicit parameter.

Static variable A variable defined in a class that has only one value for the whole class, which can be accessed and changed by any method of that class.

Stream An abstraction for a sequence of bytes from which data can be read or to which data can be written.

String A sequence of characters.

Stub A method with no or minimal functionality.

Subclass A class that inherits variables and methods from a superclass but adds instance variables, adds methods, or redefines methods.

Superclass A general class from which a more specialized class (a subclass) inherits.

Swing A Java toolkit for implementing graphical user interfaces.

Symmetric bounds Bounds that include the starting index and the ending index.

Syntax Rules that define how to form instructions in a particular programming language.

Syntax diagram A graphical representation of grammar rules.

Syntax error An instruction that does not follow the programming language rules and is rejected by the compiler. (A form of compile-time error.)

Tab character The `'\t'` character, which advances the next character on the line to the next one of a set of fixed positions known as tab stops.

TCP/IP (Transmission Control Protocol/Internet Protocol) The pair of communication protocols that is used to establish reliable transmission of data between two computers on the Internet.

Ternary operator An operator with three arguments. Java has one ternary operator, `a ? b : c`.

Test coverage The instructions of a program that are executed in a set of test cases.

Test harness A program that calls a function that needs to be tested, supplying parameters and analyzing the function's return value.

Test suite A set of test cases for a program.

Text field A user-interface component that allows a user to provide text input.

Text file A file in which values are stored in their text representation.

Throwing an exception Indicating an abnormal condition by terminating the normal control flow of a program and transferring control to a matching `catch` clause.

`throws` specifier Indicates the types of the checked exceptions that a method may throw.

Token A sequence of consecutive characters from an input source that belongs together for the purpose of analyzing the input. For example, a token can be a sequence of characters other than white space.

Total ordering An ordering relationship in which all elements can be compared to each other.

Trace message A message that is printed during a program run for debugging purposes.

Tree A data structure consisting of nodes, each of which has a list of child nodes, and one of which is distinguished as the root node.

`try` block A block of statements that contains exception processing clauses. A `try` block contains at least one `catch` or `finally` clause.

Turing machine A very simple model of computation that is used in theoretical computer science to explore computability of problems.

Two-dimensional array A tabular arrangement of elements in which an element is specified by a row and a column index.

Type A named set of values and the operations that can be carried out with them.

Type parameter A parameter in a generic class or method that can be replaced with an actual type.

Type variable A variable in the declaration of a generic type that can be instantiated with a type.

Unary operator An operator with one argument.

Unchecked exception An exception that the compiler doesn't check.

Unicode A standard code that assigns code values consisting of two bytes to characters used in scripts around the world. Java stores all characters as their Unicode values.

Unified Modeling Language (UML) A notation for specifying, visualizing, constructing, and documenting the artifacts of software systems.

Uninitialized variable A variable that has not been set to a particular value. In Java, using an uninitialized local variable is a syntax error.

Unit test A test of a method by itself, isolated from the remainder of the program.

URL (uniform resource locator) A pointer to an information resource (such as a web page or an image) on the World Wide Web.

User-interface component A building block for a graphical user interface, such as a button or a text field. User-interface components are used to present information to the user and allow the user to enter information to the program.

User-interface event A notification to a program that a user action such as a key press, mouse move, or menu selection has occurred.

Variable A symbol in a program that identifies a storage location that can hold different values.

Virtual machine A program that simulates a CPU that can be implemented efficiently on a variety of actual machines. A given program in Java bytecode can be executed by any Java virtual machine, regardless of which CPU is used to run the virtual machine itself.

Visual programming Programming by arranging graphical elements on a form, setting program behavior by selecting properties for these elements, and writing only a small amount of "glue" code linking them.

void A reserved word indicating no type or an unknown type.

Watch window A window in a debugger that shows the current values of selected variables.

Waterfall model A sequential process model of software development, consisting of analysis, design, implementation, testing, and deployment.

White-box testing Testing methods by taking their implementations into account, in contrast to black-box testing; for example, by selecting boundary test cases and ensuring that all branches of the code are covered by some test case.

White space Any sequence of only space, tab, and newline characters.

Wrapper class A class that contains a primitive type value, such as `Integer`.

Writer In the Java input/output library, a class to which characters are to be sent.

INDEX

Page references followed by *t* indicate material in tables. Java library classes are indexed under `java`, as for example "`java.util.Scanner` class."

\ (backslash)
  escape character, 410
  in file names, 410
+ (plus sign)
  addition operator, 123
  string concatenation, 135
; (semicolon)
  ending method statements, 11
  errors in `for` loops, 207–208
  `if` statement terminator, 156
  omitting, 13
, (comma), in number literals, 33
. (dot), in package names, 314
`{ }` (curly brackets)
  around method statements, 11
  array initialization, 243
  in block statements, 153
  lining up, 154–155
`[ ]` (square brackets, array indexing), 243
`&&` (ampersands), *and* logical operator, 174, 177
`$` (dollar sign), in names, 35
`=` (equal sign), *vs.* equality operator (`==`), 157*t*
`==` (equal signs), equality operator
  comparing objects, 161
  comparing strings, 158
  description, 157*t*
  testing for `null`, 162
  vs. `=` (equal sign), assignment operator, 157*t*
`!` (exclamation point), *not* logical operator, 175
`!=` (exclamation point, equal), not-equal operator, 157*t*, 208
`<` (left angle bracket), less-than operator, 157*t*
`<=` (left angle bracket, equal), less-than-or-equal operator, 157*t*
`%` (percent sign), remainder of division operator, 124
`++` (plus signs), increment operator, 123–124
`>` (right angle bracket), greater-than operator, 157*t*
`>=` (right angle bracket, equal), greater-than-or-equal operator, 157*t*
_ (underscore), in variable identifiers, 35
`||` (vertical bars), *or* logical operator, 175, 177
`-` (minus sign), subtraction operator, 123
`/` (slash), division operator, 123
`--` (minus signs), decrement operator, 123–124
40-hour week, Extreme Programming, 445

A
`abs` method, `java.lang.Math` class, 126*t*, 611
absolute values, 126*t*
abstract arrays, 574
abstract classes, 385
abstract data types, 572–574
abstract lists, 574
abstract methods, 385
abstract windowing toolkit package, 311*t*
access to packages, 314
accessor methods, 46, 294, 396
`AccountTester.java` class, 384
`acos` method, `java.lang.Math` class, 126*t*, 611
`actionPerformed` method, `java.awt.event.ActionListener` interface, 353, 603
actors, 290
`add` method
  `java.awt.Container` class, 601
  `java.math.BigDecimal` class, 616
  `java.math.BigInteger` class, 616
  `java.util.ArrayList` class, 250*t*
  `java.util.ArrayList<E>` class, 617
  `java.util.Collection<E>` interface, 559, 618
  `java.util.ListIterator<E>` interface, 560*t*, 620
  `javax.swing.ButtonGroup` class, 623
  `javax.swing.JMenu` class, 625
  `javax.swing.JMenuBar` class, 625
`addActionListener` method, `javax.swing.AbstractButton` class, 623
`addChangeListener` method, `javax.swing.JSlider` class, 626
`addFirst` method, `java.util.LinkedList<E>` class, 557*t*, 563, 620
adding
  array elements, 259, 264–265
  array list elements, 250, 254–255
  linked list nodes, 556–557, 563, 566–567
  trace messages, 503
`addItem` method, `javax.swing.JComboBox` class, 624
addition (mathematical). *See also* incrementing.
  operator for, 123
  order of operations, 123
  summing array elements, 259–260
addition operator (+), 123
`addLast` method, `java.util.LinkedList<E>` class, 557*t*, 620
`addMouseListener` method, `java.awt.Component` class, 601
`Address.java` class, 462–463
aggregation
  definition, 450
  UML relationship symbol, 451*t*
algorithms
  definition, 21
  describing, 22–23
  developing, 22–23
  executable, 21
  How To example, 22–23
  planning, 19–22
  pseudocode for, 20
  reusing. *See* interface types.
  terminating, 21
  unambiguous, 21
ampersands (`&&`), *and* logical operator, 174, 177

analysis phase, software life cycle, 442
and logical operator (`&&`), 174, 177
anonymous classes, 345
API documentation, 47–49
`append` method, `javax.swing.JTextArea` class, 627
Apple Macintosh, history of computers, 316
applets, graphical applications, 59
applets package, 311*t*
arc cosines, 126*t*
arc sines, 126*t*
arc tangent, 126*t*
arguments, passing to programs, 411
Ariane rocket incident, 434
arithmetic operations. *See also* numbers; static methods.
  `%` (percent sign), remainder of division operator, 124
  `+` (plus sign), addition operator, 123
  `++` (plus signs), increment operator, 123–124
  `-` (minus sign), subtraction operator, 123
  `/` (slash), division operator, 123
  `--` (minus signs), decrement operator, 123–124
  `abs` method, 126*t*
  absolute values, 126*t*
  `acos` method, 126*t*
  addition, 123. *See also* incrementing.
  arc cosines, 126*t*
  arc sines, 126*t*
  arc tangent, 126*t*
  `asin` method, 126*t*
  `atan` method, 126*t*
  `atan2` method, 126*t*
  big numbers, 118
  binary numbers, 118
  casting, 126–128
  `ceil` method, 126*t*
  combining with assignment, 130
  computation overflow, 116
  constants, 118–122
  `cos` method, 126*t*
  cosines, 126*t*
  decrementing, 123–124. *See also* subtraction.
  division, 123, 124–125
  `exp` method, 126*t*
  exponential notation, 33
  exponentiation, 126*t*
  expressions, 33
  `floor` method, 126*t*
  fractional numbers. *See* floating-point numbers.
  How To example, 132–134
  incrementing, 123–124. *See also* addition.
  integer division errors, 128
  largest integer, determining, 126*t*
  `log` method, 126*t*
  `max` method, 126*t*
  methods for. *See* static methods.
  `min` method, 126*t*
  multiplication, 123
  natural logs, 126*t*
  number literals, 33
  `pow` method, 125–126*t*
  powers, 125–126
  primitive types, 116–117*t*
  remainder of division, 124–125
  roots, 125–126
  `round` method, 126*t*
  rounding, 126–128, 126*t*
  rounding errors, 117
  `sin` method, 126*t*
  sine, in radians, 126*t*
  smallest integer, determining, 126*t*
  `sqrt` method, 125–126*t*
  square roots, 126*t*
  subtraction, 123. *See also* decrementing.
  `tan` method, 126*t*
  tangents, 126*t*
  `toDegrees` method, 126*t*
  `toRadians` method, 126*t*
  whole numbers. *See* integers.
  Worked Example: volume and surface of a pyramid, 134
arithmetic operations, conversions. *See also* casting.
  degrees to radians, 126*t*
  `double` to `int`, 126–128
  radians to degrees, 126*t*
  rounding errors, 117
array lists
  auto-boxing, 254–255
  How To example, 269–271
  inserting elements, 250, 254–255
  `java.util.ArrayList` class, 250
  printing, 268
  removing elements, 250
  size, determining, 253
  syntax, 250
  variable-size objects, 248–253
  wrapper classes, 254–255
`arraycopy` method, `java.lang.System` class, 615
`ArrayList` constructor, `java.util.ArrayList<E>` class, 616
`ArrayListTester.java` class, 251
arrays
  bounds errors, 244, 245
  declaring, examples, 244*t*
  definition, 242
  fixed length, 244
  How To example, 269–271
  initialization, 242–243
  iterating through, 255–257
  length, determining, 253
  length of, 242
  matrices, 274–276
  multidimensional, 277
  of objects, 246–247
  parallel, 246–247
  partially filled, 257–258
  printing, 268
  printing element separators, 265–268
  sequences of related values, 246
  specifying elements of, 243
  syntax, 245
  two-dimensional, 274–276
  underestimating data size, 259
  variable row lengths, 277
  Worked Example: world population table, 277
arrays, common algorithms
  animated lessons, 262, 263
  averaging elements, 259–260
  copying arrays, 264–265
  counting matches, 260
  element position, finding, 261
  filling, 259
  growing arrays, 264–265
  inserting elements, 263
  maximum value, finding, 260–261
  minimum value, finding, 260–261
  printing element separators, 265–268
  removing elements, 262
  searching for values, 261
  summing elements, 259–260
`ArrayUtil.java` class, 529
artificial intelligence, 178

