NOVA SCHOOL OF SCIENCE & TECHNOLOGY
COMPUTER SCIENCE DEPARTMENT

Parallel Programming Models and Architectures

lecture 01 (2021-03-15)

Master in Computer Science and Engineering

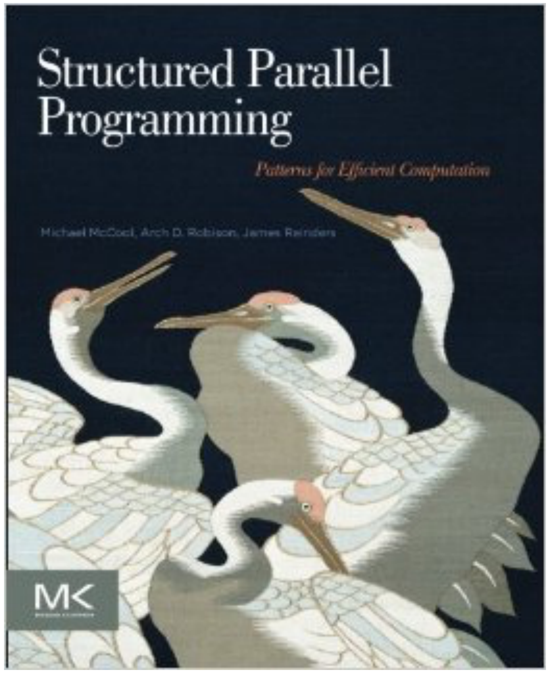
— Concurrency and Parallelism / 2020-21 —

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

Outline

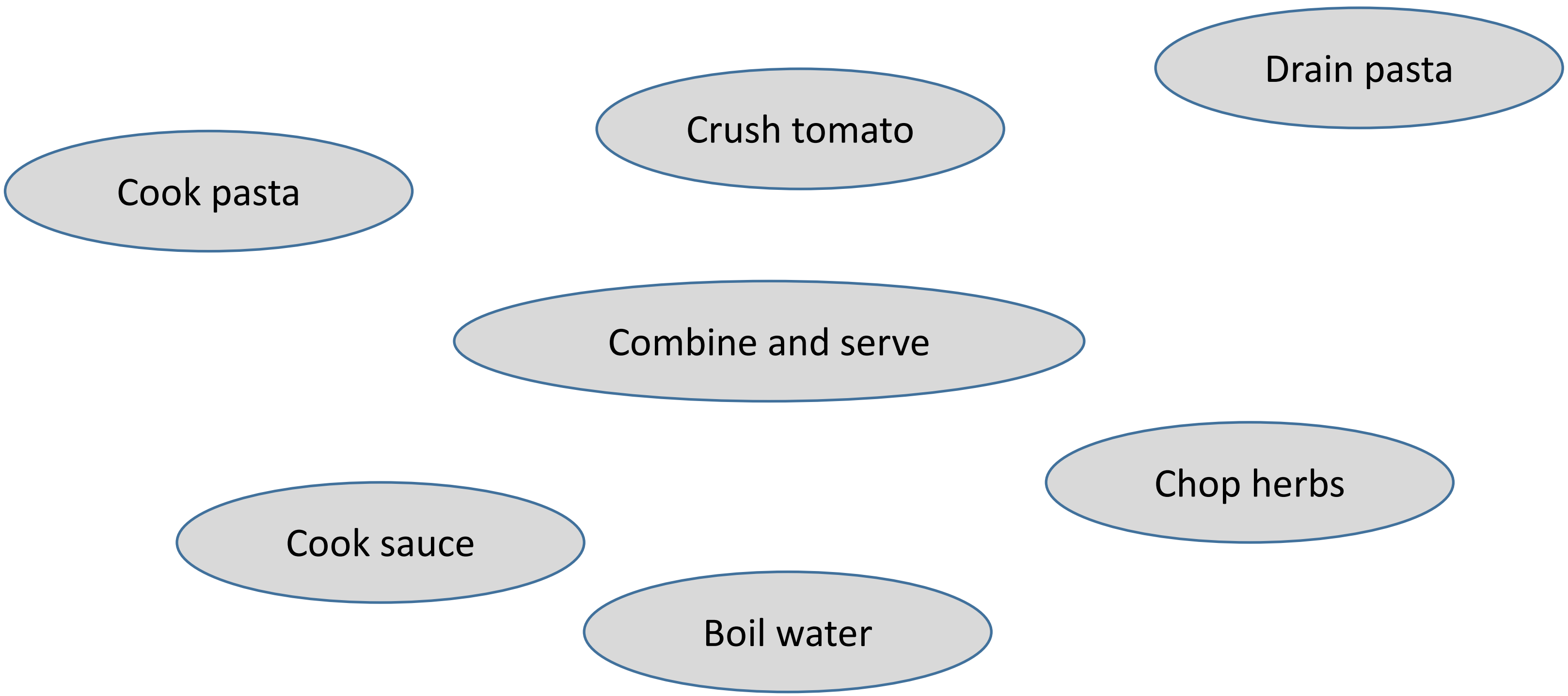
- Parallel Programming Models
- Parallel Architectures

  – Bibliography:
    - **Chapters 1 and 2** of book
      McCool M., Arch M., Reinders J.;
      Structured Parallel Programming: Patterns for Efficient Computation;
      Morgan Kaufmann (2012);
      ISBN: 978-0-12-415993-8



