NOVA SCHOOL OF
SCIENCE & TECHNOLOGY
COMPUTER SCIENCE DEPARTMENT

Parallel Programming Overview

lecture 06 (2021-04-12)

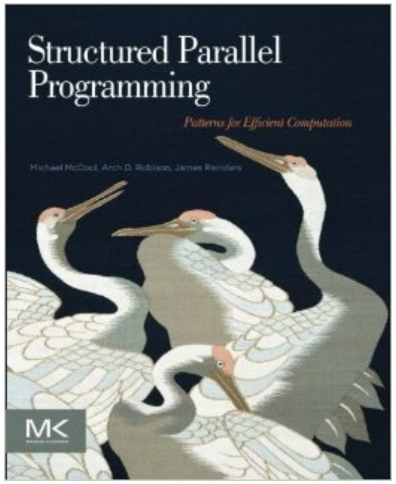
Master in Computer Science and Engineering

— Concurrency and Parallelism / 2020-21 —

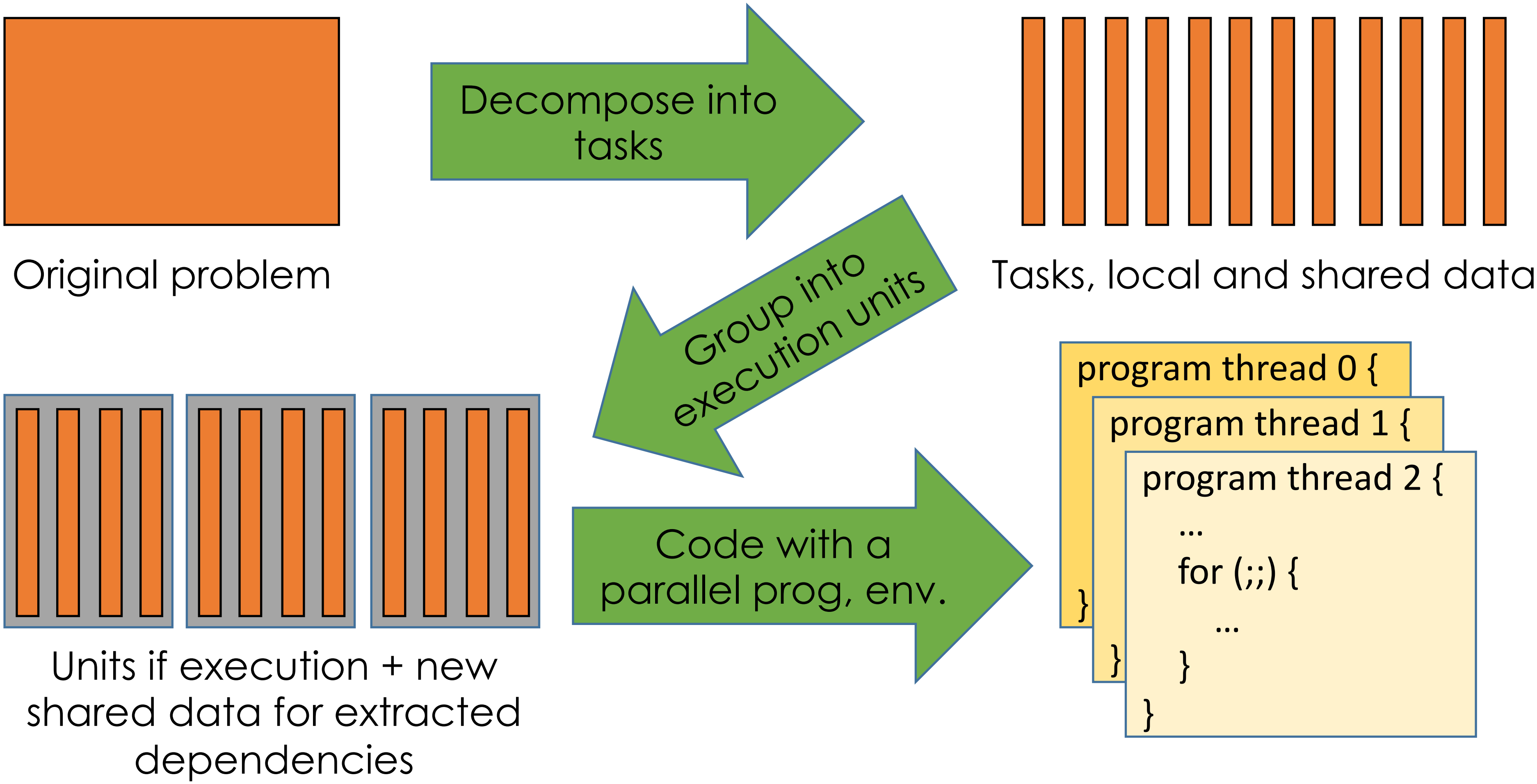
João Lourenço <joao.lourenco@fct.unl.pt>