asin method, java.lang.Math class, 126*t*, 611
assignment, combining with arithmetic operations, 130
assignment operator (=), *vs.* equality operator (==), 157*t*
assignment statements *vs.* variable declarations, 38–39
association relationships, UML, 452
asymmetric bounds, 208
atan method, java.lang.Math class, 126*t*, 611
atan2 method, java.lang.Math class, 126*t*, 611
ATM (Automatic Teller Machine). *See* case study, ATM.
ATMFrame.java class, 478–480
ATM.java class, 471–473
ATMSimulator.java class, 475–477
ATMViewer.java class, 477
attributes, in UML, 452
Augusta, Ada, 540
auto-boxing, 254–255
autoindent feature, 156
Automatic Teller Machine (ATM). *See* case study, ATM.
averaging array elements, 259–260

B

Babbage, Charles, 540
backslash (\)
  escape character, 410
  in file names, 410
backup strategies, 17
BadDataException.java class, 433
BankAccount.java class, 86–87, 251–252
BankAccountTester.java class, 91–92
Bank.java class, 266–267, 473–474
BankTester.java class, 267–268, 272
base directory, packages, 313
batch files, 273–274
Beck, Kent, 444
big numbers, 118
big-Oh notation, 533, 534
big-Omega notation, 534
big-Theta notation, 534
binary numbers
  binary/decimal conversions, 117
  encoding, 118
  overview, 118
binary searches, 542–544
binarySearch method
  java.util.Arrays class, 544, 617
  java.util.Collections class, 618
BinarySearcher.java class, 543
black box, 76
black-box testing, 178–179
block statements, 153
Boehm, Barry, 444
boolean data type, 117*t*, 173, 254*t*
Boolean expressions. *See also* comparing values.
  && (ampersands), *and* logical operator, 174, 177
  ! (exclamation point), *not logical* operator, 175
  || (vertical bars), *or* logical operator, 175, 177
  De Morgan's Law, 177
  flowchart of, 174
  lazy evaluation, 177
  multiple relational, 176–177
  negating && and || operators. *See* De Morgan's Law.
  predicate methods, 173–174
  short circuit evaluation. *See* lazy Boolean evaluation.
Boolean constructor, java.lang.Boolean class, 609
Boolean variables, 176
booleanValue method, java.lang.Boolean class, 609
BorderLayout constructor, java.awt.BorderLayout class, 600
boundary test cases, 179–180
bounds errors, arrays, 244, 245
break statements, 218
breakpoints, 224, 496
Buffon needle experiment, 221–223
bugs
  definition, 18
  first recorded, 228
bus (computer), 5
buttons
  javax.swing.JButton class, 352–355
  javax.swing.JLabel class, 352–355
  labels, 352–355
  overview, 352–355
  panels, 353
ButtonViewer.java class, 349
byte data type, 117*t*, 254*t*

C

calendar, Worked Example, 51
call by reference, 299
call by value, 299
call stack, recursion, 496
callbacks, 339–343
camel-case method names, 35
candidate classes, listing, 446
car shape, drawing, 96–100
CarComponent.java class, 98–99. *See also* drawing, shapes.
CarViewer.java class, 100
case, converting to upper case, 40
case sensitivity, Java programs, 14
case study, ATM
  ATMFrame.java class, 478–480
  ATM.java class, 471–473
  ATMSimulator.java class, 475–477
  ATMViewer.java class, 477
  Bank.java class, 473–474
  CRC cards, 465–468
  Customer.java class, 474–475
  implementation, 470–482
  KeyPad.java class, 480–482
  machine state, 466–467
  method documentation, 469–470
  requirements, 463–465
  state diagrams, 467–468
  UML diagrams, 468–469
case study, exception handling, 429–433
case study, printing invoices
  Address.java class, 462–463
  CRC cards, 453–455
  implementation, 458–463
  Invoice.java class, 460–461
  InvoicePrinter.java class, 459
  LineItem.java class, 461
  method documentation, 456–458
  overview, 452
  Product.java class, 462
  requirements, 453
  UML diagrams, 455–456
CashRegister.java class, 120–121
CashRegisterSimulator.java class, 139–140
CashRegisterTester.java class, 121–122
casting, 126–128, 337. *See also* arithmetic operations, conversions.
catch clauses, 423–425, 427
catching exceptions, 423–425
ceil method, java.lang.Math class, 126*t*, 612
central processing unit (CPU), 3–4
char data type, 117*t*, 138, 254*t*. *See also* strings.

character data. *See* strings.
characters, reading, 415
checked exceptions, 421–423
`CheckingAccount.java` class, 380
chips (computer), 3–4
circles, drawing, 59–60
class diagrams, UML, 450–452
`.class` file extension, 15
class files, Java programs, 15
class invariants, 302
class methods. *See* static methods.
classes. *See also* methods; objects; *specific classes*.
  abstract, 385
  actors, 290
  anonymous, 345
  collections of. *See* libraries; packages.
  converting to/from interface types, 336–337
  documentation. *See* API documentation.
  final, 385
  generic, 248
  immutable, 294
  importing from packages, 49, 311–312
  inner, 343–345, 350–352
  instances, 75
  interdependencies. *See* coupling.
  naming conventions, 35
  overview, 290–291
  private, 40
  public. *See* public interfaces.
  testing, interactively, 51
  utility, 291
  vs. interface types, 332
classes, implementing
  constructors, implementing, 89–90
  How To example, 88–90
  instance variables, specifying, 89
  method declaration, syntax, 86
  methods, implementing, 89–90
  overview, 84–86
  testing the class, 90–92
  Worked Example: menus, 90
classes, object-oriented design
  aggregation, 450
  candidates, listing, 446
  collaborators, 448
  CRC (classes, responsibilities, collaborators) card method, 448–449, 451–452
  dependency relationship, 450
  discovering, 446–449
  has-a relationship, 449–450
  is-a relationship, 449–450
  nouns in the task description, 446
  relationships, documenting, 449–451
  responsibilities, 448
  verbs in the task description, 448
classes, responsibilities, collaborators (CRC) card method, 448–449, 451–452
`ClickListener.java` class, 348
`clone` method
  description, 394, 613
  `java.lang.Cloneable` interface, 396
  `java.lang.Object` class, 613
cloning
  mutable instance variables, 396
  objects, 394
`close` method
  `java.io.InputStream` class, 606
  `java.io.OutputStream` class, 607
  `java.io.PrintStream` class, 607
  `java.io.PrintWriter` class, 409, 428, 607
  `java.util.Scanner` class, 428, 621–622
closing objects. *See* `close` method.
code, Java programs, 14
code coverage, 178–179
coding standards, Extreme Programming, 445
cohesiveness, public interfaces, 291–293
collaborator classes, 448
collective ownership, Extreme Programming, 445
`Color` method, `java.awt.Color` class, 600
colors
  fills, 61
  overview, 61–63
  pen, changing, 61
  predefined, 61*t*
comma (,), in number literals, 33
command line arguments, 411
comments. *See also* documentation.
  `//` (slashes), comment delimiter, 11
  methods, 81–83
  public interfaces, 81–84
`compare` method, `java.util.Comparator<T>` interface, 547, 619
`compareTo` method
  `java.lang.Comparable<T>` interface, 545–546, 609
  `java.lang.String` class, 159, 614
comparing values. *See also* Boolean expressions; decisions; `if` statements.
  adjacent, 211–212
  `compareTo` method, 159
  `else` statements, dangling, 170
  enumeration types, 172, 396
  `equals` method, 158–161
  floating-point numbers, 157–158
  multiple alternatives, 165–167
  nested branches, 167–169
  objects, 161
  relational operators, 156–157
  roundoff errors, 157–158
  side effects, 162–163
  strings, 158–160
  `switch` statements, 167
  syntax, 158
  testing for `null`, 162
compile-time errors, definition, 17
compilers, definition, 7
compiling, Java programs, 14–16
component objects, constructing and drawing on, 56–59
component size, default, 356
compound statements, 153
computation overflow, 116
computers, anatomy of
  bus, 5
  chips, 3–4
  CPU (central processing unit), 3–4
  directories, 17. *See also* files.
  file system, 16–17. *See also* files.
  folders. *See* directories.
  hard disks, 4, 5
  memory chips (illustration), 4
  memory module (illustration), 4
  motherboard, 5
  networks, 4
  peripheral devices, 4
  RAM (random access memory), 4
  removable storage, 4
  schematic diagram, 6
  storage (primary), 4. *See also* RAM (random access memory).