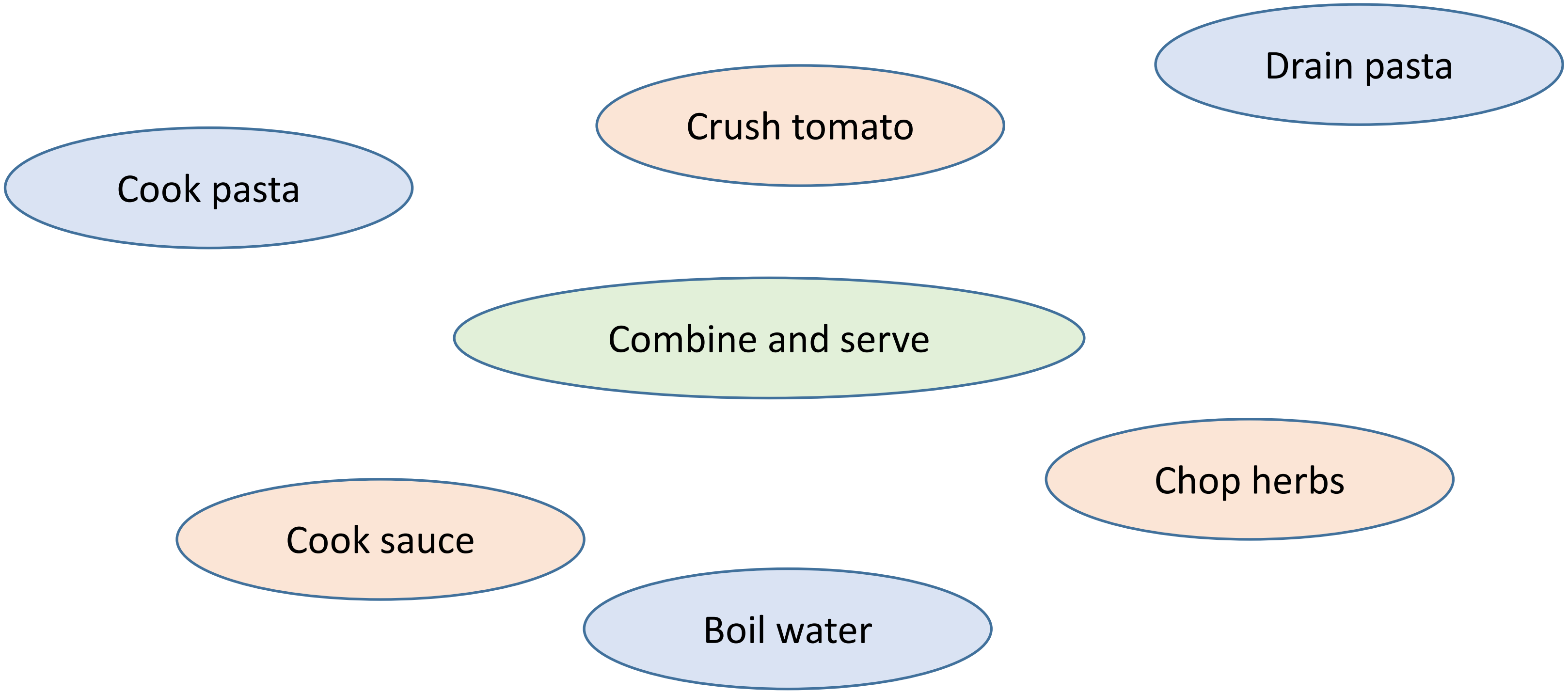
Parallel Computing

- Let's prepare a pasta



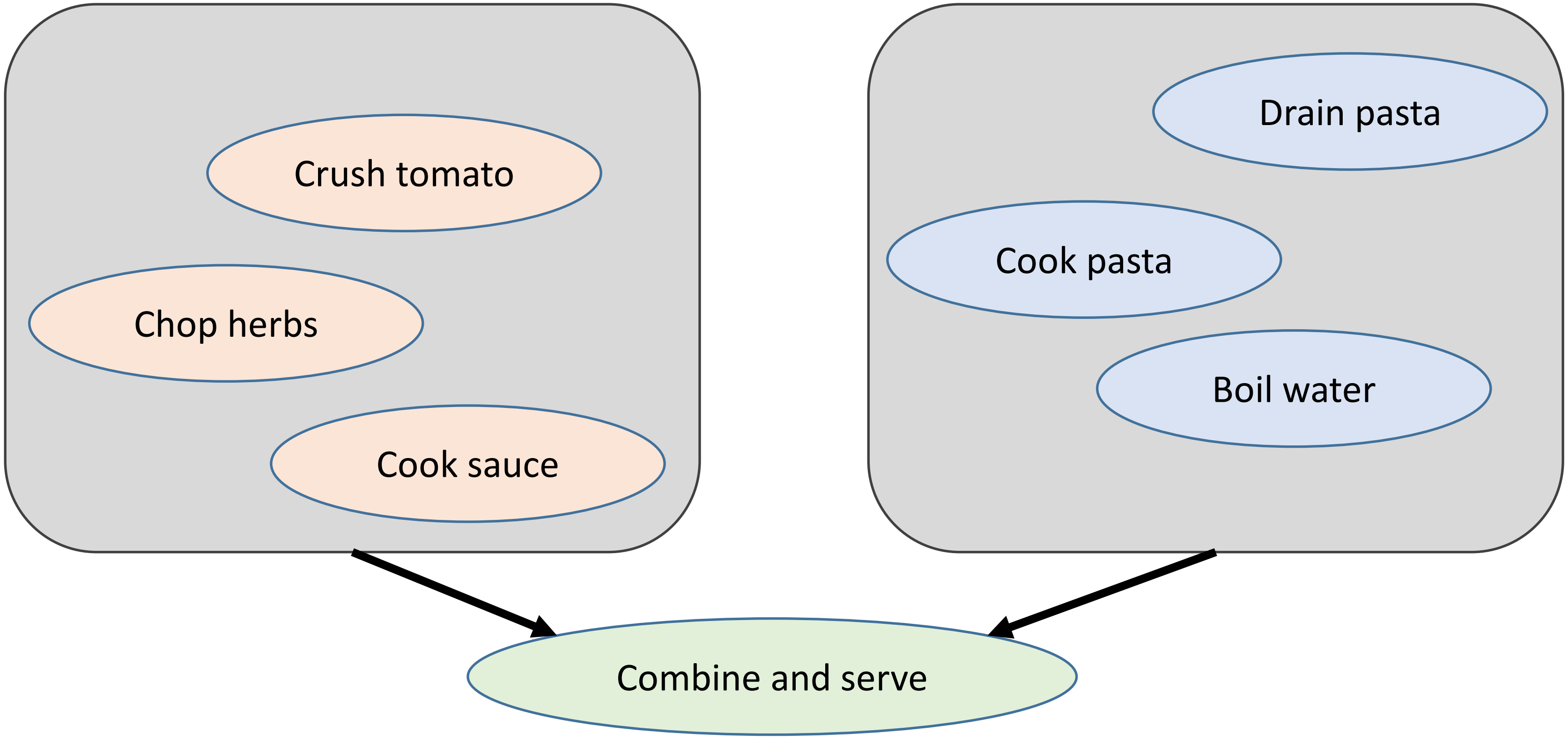
Parallel Computing

- Let's prepare a pasta



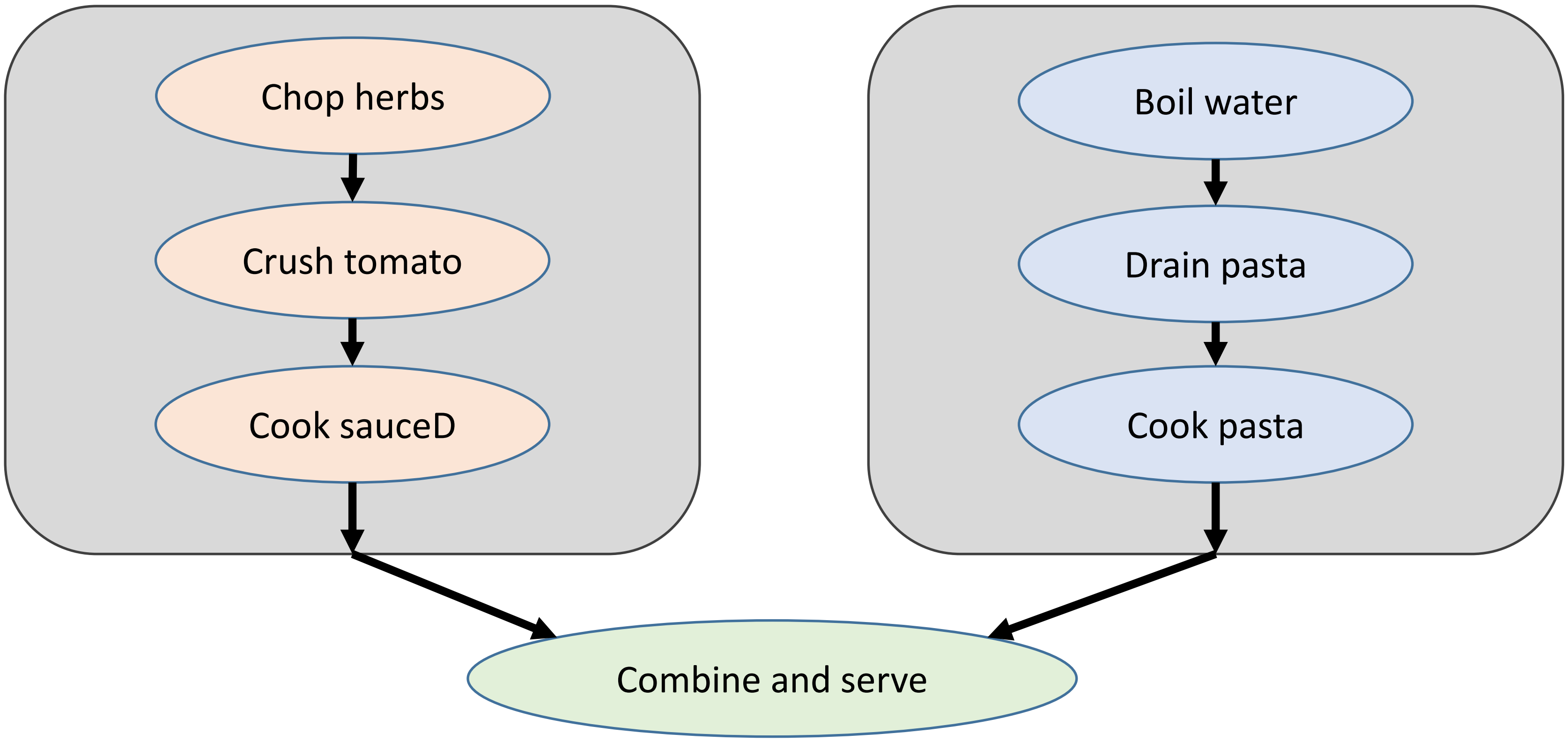
Parallel Computing

- Let's prepare a pasta



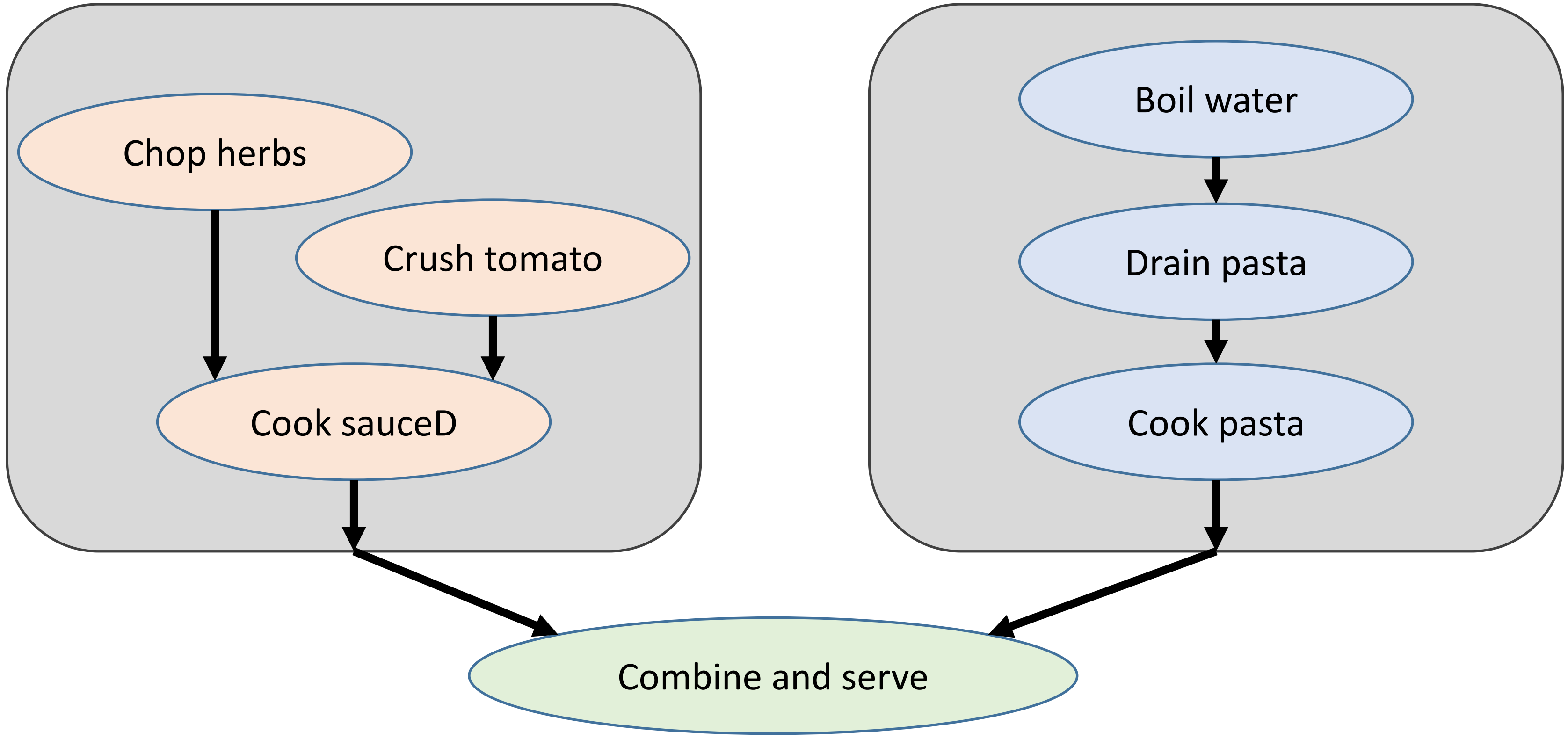
Parallel Computing

- Let's prepare a pasta



Parallel Computing

- Let's prepare a pasta



Car crash simulation example

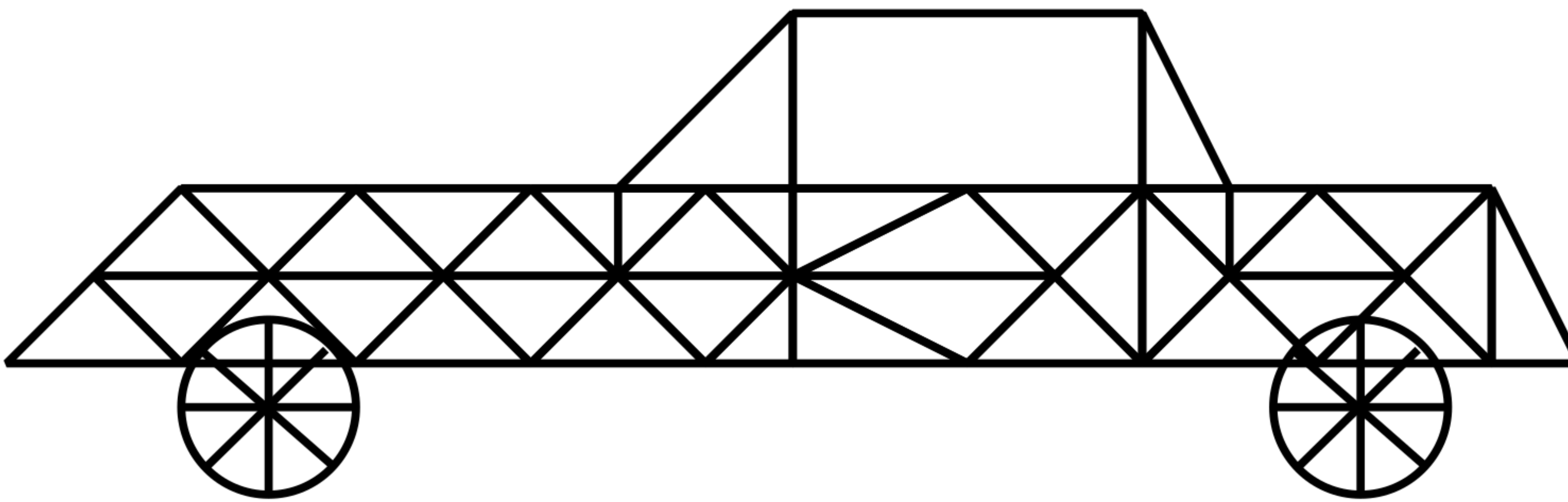
- Simplified model based on a crash simulation for the Ford Motor Company
- Illustrates various aspects common to many simulations and applications

- This example was provided by Q. Stout and C. Jablonowski of the University of Michigan

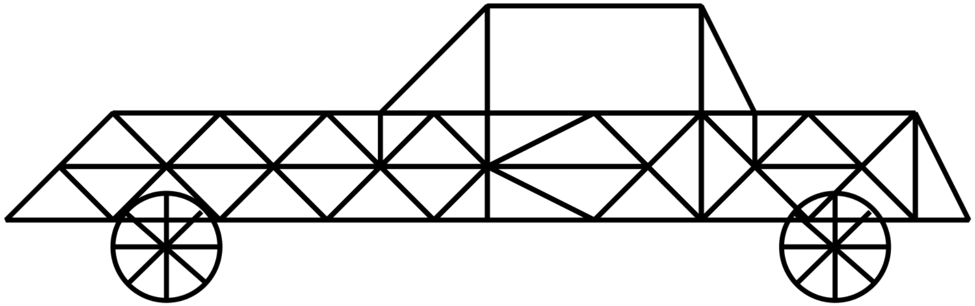