Outline

- Structured programming patterns overview
  - Concept of programming patterns
  - Serial and parallel control flow patterns
  - Serial and parallel data management patterns
  - Bibliography:
    - **Chapter 3** of book
      McCool M., Arch M., Reinders J.;
      Structured Parallel Programming: Patterns for Efficient Computation;
      Morgan Kaufmann (2012);
      ISBN: 978-0-12-415993-8



How to Create a Parallel Application



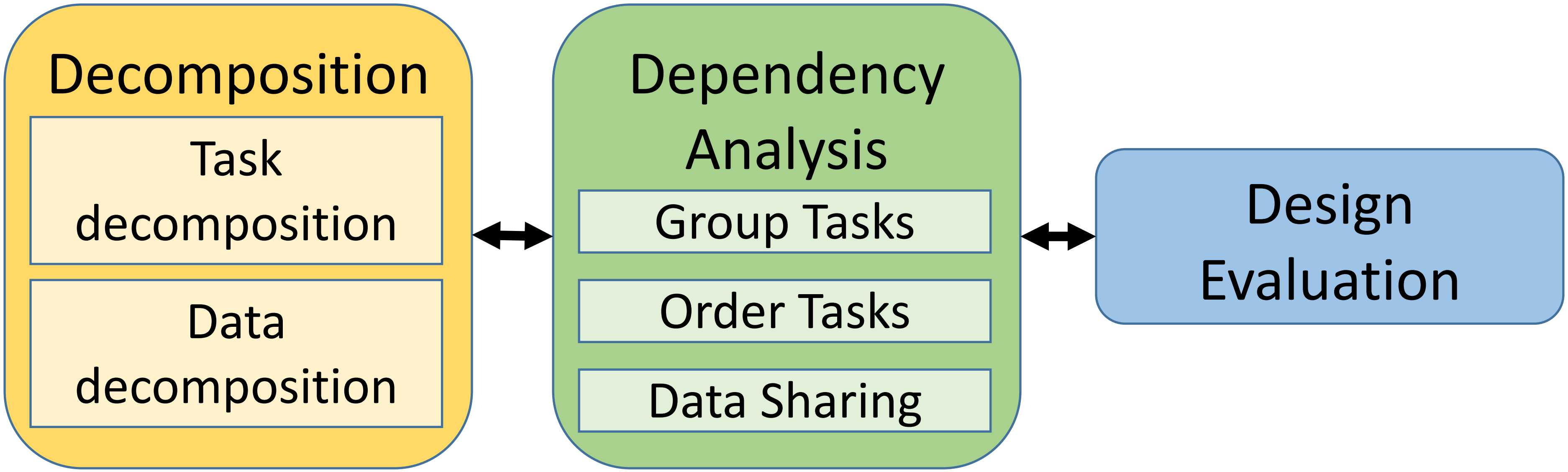
Before writing parallel programs

- Parallel programs often start as sequential programs
  - Easy to write and debug
  - Already developed/tested
- Identify program hot spots
- Parallelization
  - Start with hot spots first
  - Make sequences of small changes, each followed by testing
  - (Parallel) patterns provide guidance