storage (secondary), 4. *See also* hard disks; removable storage.
transistors, 4
computers, history of
Apple Macintosh, 316
ENIAC, 6
first usable electronic computer, 6
the Internet, 63
Macintosh, 316
mainframes, 54
vacuum tubes, 6
computing, limitations of, 510
computing totals, 210
concatenating strings, 135
consistency, public interfaces, 293–294
console window, reading input from, 138–140
constants
declaration syntax, 119
definition, 118
distinguishing from variables, 119
`final` keyword, 119
identifying, 119
interface types, 335–336
magic numbers, 122–123
naming conventions, 119
using, 119–122
constructing
component objects, 56–59
objects, 44–45
rectangles, 44–45
constructors
calling other constructors, 96
constructing objects, 44–45
declaring as `void`, 81
definition, 79
duplicate names, 79
implementing, 89–90
reinitializing existing objects, 45
subclasses, 378–380
superclass, calling, 379
uninitialized object references, 93–94
vs. methods, 45, 79
containers, as event listeners, 355–356
`contains` method, `java.util.Collection<E>` interface, 618
`continue` statements, 218
continuous integration, Extreme Programming, 445
conversions. *See also* casting.
binary/decimal, 117
degrees to radians, 126*t*
`double` to `int`, 126–128
radians to degrees, 126*t*
rounding errors, 117
strings to numbers, 135
converting strings to numbers, 135
copying
arrays, 264–265
objects. *See* `clone` method; cloning.
`copyOf` method, `java.util.Arrays` class, 264, 617
`cos` method, `java.lang.Math` class, 126*t*, 612
cosines, 126*t*
counters, 210
counting matches
in arrays, 260
keeping a counter, 210
`CountryValue.java` class, 417–418
coupling, public interfaces, 291–293
CPU (central processing unit), 3–4
CRC (classes, responsibilities, collaborators) card method, 448–449, 451–452
CRC cards, case studies
ATM, 465–468
printing an invoice, 453–455
creating. *See* implementing.
credit card processing, 218
curly brackets (`{ }`)
around method statements, 11
array initialization, 243
in block statements, 153
lining up, 154–155
`currentTimeMillis` method, `java.lang.System` class, 529, 615
`Customer.java` class, 474–475
customizing, frames, 397–398

D

data structures. *See also* linked lists.
abstract arrays, 574
abstract data types, 572–574
abstract lists, 574
FIFO (first in, first out), 575–577
LIFO (last in, first out), 575–577
queues, 575–577
random access, 557, 572
run-time stacks, 576
sequential access, 557, 572
stacks, 575–577
Worked Example: reverse Polish notation, 577
data types. *See also* arithmetic operations.
`boolean`, 117*t*
`byte`, 117*t*
`char`, 117*t*, 138. *See also* strings.
character data. *See* strings.
combining. *See* expressions.
definition, 32
`double`, 32, 117*t*
exponential notation, 33
expressions, 33
`float`, 117*t*
floating-point numbers. *See* floating-point numbers.
fractional numbers. *See* `double` data type; floating-point numbers.
`int`, 117*t*
integers. *See* integers.
`long`, 117*t*
number literals, 33
parameters, specifying, 43
primitive types, 116–117*t*
`short`, 117*t*
testing for, 382
variable, specifying, 34–36
whole numbers. *See* integers.
`DataAnalyzer.java` class, 213, 430–431
database access package, 311*t*
`DataSet.java` class, 214, 342
`DataSetReader.java` class, 432–433
`DataSetTester2.java` class, 342–343
`DataSetTester3.java` class, 344–345
`DataSetTester.java` class, 334–335
de Buffon, Georges-Louis Leclerc, 221
De Morgan's Law, 177
debuggers. *See also* testing programs.
breakpoints, 224
definition, 18, 223
description, 223–226
inspect-variable command, 224
set breakpoint command, 224
single-step command, 224
step-into command, 224
step-over command, 224
debugging. *See also* testing programs.
How To example, 226–227
recursion, 496
Worked Example: sample session, 227

decisions. *See also* comparing values.
  conditional operators, 156
  if statements, 152–156
declaring. *See also* implementing.
  interface types, 331–332
  variables, 35
decrement operator (--), 123–124
decrementing, 123–124. *See also* subtraction.
default package, 311
defensive programming, 18
degrees, converting to radians, 126*t*
deleting. *See* removing.
dependency relationship symbol, UML, 451*t*
dependency relationships, 450
deployment phase, software life cycle, 443
design phase, software life cycle, 442
destroy method, java.applet.Applet class, 600
dialog boxes
  choosing files from, 411
  reading input from, 140
  showInputDialog method, javax.swing.JOptionPane class, 626
  showMessageDialog method, javax.swing.JOptionPane class, 626
  showOpenDialog method, javax.swing.JFileChooser class, 624
  showSaveDialog method, javax.swing.JFileChooser class, 624
dice casting, analyzing, 271
Dijkstra, Edsger, 178
Dimension constructor, java.awt.Dimension class, 601
directories, 17. *See also* files.
discovering classes, 446–449
divide method, java.math.BigInteger class, 616
division
  integers, 124–125, 128
  operator for (/), 123
do loops, 201
Document Object Model package, 311*t*
documentation. *See also* comments.
  HTML-based, 84
  hyperlinks, 84
  javadoc utility, 84
  public interface, 81–84, 88–89
dollar sign ($), in names, 35
dot (.), in package names, 314
double data type
  converting to int, 126–128
  description, 117*t*
  fractional numbers, 32
  wrapper class, 254*t*
Double constructor, java.lang.Double class, 610
doubleValue method, java.lang.Double class, 255, 610
doubly linked lists, 559
draw method, java.awt.Graphics2D class, 602
drawing, computer graphics, 104
drawing, shapes. *See also* graphical applications.
  on components, 56–59
  How To example, 100–103
  shape classes, 96–100
  a simple car, 96–100
drawString method, java.awt.Graphics2D class, 602
duplicate names. *See also* overloading.
  constructors, 79
  methods, 41
  name clashes, packages, 312
dynamic method lookup, 338

E

Earthquake.java class, 165
EarthquakeRunner.java class, 166
editors, Java programs, 14
efficiency, recursion, 502–507
electronic voting machines, 96
Ellipse2D.Double constructor, java.awt.geom.Ellipse2D.Double class, 604
ellipses, drawing, 59–60
else statements, dangling, 170
empty strings, 135
EmptyFrameViewer.java class, 55
encapsulation, 76–77, 372
ENIAC computer, 6
enumeration types, 172, 396
EOFException method, java.io.EOFException class, 606
equal sign (=), *vs.* equality operator (==), 157*t*
equal signs (==), equality operator
  comparing objects, 161
  comparing strings, 158
  description, 157*t*
  testing for null, 162
  vs. assignment operator (=), 157*t*
equals method
  declaring with wrong parameter type, 395
  inheritance, 396
  java.lang.Object class, 158–161, 613
  java.lang.String class, 614
  overriding, 393–394
equalsIgnoreCase method, java.lang.String class, 614
error handling
  . (dot), in package names, 314
  array bounds errors, 245
  array length, determining, 253
  array list size, determining, 253
  arrays, underestimating data size, 259
  bugs, 18
  calling undeclared methods, 40
  comparing strings with == (equality operator), 160
  compile-time errors, 17–18
  confusing && and || operators, 177
  dangling else statements, 170
  debuggers, 18
  declaring constructors as void, 81
  declaring implementing methods as public, 335
  defensive programming, 18
  exception reports, 137
  extracting substrings, 136–137
  forgetting event listeners, 355
  infinite loops, 200
  integer division, 128
  invoking constructors like methods, 45
  logic errors. *See* run-time errors.
  misspelled words, 19
  modifying primitive type parameters, 296–298
  off-by-one errors, 200–201
  overlapping scope, 308–309
  parameter types, modifying, 349–350
  repainting graphic components, 356
  run-time errors, 18
  semicolon errors, for loops, 207–208
  semicolons in if statements, 156

shadowing, 309
string length, determining, 253
string-to-number conversions, 135
syntax errors. *See* compile-time errors.
unbalanced parentheses, 128–129
unfilled arrays, 246
uninitialized arrays, 246
uninitialized object references in constructors, 93–94
variable declarations *vs.* assignment statements, 38–39
error handling, rounding errors
binary/decimal conversions, 117
floating-point numbers, 130
error messages, retrieving, 429
escape character (\), 410
escape sequences, 137
`EtchedBorder` constructor, `javax.swing.border.EtchedBorder` class, 627
`Evaluator.java` class, 514–515
event adapters, 356
event listeners
containers as, 355–356
inner classes as, 350–352
overview, 347–350
event sources, 347–350
events, 347–350
exception classes
constructors for, 429
hierarchy of, 420
exception handlers, 421
exception handling
animated lesson, 432
Ariane rocket incident, 434
case study, 429–433
`catch` clauses, 423–425, 427
catching exceptions, 423–425
checked exceptions, 421–423
closing objects automatically, 428
`finally` clause, 426–428
recovery, 419
reporting, 419
squelching exceptions, 425–426
throw early, catch late, 425
`throw` statement, syntax, 419
throwing exceptions, 419–421, 429
`throws` clause, 422–423
`try` blocks, 423–425, 428
`try/catch` statements, 423–425, 427
unchecked exceptions, 421–423
exception reports, 137
exception types, designing your own, 428–429
exclamation point, equal (`!=`), not-equal operator, 157*t*, 208
exclamation point (`!`), *not* logical operator, 175
executable algorithms, 21
executing programs. *See* starting programs.
`exit` method, `java.lang.System` class, 615
`exp` method, `java.lang.Math` class, 126*t*, 611
explicit parameters, definition, 41
exponential notation, 33
exponentiation, 126*t*
`ExpressionCalculator.java` class, 516–517
expressions, 33
`ExpressionTokenizer.java` class, 515–516
Extreme Programming, 444–446

F
`FaceComponent.java`, 62
`FaceViewer.java`, 63
factoring out common code, 129–130
FIFO (first in, first out), 575–577
`File` constructor, `java.io.File` class, 606
file names, backslash in, 410
file system, 17
`FileInputStream` constructor, `java.io.FileInputStream` class, 606
`FileOutputStream` constructor, `java.io.FileOutputStream` class, 606
files
organizing. *See* directories.
reading text from. *See* reading input, from text files.
selecting from a dialog box, 411
storing. *See* directories.
`fill` method, `java.awt.Graphics2D` class, 602
filling arrays, 259
fills, colors, 61
`final` reserved word, 119
`finally` clause, 426–428
finding first match, 210–211
flags, Boolean, 176. *See also* Boolean variables.
`float` data type, 117*t*, 254*t*
floating-point numbers. *See also* arithmetic operations.
comparing, 157–158
definition, 32
Pentium bug, 118
vs. integers, 32
`floor` method, `java.lang.Math` class, 126*t*, 612
`FlowLayout` constructor, `java.awt.FlowLayout` class, 601
folders. *See* directories.
`Font` constructor, `java.awt.Font` class, 602
"for each" loops, 256–257, 561
`for` loops. *See also* loops.
`!=` (not equal), testing end of range, 208
animated lesson, 203
asymmetric bounds, 208–209
code sample, 205–206
counting iterations, 209
description, 202–205
enhanced, 255–257
examples, 204
flowchart, 202
iterating through arrays, 256–257
semicolon errors, 207–208
symmetric bounds, 208–209
syntax, 204
uses for, 206–207
variables, declaring, 208
`format` method, `java.lang.String` class, 614
format specifiers, numbers, 140
formatting, numbers, 140
40-hour week, Extreme Programming, 445
fractional numbers. *See* `double` data type; floating-point numbers.
`Frame` class, `main` method, 397–398
frame windows
creating, 54–56
customizing, 397–398
displaying, 58
frameworks, unit testing, 316–317
functions, describing growth behavior, 533, 534