Finite Element Representation

- Car is modeled by a triangulated surface (elements)
- The simulation models the movement of the elements, incorporating the forces on the elements to determine their new position
- In each time step, the movement of each element depends on its interaction with the other elements to which it is physically adjacent
- In a crash, elements may end up touching other elements that were not touching initially
- The state of an element is its location, velocity, and information such as whether it is metal that is bending

(Sequential) Car



Serial Crash Simulation

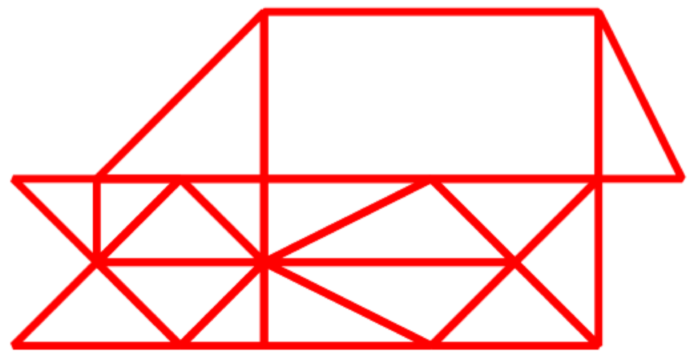


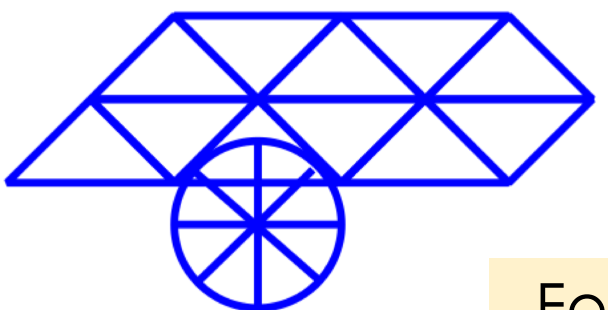
```
for all elements
   read ( State(element), Properties(element), Neighbor_list(element) )
   for step=1 to end_of_simulation
      for element=1 to num_elements
         Compute State(element) for next step,
         based on the previous state of the element
         and its neighbors and the properties of the element
```

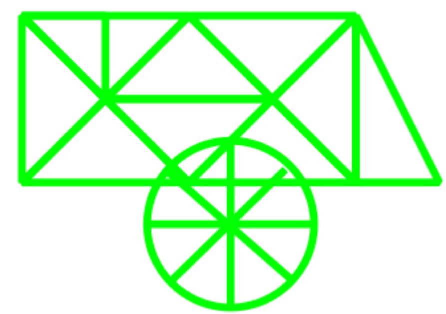
Simple Approach to Paralleization

- **Distributed Memory** – Parallel system based on processors linked with a fast network; processors communicate via messages
- **Owner Computes** – Distribute elements to processors; each processor updates its own elements
- **Single Program Multiple Data (SPMD)** – All machines run the same program on independent data; dominant form of parallel computing