Steps to Parallel Programming

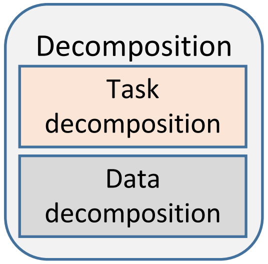
- Step 1: Find concurrency
- Step 2: Structure the algorithm so that concurrency can be exploited
- Step 3 : Implement the algorithm in a suitable programming environment
- Step 4: Execute and tune the performance of the code on a parallel system

1. Finding Concurrency



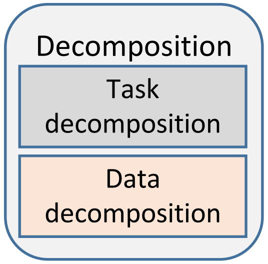
- Things to consider: Flexibility, Efficiency, Simplicity

Guidelines for Task Decomposition



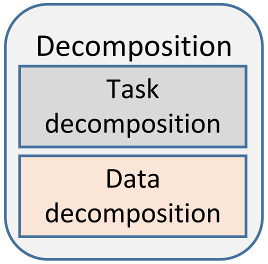
- Flexibility
  - Program design should afford flexibility in **the number** and **the size** of tasks generated
    - Tasks should not tie to a specific architecture
    - Fixed tasks vs. Parameterized tasks
- Efficiency
  - Tasks (usually) should have **enough work** to amortize the cost of creating and managing them
  - Tasks should be **sufficiently independent** so that managing dependencies doesn't become the bottleneck
- Simplicity
  - The code must remain **readable and easy to understand and debug**

Guidelines for Data Decomposition



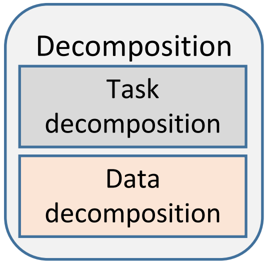
- Data decomposition is often implied by task decomposition
- Programmers need to address task and data decomposition to create a parallel program
  - Which decomposition to start with?
- Data decomposition is a good starting point when
  - Main computation is organized around manipulation of a large data structure
  - Similar operations are applied to different parts of the data structure

Guidelines for Data Decomposition



- Flexibility
  - Size and number of data chunks should support a **wide range of executions**
- Efficiency
  - Data chunks should generate **considerable amounts of work** (adequate grain), to minimize impact of communication and management
  - Data chunks should generate **comparable amounts of work**, for load balancing
- Simplicity
  - Complex data compositions can get difficult to manage and debug