G
garbage collector, 93
generic classes, 248

get method
java.util.ArrayList<E> class, 617
java.util.Calendar class, 618
java.util.Map<K, V> interface, 626
getCenterX method, java.awt.geom.RectangularShape class, 605
getCenterY method, java.awt.geom.RectangularShape class, 605
getFilePointer method, java.io.RandomAccessFile class, 608
getFirst method, java.util.LinkedList<E> class, 557*t*, 620
getGlobal method, java.util.logging.Logger class, 180, 622
getHeight method
java.awt.Component class, 601
java.awt.geom.RectangularShape class, 605
java.awt.Rectangle class, 46, 603
getLast method, java.util.LinkedList<E> class, 557*t*
getMaxX method, java.awt.geom.RectangularShape class, 605
getMaxY method, java.awt.geom.RectangularShape class, 605
getMessage method, java.lang.Throwable class, 429, 615
getMinX method, java.awt.geom.RectangularShape class, 605
getMinY method, java.awt.geom.RectangularShape class, 605
getSelectedFile method, javax.swing.JFileChooser class, 624
getSelectedItem method, javax.swing.JComboBox class, 624
getSource method, java.util.EventObject class, 619
getText method, javax.swing.text.JText-Component class, 628
getValue method, javax.swing.JSlider class, 626
getWidth method
java.awt.Component class, 601
java.awt.geom.RectangularShape class, 605
java.awt.Rectangle class, 46, 603
getX method
java.awt.event.MouseEvent class, 604
java.awt.geom.Point2D class, 605
java.awt.Rectangle class, 46, 603
getX1 method, java.awt.geom.Line2D class, 604
getX2 method, java.awt.geom.Line2D class, 604
getY method
java.awt.event.MouseEvent class, 604
java.awt.geom.Point2D class, 605
java.awt.Rectangle class, 46, 603
getY1 method, java.awt.geom.Line2D class, 604
getY2 method, java.awt.geom.Line2D class, 604
Gosling, James, 8
graphical applications. *See also* drawing; *specific components*; *specific shapes*.
applets, 59
colors, 61–63
component objects, 56–59
component size, default, 356
drawing on components, 56–59
frame windows, 54–56, 58
manipulating image pixels, 220
repainting, 356
shape classes, 96–100
Worked Example: editing photos, 51
greater-than operator (>), 157*t*
greater-than-or-equal operator (>=), 157*t*
"Green," Java code name, 8
GregorianCalendar constructor, java.util.GregorianCalendar class, 619
grep command, 415
GridLayout constructor, java.awt.GridLayout class, 602
grow method, java.awt.Rectangle class, 603
growing arrays, 264–265

H
Hamblin, Charles, 578
hand-tracing
loops, 198–199
programs, 171
hard disks, 4, 5
has-a relationship, 449–450
hash codes, 392
HashMap constructor, java.util.HashMap<K, V> class, 619
HashSet constructor, java.util.HashSet<E> class, 619
hasNext method
java.util.Iterator<E> interface, 558, 619
java.util.ListIterator<E> interface, 560*t*, 564–565
java.util.Scanner class, 622
hasNextDouble method, java.util.Scanner class
method summary, 622
reading text numbers, 414
testing calls to nextDouble, 174
hasNextInt method, java.util.Scanner class, 174, 622
hasNextLine method, java.util.Scanner class, 622
hasPrevious method, java.util.ListIterator<E> interface, 559, 560*t*, 620
"Hello World" example, Java programs, 10–13
HelloPrinter.java class, 10
hiding information, encapsulation, 76–77
hierarchies, 368. *See also* inheritance hierarchies.
high-level languages, definition, 7
HP 35 calculator, 578
HTML-based documentation, 84
hyperlinks, in documentation, 84

I
I/O. *See* reading; writing.
if statements
; (semicolon), statement terminator, 156
{ } (curly brackets), in block statements, 153
{ } (curly brackets), lining up, 154–155
autoindent, 156
block statements, 153

compound statements, 153
description, 152–153
flowchart of, 153
How To example, 163–164
indentation, 155–156
nesting levels, 155–156
simple statements, 153
syntax, 154
tab characters, 156
Tab key, 155
tabs, 155–156
IllegalArgumentException constructor, java.lang.IllegalArgumentException class, 610
image pixels, manipulating, 220
ImageIcon constructor, javax.swing.ImageIcon class, 623
images, drawing. *See* drawing; graphical applications.
immutable classes, 294
implementation phase, software life cycle
case study, ATM, 470–482
case study, printing an invoice, 458–463
definition, 442
implementing. *See also* declaring.
classes. *See* classes, implementing.
constructors, 89–90
interface types, 332–334, 335
methods, 89–90
implements reserved word, 332
implicit parameters, definition, 41
import directive, 312
importing, classes from packages, 49, 311–312
increment operator (++), 123–124
incrementing, 123–124. *See also* addition.
indentation of code, 155–156
infinite loops, 200
infinite recursion, 495
info method, java.util.logging.Logger class, 181, 623
inheritance. *See also* polymorphism.
clone method, overriding, 394
customizing frames, 397–398
encapsulation, 372
equals method, 396
syntax, 372
vs. creating an interface, 373
inheritance, equals method
declaring with wrong parameter type, 395
overriding, 393–394
inheritance, toString method
for all classes, 395
description, 395
overriding, 391–392
inheritance hierarchies. *See also* subclasses; superclasses.
definition, 368
description, 368–370
How To example, 386–390
Worked Example: employee hierarchy, 390
inheritance relationship symbol, UML, 451*t*
init method, java.applet.Applet class, 600
initialization
arrays, 242–243
instance variables, 93
variables, 37–38, 93
initialization blocks, 307
inner classes
as event listeners, 350–352
as listeners, 350–352
overview, 343–345
input, reading. *See* reading input.
input/output package, 311*t*
InputStreamReader constructor, java.io.InputStreamReader class, 607
inserting. *See* adding.
insertion sorts, 534
inspect-variable command, 224
instance variables. *See also* variables.
access specifiers, 75
definition, 75
initialization, 93
initialization blocks, 308–309
interface types, 335
mutable, cloning, 396
name, 75
parts of, 75
protecting, 386
shadowing, 374
specifying, 74–76, 89
subclasses, 371–372
syntax, 75
type, 75
vs. local, 93
instanceof operator, 382
instances, of classes, 75
instantiating, interface types, 337
int data type, 117*t*, 254*t*
Integer constructor, java.lang.Integer class, 610
integers. *See also* arithmetic operations.
computation overflow, 116
converting from strings. *See* parseInt method.
definition, 32
vs. floating-point numbers, 33
integrated circuits. *See* chips.
Intel Corporation, Pentium floating-point bug, 118
interdependencies, classes. *See* coupling.
interface implementation relationship symbol, UML, 451*t*
interface types. *See also specific interfaces.*
callbacks, 339–343
constants, 335–336
converting to/from classes, 336–337
declaring, 331–332
implemented by multiple classes. *See* polymorphism.
implementing, 332–334, 335
implements reserved word, 332
instance variables, 332
instantiating, 337
overview, 330–331
UML diagram, 334
vs. classes, 332
Worked Example: number sequences, 339
interfaces, *vs.* inheritance, 373
international characters, 138
the Internet, history of computers, 63
Internet worm, 248
intersection method, java.awt.Rectangle class, 603
intValue method, java.lang.Integer class, 610
InvestmentViewer1.java class, 351–352
InvestmentViewer2.java class, 354–355
Invoice.java class, 460–461
InvoicePrinter.java class, 459
invoices, printing. *See* case study, printing invoices.

invoking programs. *See* starting programs.
is-a relationships, 334, 449–450
isDigit method, java.lang.Character class
  method summary, 609
  reading text, line by line, 412–413
  testing characters, 173
isEditable method
  javax.swing.JComboBox class, 624
  javax.swing.text.JTextComponent class, 628
isLetter method, java.lang.Character class, 173, 609
isLowerCase method, java.lang.Character class, 173, 609
isSelected method, javax.swing.AbstractButton class, 623
isUpperCase method, java.lang.Character class, 173, 609
isWhiteSpace method, detecting whitespace, 413
iteration. *See* enumeration types; for loops; loops; while loops.
iterator method, java.util.Collection<E> interface, 618
iterators, linked lists, 557–559

J

Java language. *See also* Java programs.
  code name "Green," 8
  collections of code. *See* libraries.
  portability, 8
  safety, 8
  security, 8
  versions, summary of, 10*t*
Java operators, summary of, 593*t*–594*t*. *See also specific operators.*
Java programs. *See also* Java language; programs; *specific elements.*
  basic structure, 10–13
  case sensitivity, 14
  class files, 15
  collections of code. *See* libraries.
  compiling, 14–16
  creating and modifying code, 14
  free-form layout, 14
  "Hello World" example, 10–13
  JVM (Java Virtual Machine), 7–8
  running, 14–16
  source code, 15
Java Virtual Machine (JVM), 7–8
java.applet package, 311*t*, 600
java.applet.Applet class, method summary, 600. *See also specific methods.*
java.awt package, 311*t*, 600–603
java.awt.BorderLayout class, method summary, 600. *See also specific methods.*
java.awt.Color class
  drawing in color, 61–63
  method summary, 600. *See also specific methods.*
java.awt.Component class
  frame title bar, visibility, 55
  method summary, 601. *See also specific methods.*
  preferred size, setting, 356
  repainting graphic components, 356
java.awt.Container class, method summary, 601. *See also specific methods.*
java.awt.Dimension class, method summary, 601. *See also specific methods.*
java.awt.event package, 603–604
java.awt.event.ActionListener interface
  application buttons, 353
  method summary, 603. *See also specific methods.*
java.awt.event.MouseEvent class, method summary, 604. *See also specific methods.*
java.awt.event.MouseListener interface, method summary, 604. *See also specific methods.*
java.awt.FlowLayout class, method summary, 601. *See also specific methods.*
java.awt.Font class, method summary, 602. *See also specific methods.*
java.awt.Frame class
  frame size, setting, 55
  method summary, 602. *See also specific methods.*
java.awt.geom package, 604–605
java.awt.geom.Ellipse2D.Double class
  drawing ellipses and circles, 59–60
  method summary, 604. *See also specific methods.*
java.awt.geom.Line2D class, method summary, 604. *See also specific methods.*
java.awt.geom.Line2D.Double class
  drawing lines, 60
  method summary, 605. *See also specific methods.*
java.awt.geom.Point2D class, method summary, 605. *See also specific methods.*
java.awt.geom.Point2D.Double class
  drawing lines, 60
  method summary, 605. *See also specific methods.*
java.awt.geom.RectangularShape class, method summary, 605. *See also specific methods.*
java.awt.Graphics class
  colored drawings, 61–63
  description, 57
  examples, 57–59
  method summary, 602. *See also specific methods.*
java.awt.Graphics2D class
  casting, 57
  colored fills, 61
  description, 57
  drawing an ellipse, 60
  drawing strings, 60
  examples, 57–59
  method summary, 602. *See also specific methods.*
java.awt.GridLayout class, method summary, 602. *See also specific methods.*
java.awt.Rectangle class, method summary, 602–603. *See also specific methods.*
java.awt.Shape interface, 603
javadoc utility, 84
java.io package, 311*t*, 606–608
java.io.EOFException class, method summary, 606. *See also specific methods.*
java.io.File class. *See also* java.util.Scanner class.
  method summary, 606. *See also specific methods.*
  reading text files, 408–410