Split Car

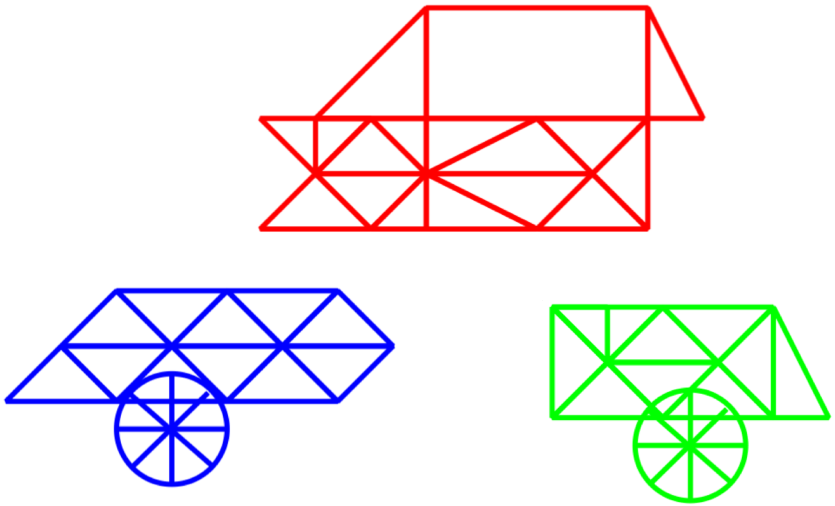






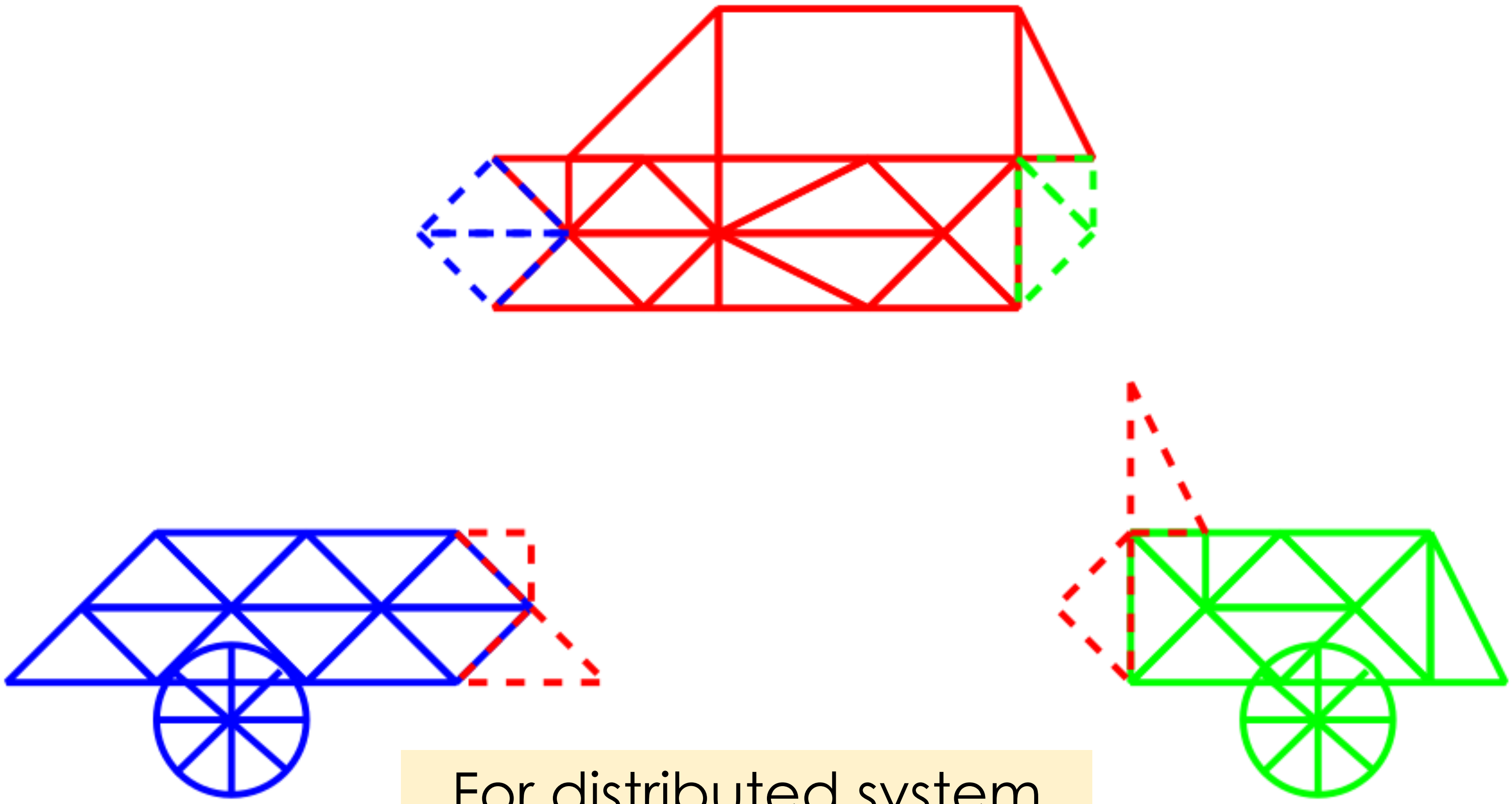
For shared memory

Basic Parallel Version



```
concurrently for all processors P
   for all elements assigned to P
      read ( State(element), ProperCes(element), Neighbor- list(element) )
      for step=1 to end_of_simulaCon
         for element=1 to num_elements_in_P
            Compute State (element) for next step, based on previous state
            of element and its neighbors, and on properties of the element
```

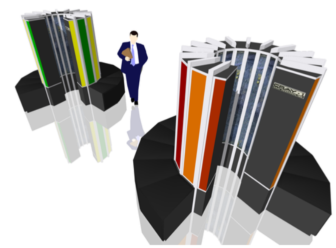
Distributed Car (w/ ghost cells)



For distributed system

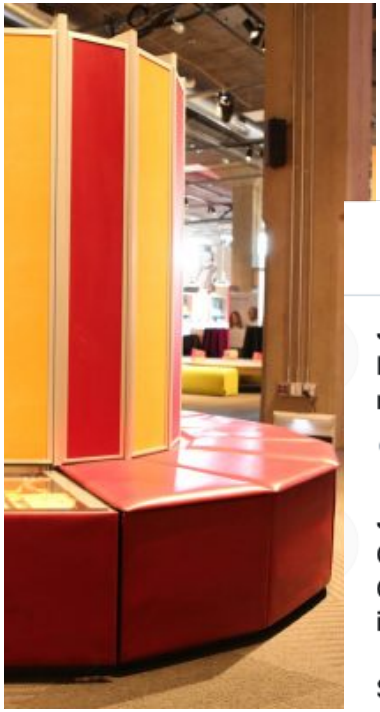
CRAY-1 Vector Machine (1976)