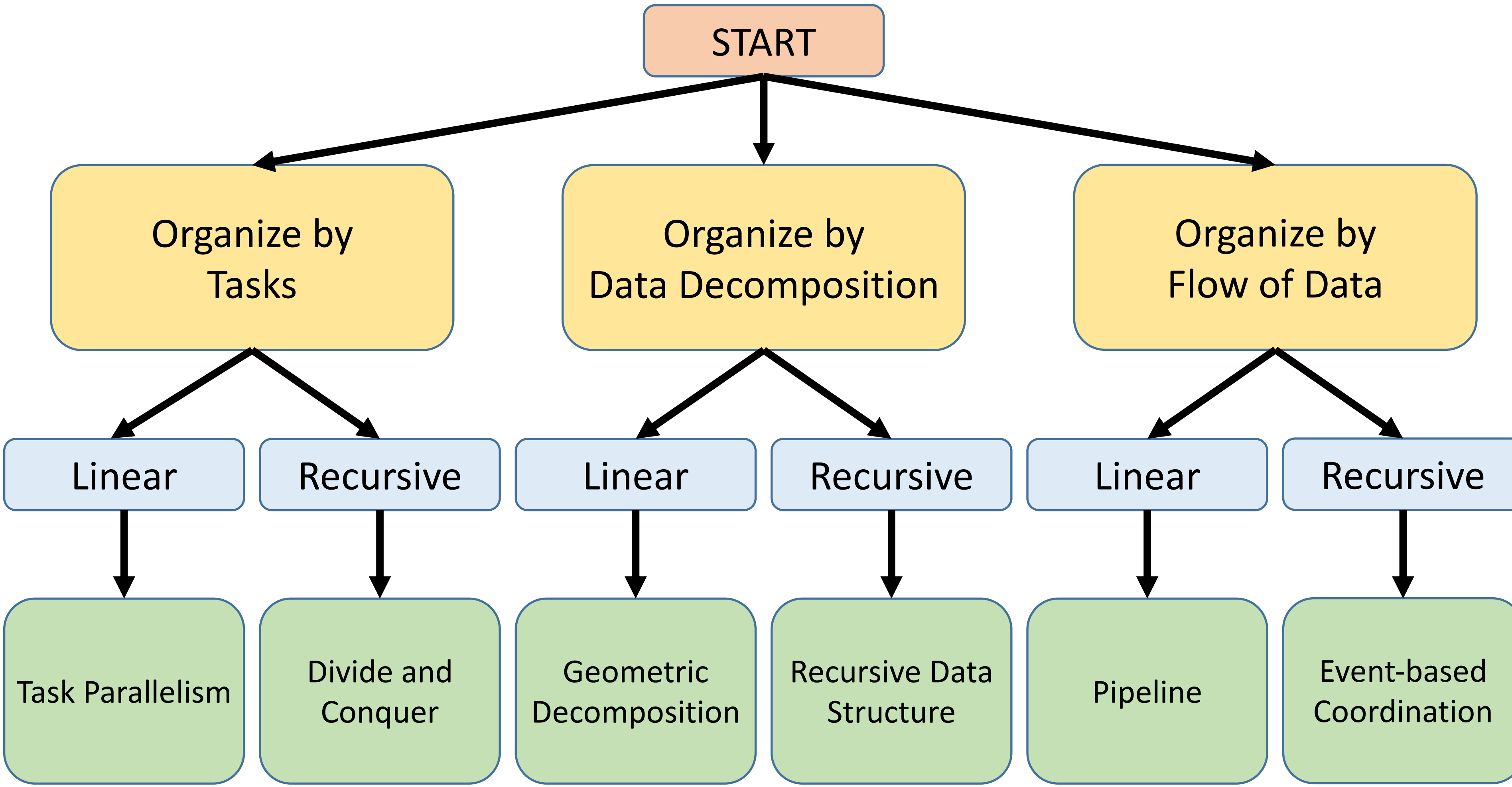
Common Data Decomposition



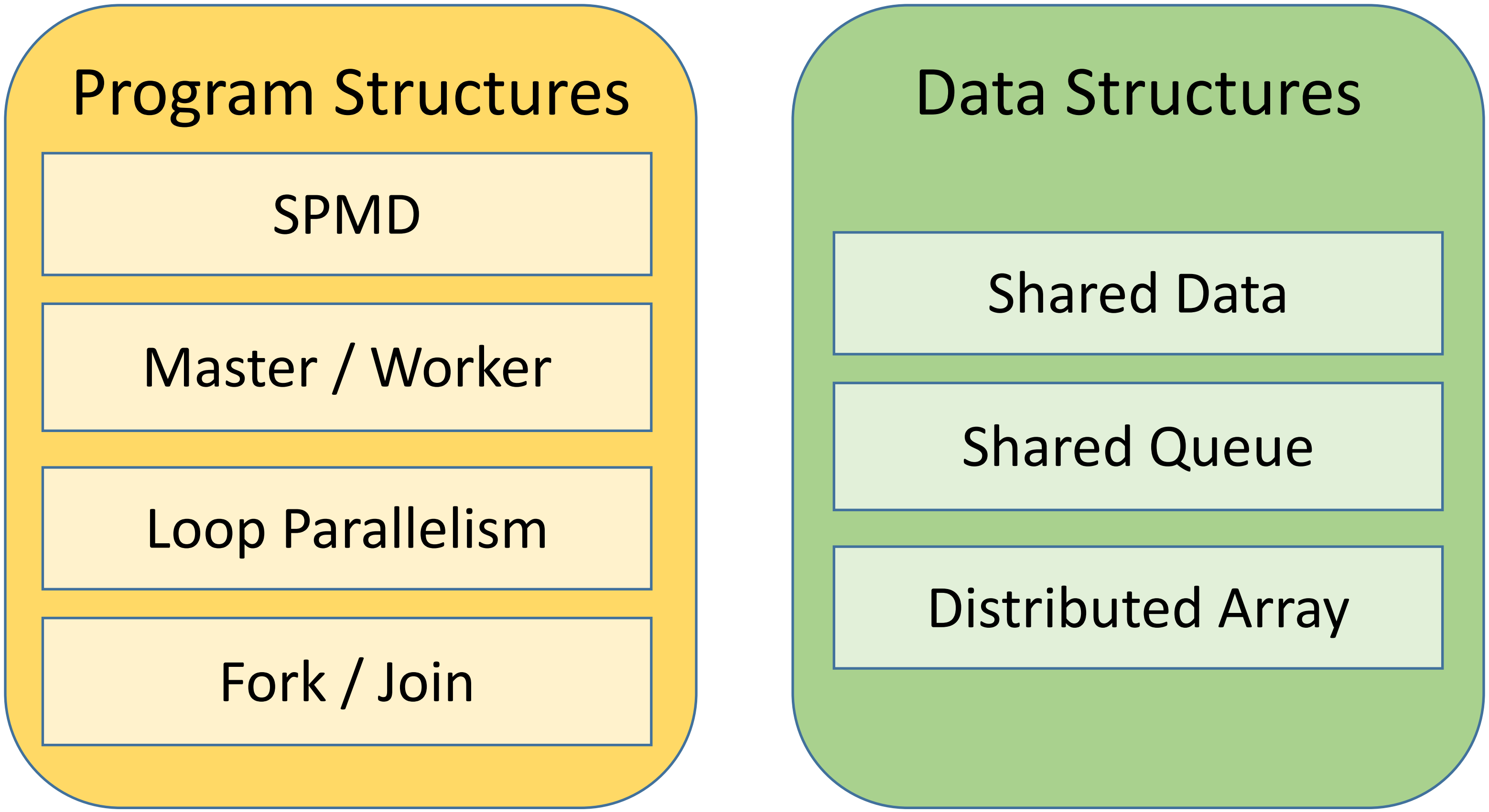
- Geometric data structures
  - Decomposition of n-dimensional arrays along rows, column, blocks

- Recursive data structures
  - Example: list, tree, graph

2. Algorithmic Structure Design Space



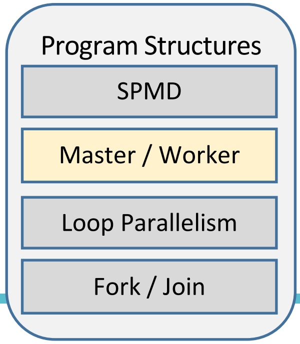
3. Implement the algorithm in a suitable progr. environment