java.io.FileInputStream class, method summary, 606. *See also specific methods.*
java.io.FileNotFoundException class
  description, 409
  input/output files missing, 409
  summary, 606
java.io.FileOutputStream class, method summary, 606. *See also specific methods.*
java.io.InputStream class, method summary, 606–607. *See also specific methods.*
java.io.InputStreamReader class, method summary, 607. *See also specific methods.*
java.io.IOException class
  checked exceptions, 421–423
  reading Web pages, 411
  summary, 607
java.io.ObjectInputStream class, method summary, 607. *See also specific methods.*
java.io.ObjectOutputStream class, method summary, 607. *See also specific methods.*
java.io.OutputStream class, method summary, 607. *See also specific methods.*
java.io.PrintStream class
  libraries, 16
  method summary, 607–608. *See also specific methods.*
java.io.PrintWriter class
  automatic object closing, 428
  closing output files, 409
  method summary, 607–608. *See also specific methods.*
  writing text files, 408–410
java.io.RandomAccessFile class, method summary, 608. *See also specific methods.*
java.lang package, 311*t*, 609–615
java.lang.Boolean class, method summary, 609. *See also specific methods.*
java.lang.Character class
  method summary, 609. *See also specific methods.*
  reading text, line by line, 412–413
  testing characters, 173
java.lang.Cloneable interface
  implementing the clone method, 396
  summary, 609
java.lang.CloneNotSupportedException class, 609
java.lang.Comparable<T> interface
  implementing, 545–546
  method summary, 609. *See also specific methods.*
  parameterized type, 547
  sorting real data, 545–546
java.lang.Double class, method summary, 610. *See also specific methods.*
java.lang.Error class, summary, 610
java.lang.IllegalArgumentException class
  method summary, 610. *See also specific methods.*
  throwing exceptions, 419
  unchecked exceptions, 421–423
java.lang.IllegalStateException class
  summary, 610
  throwing an exception, 419–421
java.lang.Integer class
  converting strings to integers, 135
  maximum values, finding, 116
  method summary, 610–611. *See also specific methods.*
  minimum values, finding, 116
java.lang.Math class, method summary, 126*t*, 611–613. *See also specific methods.*
java.lang.NullPointerException class
  summary, 613
  unchecked exceptions, 421–423
java.lang.NumberFormatException class
  reading numbers, 414
  summary, 613
  unchecked exceptions, 421–423
java.lang.Object class, method summary, 613. *See also specific methods.*
java.lang.RuntimeException class
  summary, 613
  unchecked exceptions, 421–423
java.lang.String class
  method summary, 614. *See also specific methods.*
  overview, 134–135
java.lang.System class
  libraries, 16
  method summary, 615. *See also specific methods.*
  out object, 11, 16
java.lang.Throwable class
  catching exceptions, 425
  method summary, 615. *See also specific methods.*
  retrieving error messages, 429
java.math package, 615–616
java.math.BigDecimal class, method summary, 615–616. *See also specific methods.*
java.math.BigInteger class, method summary, 616. *See also specific methods.*
java.net package, 311*t*, 616
java.net.URL class, method summary, 616. *See also specific methods.*
java.swing package, 311*t*
java.util package, 311*t*, 616–622
java.util.ArrayList class
  adding array elements, 250, 263
  array lists, 250
  examples, 250*t*
  removing array elements, 250, 262
  syntax enhancements, 253
java.util.ArrayList<E> class, method summary, 616–617. *See also specific methods.*
java.util.Arrays class
  copying arrays, 264
  method summary, 617. *See also specific methods.*
java.util.Calendar class, method summary, 618. *See also specific methods.*
java.util.Collection<E> interface, method summary, 618. *See also specific methods.*
java.util.Collections class, method summary, 619. *See also specific methods.*
java.util.Comparator<T> interface
  comparing objects, 547
  method summary, 619. *See also specific methods.*
java.util.EventObject class, method summary, 619. *See also specific methods.*
java.util.GregorianCalendar class, method summary, 619. *See also specific methods.*
java.util.HashMap<K, V> class, method summary, 619. *See also specific methods.*

java.util.HashSet<E> class, method summary, 619. *See also specific methods.*
java.util.InputMismatchException class, 619
java.util.Iterable interface, 561
java.util.Iterator<E> interface, method summary, 619. *See also specific methods.*
java.util.LinkedList<E> class, method summary, 620. *See also specific methods.*
java.util.List<E> interface, method summary, 620. *See also specific methods.*
java.util.ListIterator<E> interface
  implementing linked lists, 564–572
  method summary, 620. *See also specific methods.*
java.util.logging package, 622–623
java.util.logging.Level class, 622
java.util.logging.Logger class
  logging trace messages, 180–181
  method summary, 622–623. *See also specific methods.*
java.util.Map<K, V> interface, method summary, 620–621. *See also specific methods.*
java.util.NoSuchElementException class, 423
  reading text numbers, 414
  summary, 621
java.util.PriorityQueue<E> class, method summary, 621. *See also specific methods.*
java.util.Random class, method summary, 621. *See also specific methods.*
java.util.Scanner class. *See also* java.io.File class.
  automatic close, 428
  creating with a string, 410–411
  method summary, 621–622. *See also specific methods.*
  patterns for word boundaries, specifying, 412
  testing calls to NextDouble method, 174
java.util.Scanner class, reading input
  character by character, 415
  from a keyboard, 138–140
  line by line, 412–413
  reading text numbers, 414
  regular expressions, 415–416
  text files, 408–410
  word by word, 411–412
java.util.Set<E> interface, 622
java.util.TreeMap<K, V> class, method summary, 622. *See also specific methods.*
java.util.TreeSet<E> class, method summary, 622. *See also specific methods.*
javax.swing package, 623–627
javax.swing.AbstractButton class, method summary, 623. *See also specific methods.*
javax.swing.border package, 627
javax.swing.border.EtchedBorder class, method summary, 627. *See also specific methods.*
javax.swing.border.TitledBorder class, method summary, 627. *See also specific methods.*
javax.swing.ButtonGroup class, method summary, 623. *See also specific methods.*
javax.swing.event package, 628
javax.swing.event.ChangeEvent class, 628
javax.swing.event.ChangeListener interface, method summary, 628. *See also specific methods.*
javax.swing.ImageIcon class, method summary, 623. *See also specific methods.*
javax.swing.JButton class
  buttons, 352–355
  method summary, 623. *See also specific methods.*
javax.swing.JCheckBox class, method summary, 623. *See also specific methods.*
javax.swing.JComboBox class, method summary, 624. *See also specific methods.*
javax.swing.JComponent class, method summary, 624. *See also specific methods.*
javax.swing.JFileChooser class, method summary, 624. *See also specific methods.*
javax.swing.JFrame class
  default close operation, setting, 55
  frame size, setting, 55
  frame title, setting, 55
  frame visibility, setting, 55
  method summary, 625. *See also specific methods.*
javax.swing.JLabel class
  buttons, 352–355
  method summary, 625. *See also specific methods.*
javax.swing.JMenu class, method summary, 625. *See also specific methods.*
javax.swing.JMenuBar class, method summary, 625. *See also specific methods.*
javax.swing.JMenuItem class, method summary, 625. *See also specific methods.*
javax.swing.JOptionPane class, method summary, 626. *See also specific methods.*
javax.swing.JPanel class
  button panels, 353
  summary, 626
javax.swing.JRadioButton class, method summary, 626. *See also specific methods.*
javax.swing.JScrollPane class, method summary, 626. *See also specific methods.*
javax.swing.JSlider class, method summary, 626. *See also specific methods.*
javax.swing.JTextArea class, method summary, 627. *See also specific methods.*
javax.swing.JTextField class, method summary, 627. *See also specific methods.*
javax.swing.text package, 628
javax.swing.text.JTextComponent class, method summary, 628. *See also specific methods.*
javax.swing.Timer class, method summary, 627. *See also specific methods.*
JButton constructor, javax.swing.JButton class, 623
JCheckBox constructor, javax.swing.JCheckBox class, 623
JComboBox constructor, javax.swing.JComboBox class, 624

JFileChooser constructor, javax.swing.JFileChooser class, 624
JLabel constructor, javax.swing.JLabel class, 625
JMenu constructor, javax.swing.JMenu class, 625
JMenuBar constructor, javax.swing.JMenuBar class, 625
JMenuItem constructor, javax.swing.JMenuItem class, 625
JRadioButton constructor, javax.swing.JRadioButton class, 626
JScrollPane constructor, javax.swing.JScrollPane class, 626
JSlider constructor, javax.swing.JSlider class, 626
JTextArea constructor, javax.swing.JTextArea class, 627
JTextField constructor, javax.swing.JTextField class, 627
JUnit framework, 316–317
JVM (Java Virtual Machine), 7–8

K

keyboards
  international characters, 138
  reading input from, 138–140
KeyPad.java class, 480–482
keySet method, java.util.Map<K, V> interface, 620