Cray-1



3D rendering of two Cray-1 with a figure as scale

Design	
Manufacturer	Cray Research
Designer	Seymour Cray
Release date	1975
Units sold	Over 80
Price	US$7.9 million in 1977 (equivalent to $33.3 million in 2019)
Casing	
Dimensions	Height: 196 cm (77 in)[1] Dia. (base): 263 cm (104 in)[1] Dia. (columns): 145 cm (57 in)[1]
Weight	5.5 tons (Cray-1A)
Power	115 kW @ 208 V 400 Hz[1]
System	
Front-end	Data General Eclipse
Operating system	COS & UNICOS
CPU	64-bit processor @ 80 MHz[1]
Memory	8.39 Megabytes (up to 1 048 576 words)[1]
Storage	303 Megabytes (DD19 Unit)[1]
FLOPS	160 MFLOPS
Successor	Cray X-MP



Search Twitter

Jason Huggins @hugs · Dec 17, 2014

If a car's power is measured in horsepower, a computer's power should be measured in crays. youtu.be/atIKUEfW-Vw (iPhone 6 = 1440 Cray-1s)

2 3 3

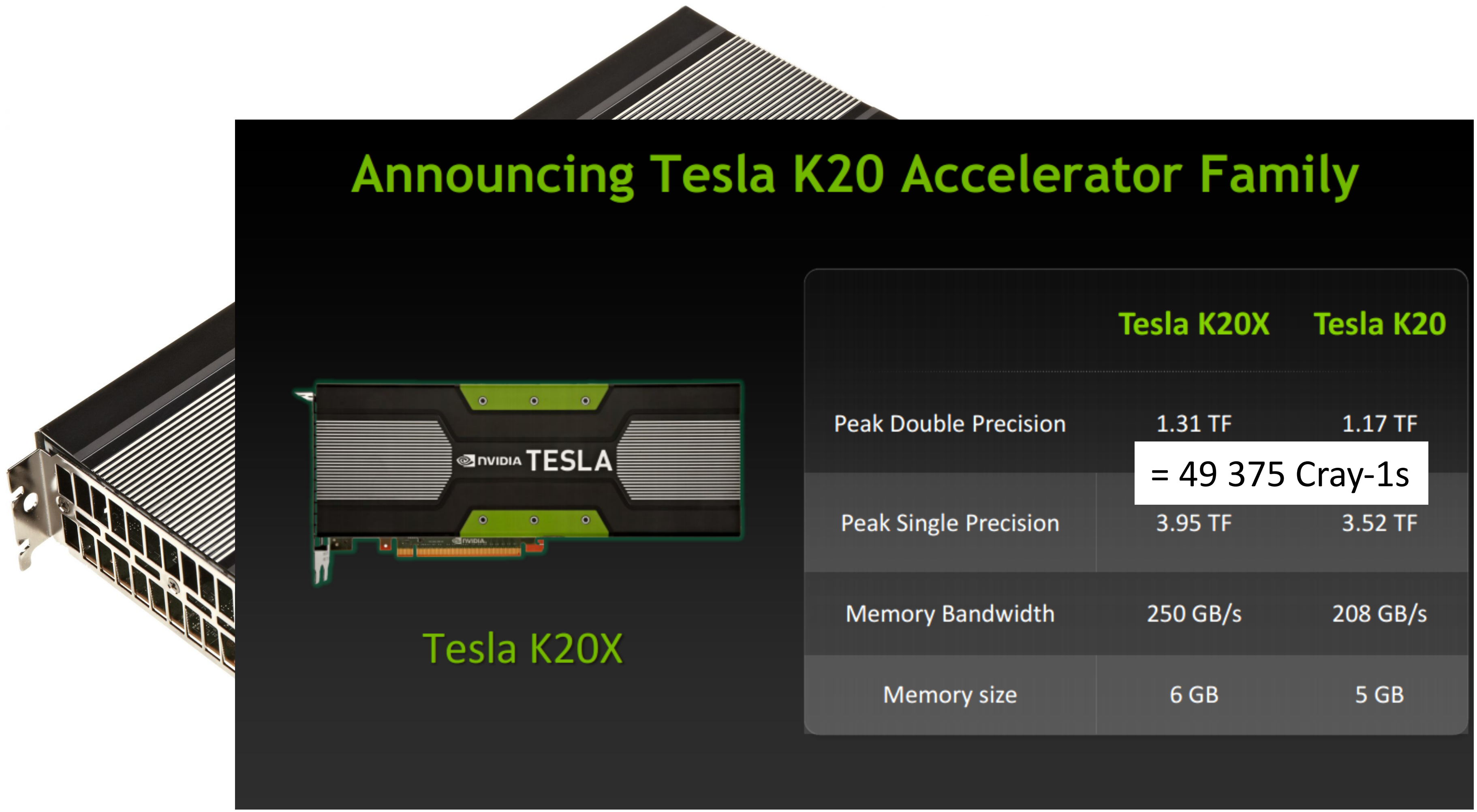
Jason Huggins @hugs · Dec 17, 2014

Cray-1: 80 MFLOPS
Cray-2: 1.9 GFLOPS
iPhone 6: 115.2 GFLOPS

Sources:
en.wikipedia.org/wiki/Cray-1
en.wikipedia.org/wiki/Cray-2
en.wikipedia.org/wiki/Apple_sys...

3 6 7

Vector Machines Today



	Tesla K20X	Tesla K20
Peak Double Precision	1.31 TF	1.17 TF
Peak Single Precision	3.95 TF	3.52 TF
Memory Bandwidth	250 GB/s	208 GB/s
Memory size	6 GB	5 GB