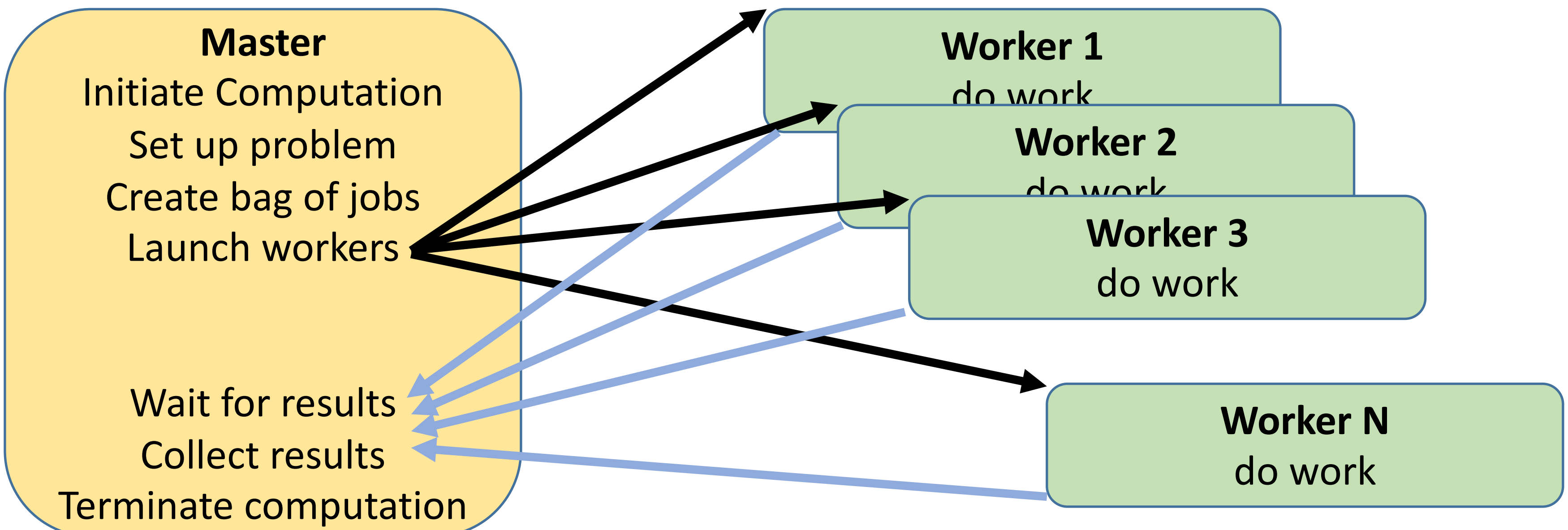
SPMD Pattern

- Single program, multiple data
- All tasks execute the same program in parallel, but each has its own set of data
  - Initialize
  - Obtain a unique identifier
  - Run the same program each processor
    - Operate on distributed data
    - Try to use local accumulators
  - Finalize
    - Merge partial results
- CUDA

Master / Worker Pattern



- A master process or thread set up a pool of worker processes of threads and a bag of tasks
- The workers execute concurrently, with each worker repeatedly removing a tasks from the bag of the tasks
- Embarrassingly parallel problems