L

labels, buttons, 352–355
language support package, 311*t*
largest integer, determining, 126*t*
launching programs. *See* starting programs.
layout, Java programs, 14
lazy Boolean evaluation, 177
left angle bracket, equal (<=), less-than-or-equal operator, 157*t*
left angle bracket (<), less-than operator, 157*t*
length
  arrays, definition, 242
  arrays, determining, 253
  strings, determining, 134–135
  of strings, zero, 135
length method
  java.io.RandomAccessFile class, 608
  java.lang.String class, 614
less-than operator (<), 157*t*
less-than-or-equal operator (<=), 157*t*
libraries. *See also* packages.
  definition, 16
  documentation. *See* API documentation.
life span, variables, 93
LIFO (last in, first out), 575–577
Line2D.Double constructor, java.awt.geom.Line2D.Double class, 605
linear searches, 540–542
LinearSearchDemo.java class, 541–542
LinearSearcher.java class, 541
LineItem.java class, 461
LineNumberer.java class, 409–410
lines (graphic), drawing, 60
lines of text, reading, 413
lineScanner method, 413
linked lists. *See also* data structures.
  animated lesson, 559
  definition, 556
  doubly linked lists, 559
  "for each" loops, 561
  implementing, 561–571
  iterators, 557–559
  java.util.Iterable interface, 561
  LinkedList.java class, 568–571
  ListIterator.java class, 571
  ListTester.java class, 560–561
  methods for, 557*t*
  random access, 557
  sequential access, 557
  static inner classes, 571
linked lists, nodes
  adding, 556–557, 563, 566–567
  definition, 556
  getting, 557
  removing, 557, 565–567
LinkedList.java class, 568–571
listIterator method
  java.util.LinkedList<E> class, 557*t*, 558
  java.util.List<E> interface, 620
ListIterator.java class, 571
ListTester.java class, 560–561
literals, creating, 134
local variables, 92–93, 309
log method, java.lang.Math class, 126*t*, 612
log10 method, java.lang.Math class, 126*t*, 612
logging programs, 180–181
long data type, 117*t*, 254*t*
loop and a half pattern, 213, 218
loop invariants, 223
LoopFib.java, 505
loops. *See also* for loops; while loops.
  break statements, 218
  continue statements, 218
  do loops, 201
  hand-tracing, 198–199
  How To example, 215–218
  infinite, 200
  loop and a half pattern, 213, 218
  nesting, 218–220
  off-by-one errors, 200–201
  testing for termination, 213
  tracing, animated lesson, 196
  Worked Example: credit card processing, 218
  Worked Example: manipulating image pixels, 220
loops, common algorithms
  comparing adjacent values, 211–212
  computing totals, 210
  counters, 210
  counting matches, 210
  finding first match, 210–211
  prompting for first match, 211
  sentinel values, 212–215
Lovelace, Ada, 540
Lukasiewicz, Jan, 578

M

machine instructions, definition, 7–8
machine state, ATM case study, 466–467
Macintosh, history of computers, 316
magic numbers, 122–123
main method
  args parameter, 11
  calling, 12
  description, 11
  Frame class, 397–398
  "Hello World" example, 12
mainframe computers, 55–56
mathematical computations. *See* arithmetic operations.
matrices, 274–276. *See also* arrays.
max method, java.lang.Math class, 126*t*, 612

maximum value, finding in arrays, 260–261
MAX_VALUE method, java.lang.Integer class, 116
Measurer.java class, 341
memory chips (illustration), 4
memory module (illustration), 4
menus, Worked Example, 90
merge sorts
  algorithm, 537–540
  MergeSortDemo.java class, 537
  MergeSorter.java class, 535–537
  overview, 534–537
MergeSortDemo.java class, 537
MergeSorter.java class, 535–537
metaphor, Extreme Programming, 445
method calls
  postconditions, 299–302
  preconditions, 299–302
  required parameters, 12
  syntax, 12
  throwing exceptions, 300
method documentation
  case study, ATM, 469–470
  case study, printing an invoice, 456–458
methods. *See also* classes; objects; return values; *specific methods*.
  abstract, 385
  for accessing objects. *See* accessor methods.
  accessor, 46, 294
  animated lesson, 297
  for arithmetic operations. *See* static methods.
  camel case names, 35
  for changing objects. *See* mutator methods.
  commenting, 81–83
  declaration syntax, 86
  documentation. *See* API documentation.
  duplicate names, 41
  final, 385
  implementing, 89–90
  modifying primitive type parameters, 296–298
  naming conventions, 35
  overloading, 41
  overriding to a lower access level, 385
  passing information to. *See* parameters.
  private, 78
  return values, 42–43
  running time, measuring, 532
  subclasses, calling syntax, 376
  subclasses, inherited from superclasses, 371
  summary table of, 82
  terminating on checked exceptions. *See* throws clause.
  in UML, 452
  undeclared, calling, 40
  unspecified implementation. *See* abstract methods.
  void reserved word, 43
  vs. constructors, 45, 79
methods, parameters
  passing, 42–43
  variable number of, 247
microprocessors, history of computers, 316
min method, java.lang.Math class, 126*t*, 612
minimum value, finding in arrays, 260–261
minus sign (-), subtraction operator, 123
minus signs (--), decrement operator, 123–124
MIN_VALUE method, java.lang.Integer class, 116
misspelled words, error handling, 19
mock objects, 345–346
mod method, java.math.BigInteger class, 616
moth, as first computer bug, 228
motherboard, 5
mouseClicked method, java.awt.event.MouseListener interface, 604
mouseEntered method, java.awt.event.MouseListener interface, 604
mouseExited method, java.awt.event.MouseListener interface, 604
mousePressed method, java.awt.event.MouseListener interface, 604
mouseReleased method, java.awt.event.MouseListener interface, 604
MoveTester.java class, 50–51
moving, rectangles, 46, 50–51
multidimensional arrays, 277
multiple relational operators, 176–177
multiplication, 123
multiply method
  java.math.BigDecimal class, 616
  java.math.BigInteger class, 616
mutator methods
  definition, 46
  description, 46
  immutable classes, 294
  side effects, 295–296, 298
mutual recursion. *See* recursion, mutual.

N

name clashes, packages, 312
naming conventions
  classes, 35
  constants, 119
  identical variable names, 308–309
  methods, 35
  packages, 312–313
  static methods, 131
  variables, 34–36, 309
natural logs, 126*t*
Naughton, Patrick, 8
negating && and || operators. *See* De Morgan's law.
nested branches, 167–169
nesting
  directories, 17
  loops, 218–220
nesting levels, 155–156
networking package, 311*t*
networks, definition, 4
next method
  java.util.Iterator<E> interface, 558, 619
  java.util.ListIterator<E> interface, 560*t*, 564–565
  java.util.Scanner class, 139, 408, 622
nextDouble method
  java.util.Random class, 621
  java.util.Scanner class, 138–140, 408, 414, 622
nextInt method, java.util.Random class, 621
nextInt method, java.util.Scanner class
  description, 622
  reading input, 138–140
  reading text files, 408
  reading text numbers, 414

nextLine method, java.util.Scanner class
description, 622
reading input, 138–140
reading text, line by line, 412–413
reading text files, 408
reading text numbers, 414
nodes. *See* linked lists, nodes.
not-equal operator (!=), 157*t*, 208
not logical operator (!), 175
notify method, java.lang.Object class, 613
notifyAll method, java.lang.Object class, 613
nouns in the class task description, 446
null, testing for, 162
number literals, 33
number sequences, Worked Example, 339
number variables *vs.* object variables, 52–53
numbers. *See also* arithmetic operations.
format specifiers, 140
formatting, 140
reading, 414

O

object-oriented design
class diagrams, 450–452. *See also* UML (Unified Modeling Language).
software development models, 443–446
software life cycle, phases of, 442–443
object-oriented design, case study (ATM)
ATMFrame.java class, 478–480
ATM.java class, 471–473
ATMSimulator.java class, 475–477
ATMViewer.java class, 477
Bank.java class, 473–474
CRC cards, 465–468
Customer.java class, 474–475
implementation, 470–482
KeyPad.java class, 480–482
machine state, 466–467
method documentation, 469–470
requirements, 463–465
state diagrams, 467–468
UML diagrams, 468–469
object-oriented design, case study (printing invoices)
Address.java class, 462–463
CRC cards, 453–455
implementation, 458–463
Invoice.java class, 460–461
InvoicePrinter.java class, 459
LineItem.java class, 461
method documentation, 456–458
overview, 452
Product.java class, 462
requirements, 453
UML diagrams, 455–456
object-oriented design, classes
aggregation, 449–450
candidates, listing, 448
collaborators, 448
CRC (classes, responsibilities, collaborators) card method, 448–449, 451–452
dependency relationship, 450
discovering, 446–449
has-a relationship, 449–450
is-a relationship, 449–450
nouns in the task description, 446
relationships, documenting, 449–451
responsibilities, 448
uses relationship. *See* dependency relationship.
verbs in the task description, 448
object references
animated lesson, 53
definition, 52
number variables *vs.* object variables, 52–53
to same object, 52–53
object variables *vs.* number variables, 52–53
ObjectInputStream constructor, java.io.ObjectInputStream class, 607
ObjectOutputStream constructor, java.io.ObjectOutputStream class, 607
objects. *See also* classes; methods.
arrays of, 246–247
comparing, 161
construction, 44–45
construction parameters, 45
constructors *vs.* methods, 45
copying. *See* clone method.
definition, 39
mock, 345–346
reinitializing with constructors, 45
string, creating, 134–135
off-by-one errors, 200–201
omg.w3c.dom package, 311*t*
on-site customers, Extreme Programming, 445
online help, 49
openStream method, java.net.URL class, 616
operating systems, typical services, 345
operators, summary of, 593*t*–594*t*. *See also specific operators.*
or logical operator (||), 175, 177
out object, java.lang.System class, 11, 16
output destination, system output, 12
overflow, computation, 116
overlapping scope, 308–310
overloading. *See also* duplicate names.
methods, 41
subclasses, accidentally, 377–378
overriding
clone method, 394
equals method, 393–394
final methods, 385
methods to a lower access level, 385
superclass methods, 375–378
toString method, 391–392