= 49 375 Cray-1s

Flynn's Taxonomy

- Single Instruction, Single Data (SISD) architecture

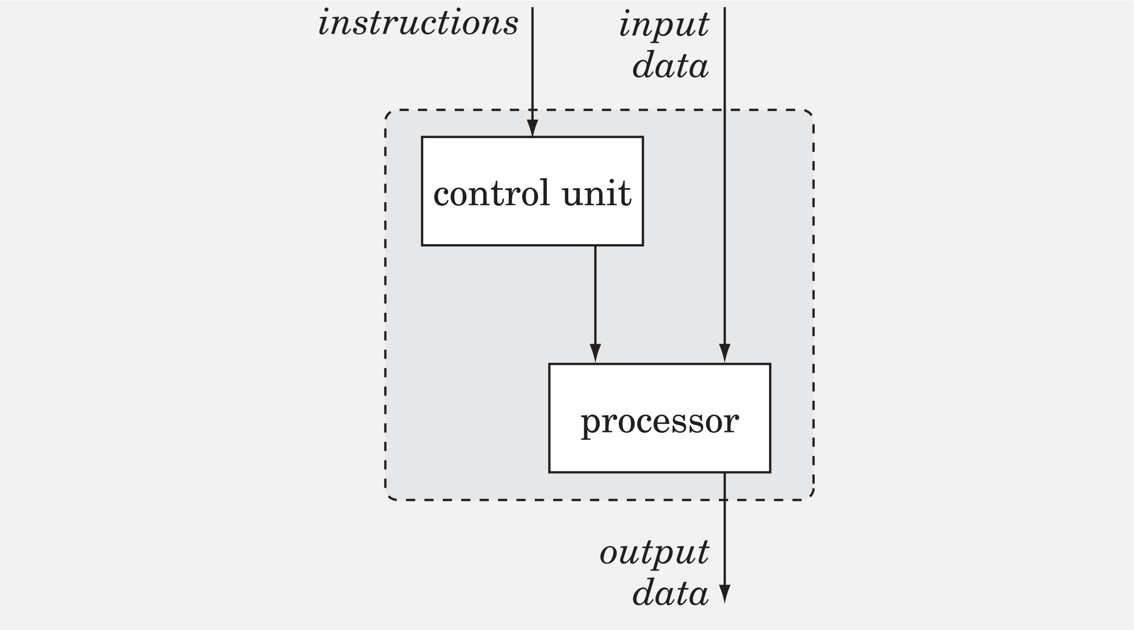


Image from: Mattson T., Sanders B., Massingill B.; Patterns for Parallel Programming; Addison-Wesley(2004).

Flynn's Taxonomy

- Single Instruction, Multiple Data (SIMD) architect.

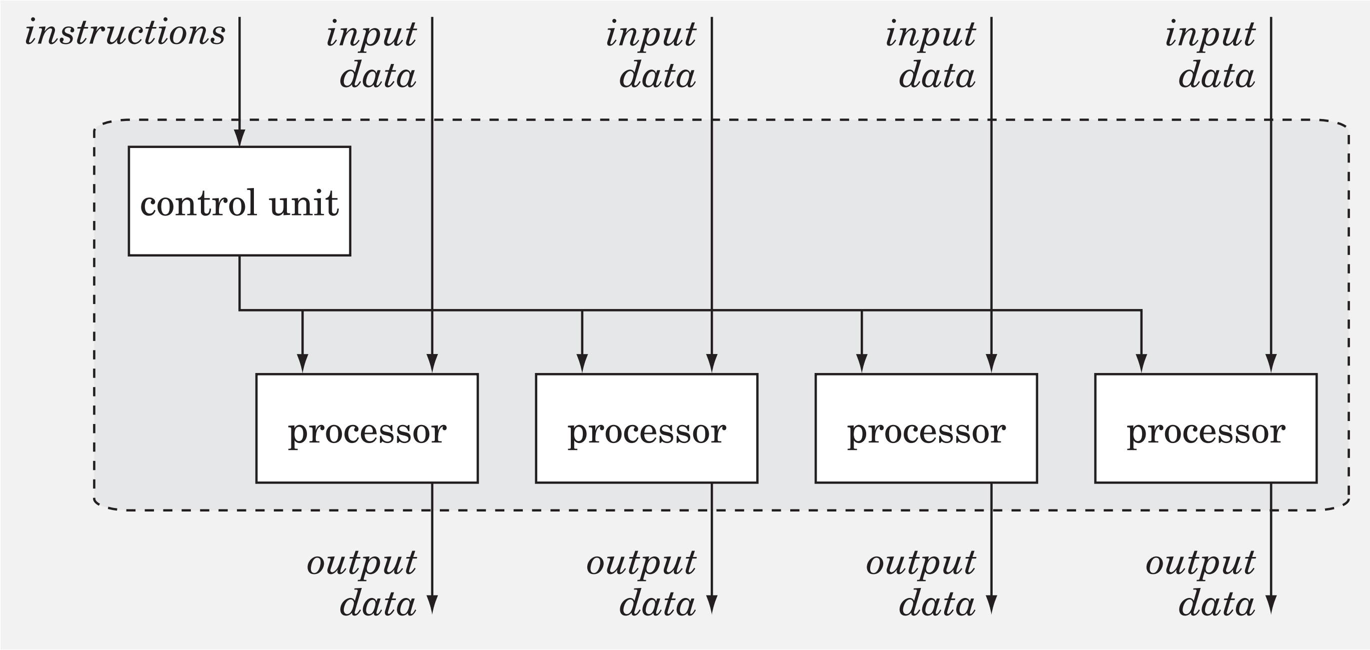
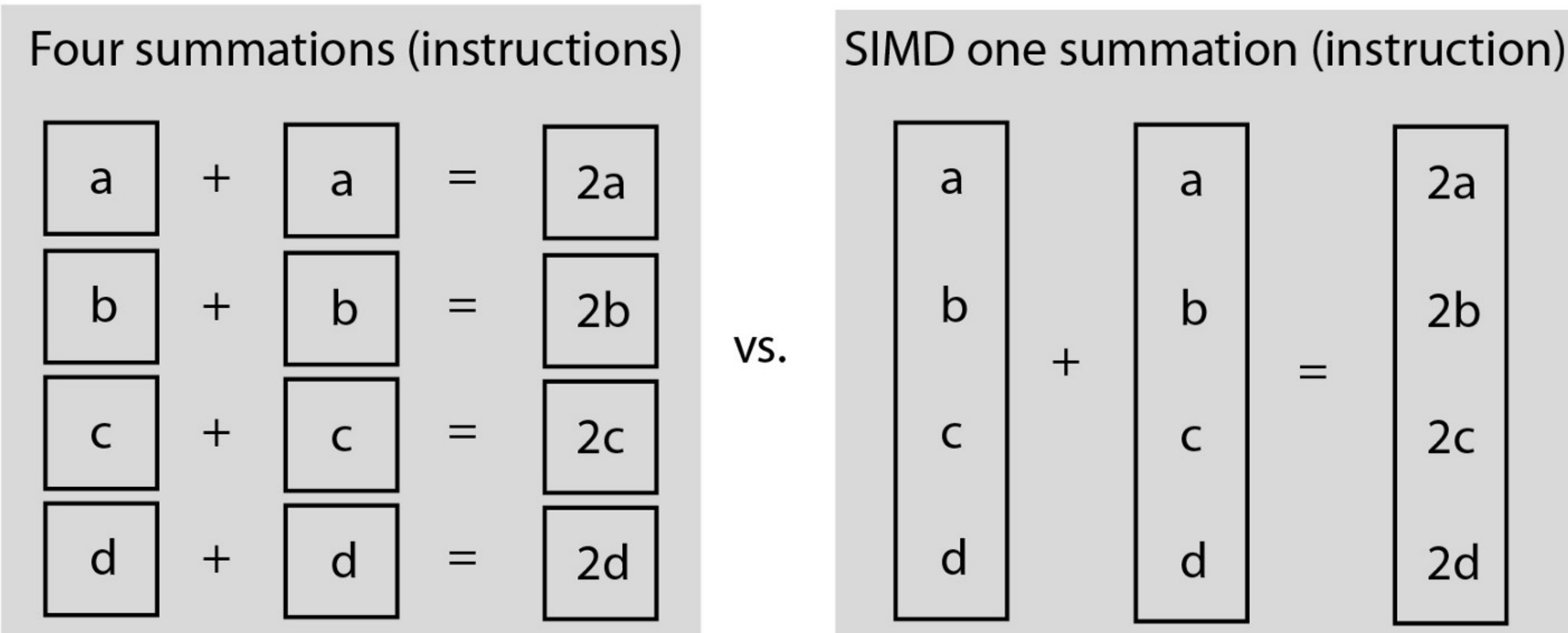


Image from: Mattson T., Sanders B., Massingill B.; Patterns for Parallel Programming; Addison-Wesley(2004).