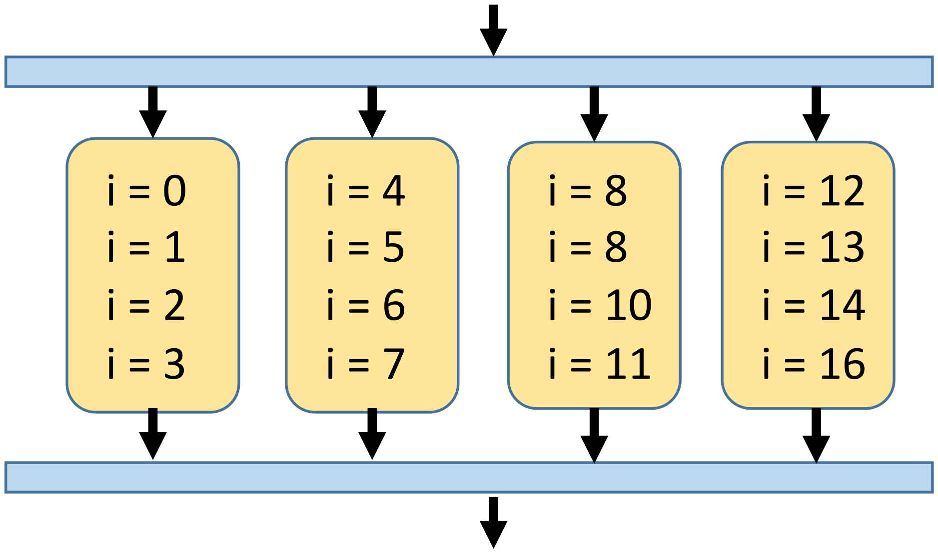
Loop Parallelism Pattern

Program Structures

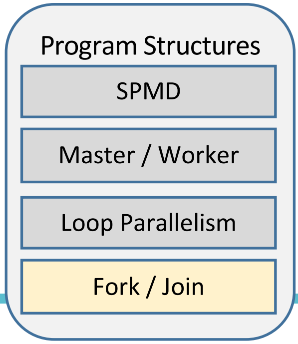
- SPMD
- Master / Worker
- Loop Parallelism
- Fork / Join

- Many programs are expressed using iterative constructs
  - Programming models like OpenMP provide directives to automatically assign loop iteration to execution units
  - Especially good when code cannot be massively restructured

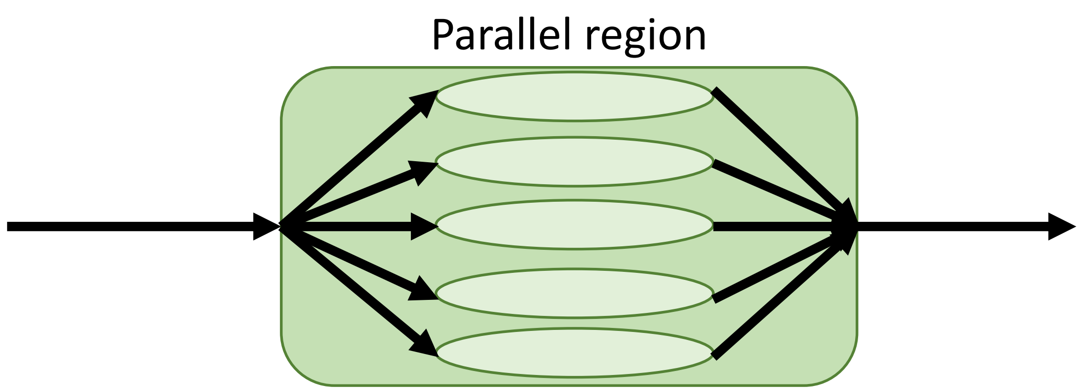
```
#pragma omp parallel for
for (i = 0; i < 16; i++)
    c[i] = A[i]+B[I];
```



Fork / Join Pattern



- A main task forks off some number of other tasks that then continue in parallel to accomplish some portion of the overall work
- Parent tasks creates new tasks (fork) then waits until all they complete (join) before continuing with the computation



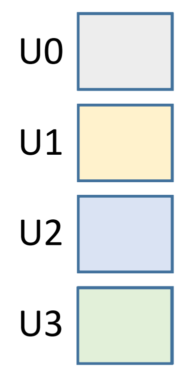
Pipeline Pattern

Program Structures
- SPMD
- Master / Worker
- Loop Parallelism
- Fork / Join
- Pipeline

- Tasks are applied in sequence to data

- Examples:
  - Instruction pipeline in modern CPUs
  - Algorithm level pipelining
  - Signal processing
  - Graphics
  - Shell programs
    - cat sampleFile | grep “word” | wc

4 stages pipeline



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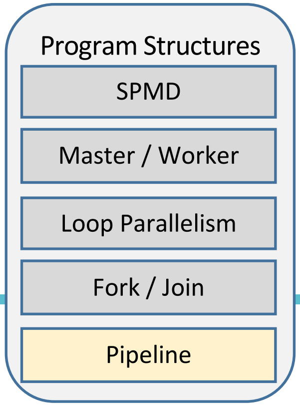

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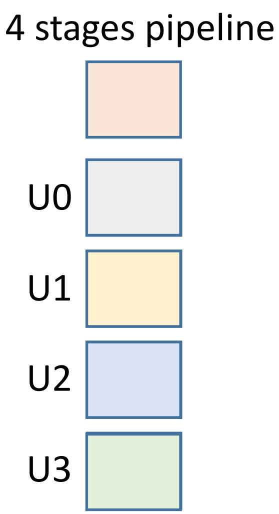