P

packages. *See also* libraries; *specific packages.*
. (dot), in package names, 314
abstract windowing toolkit, 311*t*
access, 314
applets, 311*t*
base directory, 313
default, 311
definition, 49
How To example, 315–316
import directive, 312
importing classes from, 49, 311–312
input/output, 311*t*
in the Java library, list of, 311*t*
java.applet, 311*t*
java.awt, 311*t*
java.io, 311*t*
java.lang, 311*t*

packages (*continued*)
  java.net, 311*t*
  java.swing, 311*t*
  java.util, 311*t*
  language support, 311*t*
  name clashes, 312
  naming conventions, 312–313
  networking, 311*t*
  omg.w3c.dom, 311*t*
  organizing classes into, 311
  security exposure, 314
  source files, 313
  SQL database access, 311*t*
  swing user interface, 311*t*
  syntax, 310
  utilities, 311*t*
  XML Document Object Model, 311*t*
paintComponent method, javax.swing.JComponent class, 56–59, 624
pair programming, Extreme Programming, 445
panels, graphic, 353
parallel arrays, 246–247
parameter types, modifying, 349–350
parameter variables
  call by reference, 299
  call by value, 299
  changing contents of, 298–299
  definition, 92–93
  reference parameters, 299
  scope, 307–309
parameters. *See also* methods; return values.
  animated lesson, 42
  definition, 12
  explicit, 41
  implicit, 41, 94–96
  in methods, variable number of, 247
  passing to methods, 42–43
  from return values, 42
  type, 248
  type, specifying, 43
parentheses, unbalanced, 128–129
parseDouble method, java.lang.Double class, 135, 610
parseInt method, java.lang.Integer class
  converting strings to integers, 135, 413
  method summary, 610
patterns for word boundaries, specifying, 412
pen color, changing, 61
percent sign (%), remainder of division operator, 124
peripheral devices, 4. *See also specific devices.*
PermutationGeneratorDemo.java, 507–508
PermutationGenerator.java, 509–510
permutations, 507–510
pictures, drawing. *See* drawing; graphical applications.
planning, Extreme Programming, 445
plus sign (+)
  addition operator, 123
  string concatenation, 135
plus signs (++), increment operator, 123–124
Point2D.Double constructor, java.awt.geom.Point2D.Double class, 605
polymorphism. *See also* inheritance.
  animated lesson, 338
  definition, 338
  dynamic method lookup, 338, 383–386
  overview, 338
PopulationDensity.java class, 418
portability, Java language, 8
postconditions, 299–302
pow method, java.lang.Math class, 125–126*t*, 612
powers, 125–126, 612
preconditions, 299–302
predicate methods, 173–174
previous method, java.util.ListIterator<E> interface, 559, 620
primitive data types
  list of, 116–117*t*
  modifying, 296–298
  wrapper classes, 254–255
primitive numbers, 33
print method
  java.io.PrintStream class, 13, 608
  java.io.PrintWriter class, 408–410, 608
printf method, java.io.PrintWriter class, 408–410
printing
  array element separators, 265–268
  array lists, 268
  arrays, 268
  formatting numbers, 140
  numerical values, 12
  starting a new line. *See* print method; println method.
println method
  java.io.PrintStream class, 12–13
  java.io.PrintWriter class, 408–410
  passing parameters to, 41
  returning values from, 42
printStackTrace method, java.lang.Throwable class, 425, 615
PrintStream constructor
  java.io.PrintStream class, 607
  java.io.PrintWriter class, 607
PrintWriter constructor
  java.io.PrintStream class, 607
  java.io.PrintWriter class, 607
PriorityQueue constructor, java.util.PriorityQueue<E> class, 621
private implementation, classes, 40
Product.java class, 462
programmer productivity, 446
programmers
  application, 47
  first, 540
  system, 47
programming. *See also* software development.
  description, 2–3
  scheduling for unexpected problems, 172
programming languages, history of, 356. *See also specific languages.*
programs. *See also* Java programs; software.
  comparing, limitations of, 510
  compilers, 7
  high-level languages, 7
  machine instructions, 7–8
  variables, 8
prompting
  for first match, 211
  for input, 138
protected access feature, 386
prototypes, 444
pseudorandom numbers, 222, 621
public interfaces, classes
  cohesiveness, 291–293
  commenting, 81–84
  consistency, 293–294
  coupling, 291–293

documenting, 81–84, 88–89
specifying, 77–81, 88
syntax, 80
put method, java.util.Map<K, V> interface, 621
pyramid, calculating volume and surface, 134

Q
queues, 575–577
quicksort algorithm, 540

R
radians, converting to degrees, 126*t*
radiation overdose incidents, 273
RAM (random access memory), 4
random access. *See also* java.io.RandomAccessFile class.
data structures, 557, 572
linked lists, 557
Random constructor, java.util.Random class, 621
random number generation, 221–223, 621
RandomAccessFile constructor, java.io.RandomAccessFile class, 608
Rational Unified Process (RUP), 444, 445
read method, java.io.InputStream class, 607
readability, adding white space to code, 129–130
readChar method, java.io.RandomAccessFile class, 608
readDouble method, java.io.RandomAccessFile class, 608
reading input. *See also* writing output.
from a console window, 138–140
from dialog boxes, 140
input redirection, 273
from a keyboard, 138–140
prompts, 141
selecting files for, 411
from Web pages, 411
white space, 139, 412
reading input, from text files. *See also* java.io.File class; java.util.Scanner class.
character by character, 415
How To example, 416–418
line by line, 413
numbers, 414
overview, 408–410
patterns for word boundaries, 412
strings, converting to integers, 413
using regular expressions, 412
white space, consuming, 412
with wildcards. *See* regular expressions.
word by word, 411–412
Worked Example: baby names, 419
readInt method, java.io.RandomAccessFile class, 608
readObject method, java.io.ObjectInputStream class, 607
realistic planning, Extreme Programming, 445
recovery from exceptions, 419. *See also* exception handling.
Rectangle class
accessor methods, 46
constructing rectangles, 44–45
getHeight method, 46
getWidth method, 46
getX method, 46
getY method, 46
importing, 49
moving rectangles, 46, 50–51
mutator methods, 46
testing rectangle movement, 50–51
translate method, 46
Rectangle method, java.awt.Rectangle class, 603
RectangleMeasurer.java class, 341
rectangles
constructing, 44–45
drawing on components, 56–59
moving, 46, 50–51
testing, 50–51
RectangleViewer.java class, 58
recursion
animated lesson, 494
breakpoints, 496
call stack, 496
debugging, 496
efficiency, 502–507
example, 492–495
How To example, 497–500
infinite, 495
LoopFib.java, 505
PermutationGeneratorDemo.java, 507–508
PermutationGenerator.java, 509–510
permutations, 507–510
RecursiveFib.java, 502
RecursiveFibTracer.java, 503
stack faults, 495
trace messages, inserting, 503
tracing, 496
triangle numbers, 492–495
Triangle.java class, 494–495
TriangleTester.java class, 495
Worked Example: finding files, 500
recursion, mutual
Evaluator.java class, 514–515
ExpressionCalculator.java class, 516–517
ExpressionTokenizer.java class, 515–516
overview, 510–513
syntax diagrams, 511–512
recursive helper methods, 500–501
recursive methods, 493–494
RecursiveFib.java, 502
RecursiveFibTracer.java, 503
refactoring, Extreme Programming, 445
reference parameters, 299
regular expressions, 412, 415–416
relational operators, 156–157
multiple, 176–177
relationship symbols, UML, 451
relationships between classes, documenting, 449–451
releases, Extreme Programming, 445
remainder of division, 124–125
remainder operator (%), 124
removable storage, 4
remove method
java.util.ArrayList class, 250*t*, 262
java.util.ArrayList<E> class, 617
java.util.Collection<E> interface, 559, 618
java.util.Iterator<E> interface, 619
java.util.ListIterator<E> interface, 565–566
java.util.Map<K, V> interface, 621
java.util.PriorityQueue<E> class, 621

removeFirst method
java.util.LinkedList<E> class, 557*t*, 620
java.util.ListIterator<E> interface, 565
removeLast method, java.util.LinkedList<E> class, 557*t*, 620
removing
array elements, 250, 262
array list elements, 250
linked list nodes, 557, 565–567
whitespace, 413
repaint method, java.awt.Component class, 356, 601
repainting graphic components, 356, 601
replace method, java.lang.String class, 614
reporting exceptions, 419. *See also* exception handling.
requirements
case study, ATM, 463–465
case study, printing an invoice, 453
software life cycle, 442
reserved words
summary of, 595*t*–596*t*
in variable identifiers, 35
responsibilities of classes, 448
return values. *See also* methods; parameters.
methods, 42–43
from parameters, 42
type, specifying, 43
reusing algorithms. *See* interface types.
right angle bracket, equal (>=), greater-than-or-equal operator, 157*t*
right angle bracket (>), greater-than operator, 157*t*
rocket incident, 434
roots, 125–126
round method, java.lang.Math class, 126*t*, 612
rounding, 126–128, 126*t*
rounding errors
binary/decimal conversions, 117
floating-point numbers, 130
roundoff errors, 157–158
RPN (reverse Polish notation), 578
run-time errors, definition, 17–18
run-time stacks, 576
running, Java programs, 14–16
running programs. *See* starting programs.
RUP (Rational Unified Process), 444, 445

S

safety, Java language, 8
SavingsAccount.java class, 373
Scanner constructor, java.util.Scanner class, 621
scope of variables
with identical names, 308–309
local variables, 309
minimizing, 310
overlapping, 308–310
parameter variables, 307–309
shadowing, 309
scripting languages, 396
searching
binary, 542–544
BinarySearcher.java class, 543
linear, 540–542
LinearSearchDemo.java class, 541–542
LinearSearcher.java class, 541
sequential, 540–542
security
Java language, 8
package access, 314
seek method, java.io.RandomAccessFile class, 608
selecting files. *See* files, selecting from a dialog box.
selection sorts. *See* sorting, selection sorts.
SelectionSortDemo.java class, 528
SelectionSorter.java class, 527–528
SelectionSortTimer.java class, 531
semicolon (;)
ending method statements, 11
errors in for loops, 207–208
if statement terminator, 156
omitting, 13
sentinel values, 212–215
sequential access
data structures, 557, 572
linked lists, 557
sequential searches, 540–542
set-breakpoint command, 224
set method
java.util.ArrayList<E> class, 617
java.util.ListIterator<E> interface, 565, 620
setBorder method, javax.swing.JComponent class, 624
setColor method, java.awt.Graphics class, 61–63, 602
setDefaultCloseOperation method, javax.swing.JFrame class, 625
closing frame windows, 55
frame, default close operation, 55
setEditable method
javax.swing.JComboBox class, 624
javax.swing.text.JTextComponent class, 628
setFont method, javax.swing.JComponent class, 624
setJMenuBar method, javax.swing.JFrame class, 625
setLayout method, java.awt.Container class, 601
setLevel method, java.util.logging.Logger class, 181, 623
setLine method, java.awt.geom.Line2D class, 604
setLocation method
java.awt.geom.Point2D class, 605
java.awt.Rectangle class, 603
setPreferredSize method, java.awt.Component class, 356, 601
setSelected method, javax.swing.AbstractButton class, 623
setSize method
java.awt.Component class, 55, 601
java.awt.Rectangle class, 603
setText method, javax.swing.text.JTextComponent class, 628
setTitle method, java.awt.Frame class, 55, 602
setVisible method, java.awt.Component class, 55, 601
shadowing, 309, 374
shape classes, 96–100
shapes, drawing. *See* drawing, shapes; graphical applications.
shell scripts, 273–274
short circuit Boolean evaluation. *See* De Morgan's law.