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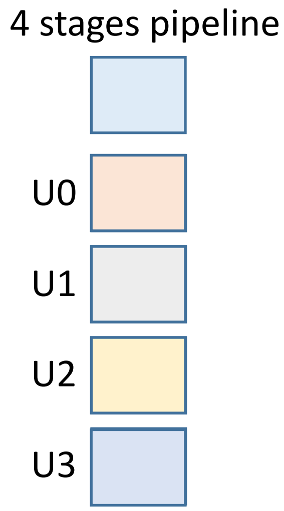

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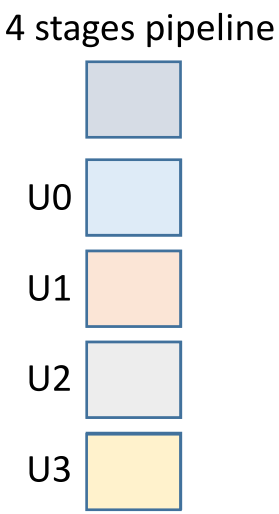

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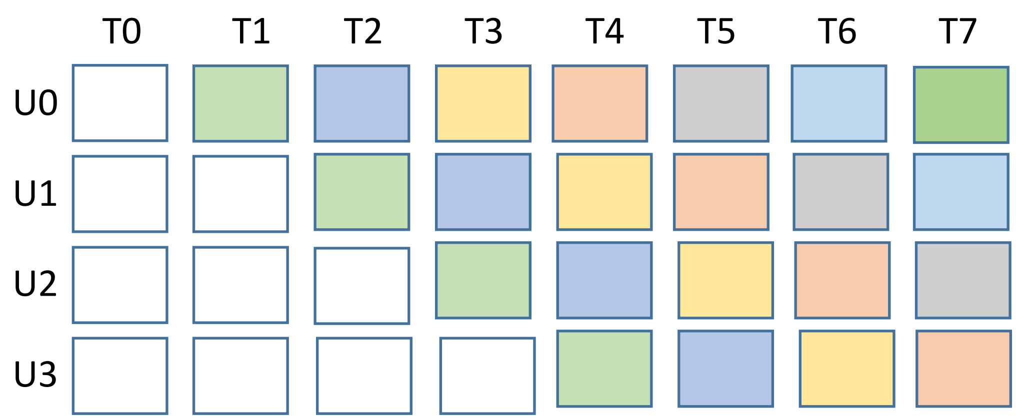
4 stages pipeline



Choosing the Patterns

Structure / Pattern	Task Parallel	Divide / Conquer	Geometric Decomp.	Recursive Data	Pipeline	Event-based
SPMD	☺ ☺ ☺ ☺	☺ ☺ ☺	☺ ☺ ☺ ☺	☺ ☺	☺ ☺ ☺	☺ ☺
Loop parallel	☺ ☺ ☺ ☺	☺ ☺	☺ ☺ ☺			
Master / Worker	☺ ☺ ☺ ☺	☺ ☺	☺	☺	☺	☺
Fork / Join	☺ ☺	☺ ☺ ☺ ☺	☺ ☺		☺ ☺ ☺ ☺	☺ ☺ ☺ ☺

Choosing the Programming Environment

Pattern \ Prog. Env.	OpenMP	MPI	CUDA
SPMD	☺ ☺ ☺	☺ ☺ ☺ ☺	☺ ☺ ☺ ☺ ☺
Loop parallel	☺ ☺ ☺ ☺	☺	
Master / Worker	☺ ☺	☺ ☺ ☺	
Fork / Join	☺ ☺ ☺		

3. The Implementations Mechanisms Design Space

Task Management
- Thread control
- Process control

Synchronization
- Mutual exclusion
- Monitors
- Barriers
- Non-blockin programming

Communication
- Shared memory
- Message passing
- Collective commun

The END