short data type, 117*t*, 254*t*
showInputDialog method,
    javax.swing.JOptionPane class, 626
showMessageDialog method,
    javax.swing.JOptionPane class, 626
showOpenDialog method,
    javax.swing.JFileChooser class, 624
showSaveDialog method,
    javax.swing.JFileChooser class, 624
side effects, 162–163, 295–296, 298
simple if statements, 153
simplicity, Extreme Programming, 445
simulation programs
  Buffon needle experiment, 221–223
  definition, 221
  pseudorandom numbers, 222
  random number generation, 221–223
sin method, java.lang.Math class, 126*t*, 612
sine, in radians, 126*t*
single-step command, 224
size method
  java.util.ArrayList<E> class, 617
  java.util.Collection<E> interface, 618
slash (/), division operator, 123
slashes (//), comment delimiter, 11
small releases, Extreme Programming, 445
smallest integer, determining, 126*t*
software development. *See also* programming.
  art *vs.* science, 482
  programmer productivity, 446
  prototypes, 444
  user interface prototypes, 444
software development models
  Extreme Programming, 444–446
  RUP (Rational Unified Process), 444, 445
  spiral, 444
  waterfall, 443–444
software life cycle
  analysis phase, 442
  deployment phase, 443
  design phase, 442
  implementation phase, 442
  phases of, 442–443
  requirements documents, 442
  testing phase, 443
sort method
  java.util.Arrays class, 617
  java.util.Collections class, 546, 618
sorting
  algorithms, 526
  insertion sorts, 534
  quicksort algorithm, 540
sorting, merge sorts
  algorithm, 537–540
  MergeSortDemo.java class, 537
  MergeSorter.java class, 535–537
  overview, 534–537
sorting, selection sorts
  algorithm performance, 532–534
  algorithm profile, 529–532
  ArrayUtil.java class, 529
  big-Oh notation, 53, 533
  overview, 526–529
  SelectionSortDemo.java class, 528
  SelectionSorter.java class, 527–528
  SelectionSortTimer.java class, 531
  StopWatch.java class, 530–531
source code, Java programs, 15
source files, packages, 313
spaces, in variable identifiers, 35
spiral model, software development, 444
SQL database access package, 311*t*
sqrt method, java.lang.Math class, 125–126*t*, 612
square brackets, array indexing ([ ]), 243
square roots, 125–126*t*, 612
squelching exceptions, 425–526
stack faults, recursion, 495
stacks, 575–577
standards for coding, 445, 575
start method
  java.applet.Applet class, 600
  javax.swing.Timer class, 627
starting programs, 411
state diagrams, ATM case study, 467–468
stateChanged method,
    javax.swing.event.
    ChangeListener interface, 628
states, ATM case study, 466–467
static inner classes, linked lists, 571
static methods
  calling, 131
  definition, 131
  minimizing use of, 305
  naming conventions, 131
  overview, 302–303
  placing in classes, 303
  syntax, 131
static variables. *See also* variables.
  initialization blocks, 308–309
  overview, 304–306
  without class prefixes, 306
step-into command, 224
step-over command, 224
stop method
  java.applet.Applet class, 600
  javax.swing.Timer class, 627
StopWatch.java class, 530–531
storage, computer
  hard disks, 4, 5
  primary, 4
  removable, 4
  secondary, 4
string concatenation operator (+), 135
string-to-number conversions, error handling, 135
strings
  "..." (double quotation marks), string indicators, 12
  + (plus sign), string concatenation, 135
  case, ignoring, 159
  char data type, 117*t*, 138
  char type, 138
  comparing, 158–160
  concatenating, 135
  converting to integers. *See* parseInt method.
  converting to numbers. *See* parseInt method.
  converting to upper case, 40
  in dictionary order, 159
  empty, 135
  escape sequences, 137
  indicating, 12
  international characters, 138
  length, determining, 39–40, 134–135, 253
  length of zero, 135
  literals, creating, 134
  number of characters, counting, 39–40
  objects, creating, 134
  search-and-replace, 42–43

strings (*continued*)
String class. *See* java.lang.String class.
strings, substrings
error handling, 136–137
extracting, 136–137
length, determining, 136–137
Worked Example: extracting initials, 140
Worked Example: extracting the middle, 164
subclasses. *See also* inheritance; superclasses.
accidental overloading, 377–378
animation lesson, 377
calling methods, syntax, 376
cloning mutable instance variables, 396
confusing with superclasses, 373–374
constructors, 378–380
converting to superclasses, 381–383
definition, 368
failure to invoke superclass method, 378
of final classes, 385
implementing, 371–374
inherited methods, 371
instance variables, 371–372
overriding superclass methods, 375–378
preventing an override, 385
shadowing instance variables, 374
substring method, java.lang.String class, 136–137, 614
substrings. *See* strings, substrings.
subtract method
java.math.BigDecimal class, 616
java.math.BigInteger class, 616
subtraction, 123. *See also* decrementing.
subtraction operator (-), 123
summing array elements, 259–260. *See also* addition (mathematical).
super reserved word, 379
superclasses. *See also* inheritance; subclasses.
confusing with subclasses, 373–374
converting to subclasses, 381–383
definition, 368
for the Object class, 391
swing user interface package, 311*t*
switch statements, 167
symmetric bounds, 208

T

tab characters, indenting code, 156
Tab key, indenting code, 155
tabs, indenting code, 155–156
tally counter, example, 74–76
tan method, java.lang.Math class, 126*t*, 611
tangents, 126*t*
TaxCalculator.java class, 168–169
TaxReturn.java class, 168–169
terminating algorithms, 21
test cases, preparing, 179
tester class, 91–92
testing phase, software life cycle, 443
testing programs. *See also* debuggers; debugging.
archiving test cases, 273
assertions, 300–301
black-box testing, 178
boundary test cases, 179–180
calculating sample data, 179
classes, 90–92
classes, interactively, 51
code coverage, 178–179
Extreme Programming, 445
hand-tracing, 171
input redirection, 273
logging, 180–181
for loop termination, 213
mock objects, 345–346
for null, 162
output redirection, 273
rectangle movement, 50–51
regression testing, 271–273
test cases, preparing, 179
test suites, 271
tracing, 180–181
white-box testing, 178
text, drawing, 60
Therac-25 incidents, 273
throw early, catch late, 425
throw statement, syntax, 419
Throwable constructor, java.lang.Throwable class, 615
throwing exceptions, 300, 419–421, 429. *See also* exception handling.
throws clause, 422–423
TicTacToe.java class, 275
TicTacToeRunner.java class, 276
Timer constructor, javax.swing.Timer class, 627
TitledBorder constructor, javax.swing.border.TitledBorder class, 628
toDegrees method, java.lang.Math class, 126*t*, 611
toLowerCase method, java.lang.String class, 614
toRadians method, java.lang.Math class, 126*t*, 611
toString method
for all classes, 395
description, 395
java.lang.Integer class, 611
java.lang.Object class, 613
java.util.Arrays class, 617
overriding, 391–392
toUpperCase method, java.lang.String class, 614
trace messages, inserting, 503
tracing
loops, animated lesson, 196
recursion, 496
while loops, animated lesson, 196
tracing programs, 180–181
transistors, 4
translate method, java.awt.Rectangle class, 46, 603
TreeMap constructor, java.util.TreeMap<K, V> class, 622
TreeSet constructor, java.util.TreeSet<E> class, 622
triangle numbers, recursion, 492–495
Triangle.java class, 494–495
TriangleTester.java class, 495
trim method, removing whitespace, 413
try blocks, 423–425, 428
try/catch statements, 423–425, 427
two-dimensional arrays, 274–276
type parameters, 248
types of data. *See* data types.

U

UML (Unified Modeling Language)
aggregation, relationship symbol, 451*t*
and association, 452
association relationships, 452
attributes, 452
class diagrams, 450–452

dependency relationship symbol, 451*t*
inheritance relationship symbol, 451*t*
interface implementation relationship symbol, 451*t*
interface types, 334
is-a relationships, 334
methods, 452
object diagrams *vs.* class diagrams, 293
relationship multiplicities, 452
relationship symbols, 451
uses relationships, 334
UML diagrams
case study, ATM, 468–469
case study, printing an invoice, 455–456
unambiguous algorithms, 21
unchecked exceptions, 421–423
undeclared methods, calling, 40
underscore (_), in variable identifiers, 35
Unicode encoding, 589*t*–591*t*, 979*t*–981*t*
The Unified Modeling Language User Guide, 444
uninitialized variables, 37
`union` method, `java.awt.Rectangle` class, 603
unit testing
definition, 90
frameworks, 316–317
JUnit framework, 316–317
tester class, 91–92
`URL` constructor, `java.net.URL` class, 616
`useDelimiter` method, `java.util.Scanner` class, 622
patterns for word boundaries, specifying, 412
reading text, character by character, 415
reading text, word by word, 412
regular expressions, 415–416
user interface prototypes, 444
uses relationships, 334, 450
utilities package, 311*t*
utility classes, 291

V
vacuum tubes, history of computers, 6
variable declarations *vs.* assignment statements, 38–39
variables
animated lesson, 92
changing value of, 37–38
declaration syntax, 35
declaring in `for` loops, 208
definition, 8, 34
descriptive names, 36
distinguishing from constants, 119
garbage collector, 93
identifiers, naming conventions, 35–36
initialization, 37–38, 93
instance. *See* instance variables.
life span, 93
local, 92–93
naming conventions, 34–36
parameter. *See* parameter variables.
static. *See* static variables.
type, specifying, 34–35
uninitialized, 37
variable declarations *vs.* assignment statements, 38–39
verbs in the class task description, 448
versions of Java, summary of, 10*t*
vertical bars (`||`), *or* logical operator, 175, 177
viruses, computer, 248
`void` reserved word, 43
voting machines, 96

W
`wait` method, `java.lang.Object` class, 613
waterfall model, software development, 443–444
Web pages, reading from, 411
`while` loops. *See also* loops.
code sample, 196–197
description, 194–196
examples, 197
flow chart, 196
syntax, 196
tracing, animated lesson, 196
`while` statement, syntax, 196
white-box testing, 178
white space
consuming, 412
improving code readability, 129–130
reading input, 139
removing, 413
whole numbers. *See* integers.
Wilkes, Maurice, 228
words, reading, 411–412
world population table, 277
worms, computer, 248
wrapper classes, 254–255
`write` method, `java.io.OutputStream` class, 607
`writeChar` method, `java.io.RandomAccessFile` class, 608
`writeChars` method, `java.io.RandomAccessFile` class, 608
`writeDouble` method, `java.io.RandomAccessFile` class, 608
`writeInt` method, `java.io.RandomAccessFile` class, 608
`writeObject` method, `java.io.ObjectOutputStream` class, 607
writing output. *See also* reading input.
closing the print stream, 409
to dialog boxes, 140
line numbers, 409
output redirection, 273
to text files, 408–410, 416–418

X
XML Document Object Model package, 311*t*

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