SISD vs. SIMD - example



Flynn's Taxonomy

- Multiple Instruction, Single Data (MISD)

Flynn's Taxonomy

- Multiple Instruction, Multiple Data (MIMD) archit.

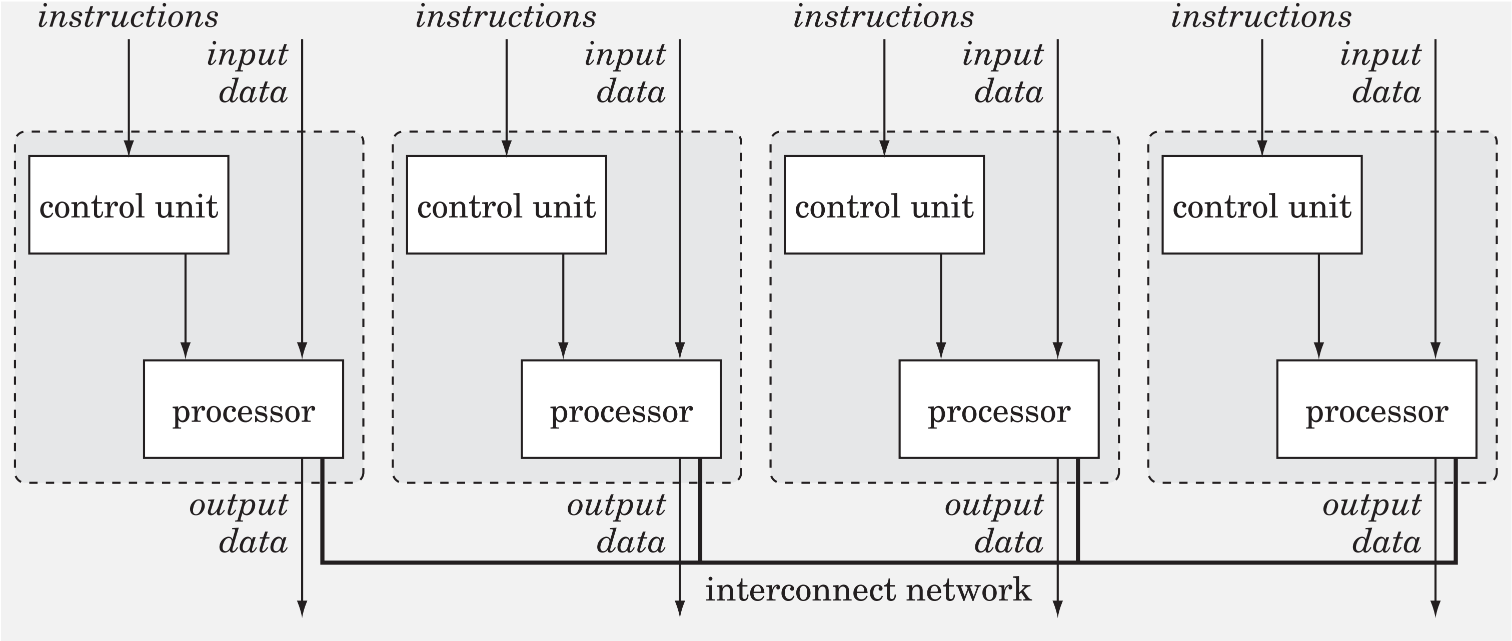


Image from: Mattson T., Sanders B., Massingill B.; Patterns for Parallel Programming; Addison-Wesley(2004).

Parallel Architectures

- The Symmetric Multiprocessor (SMP) architecture

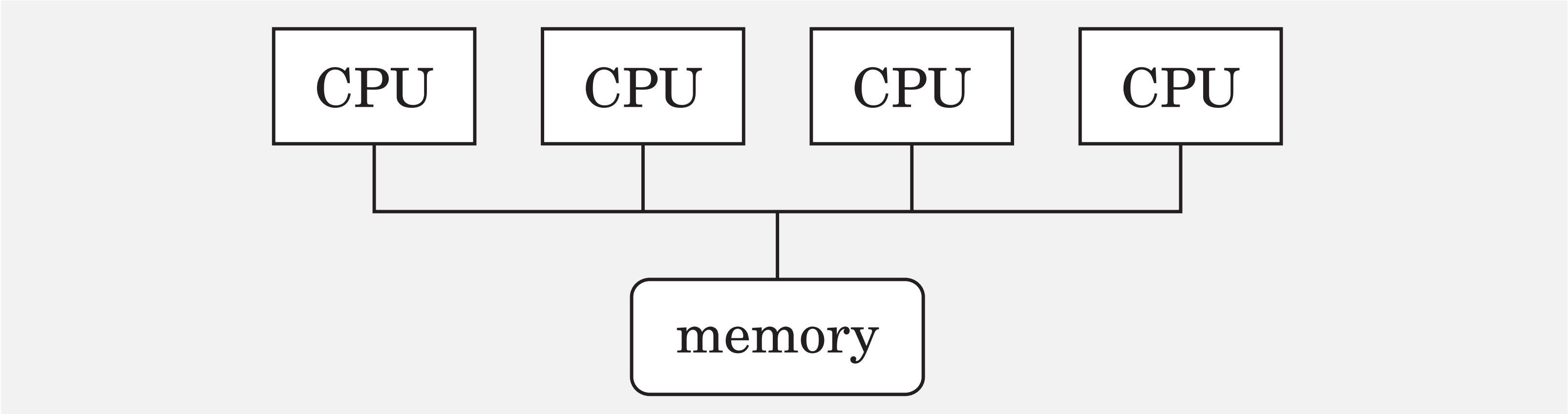


Image from: Mattson T., Sanders B., Massingill B.; Patterns for Parallel Programming; Addison-Wesley(2004).

Parallel Architectures

- Nonuniform memory access (NUMA) architect.

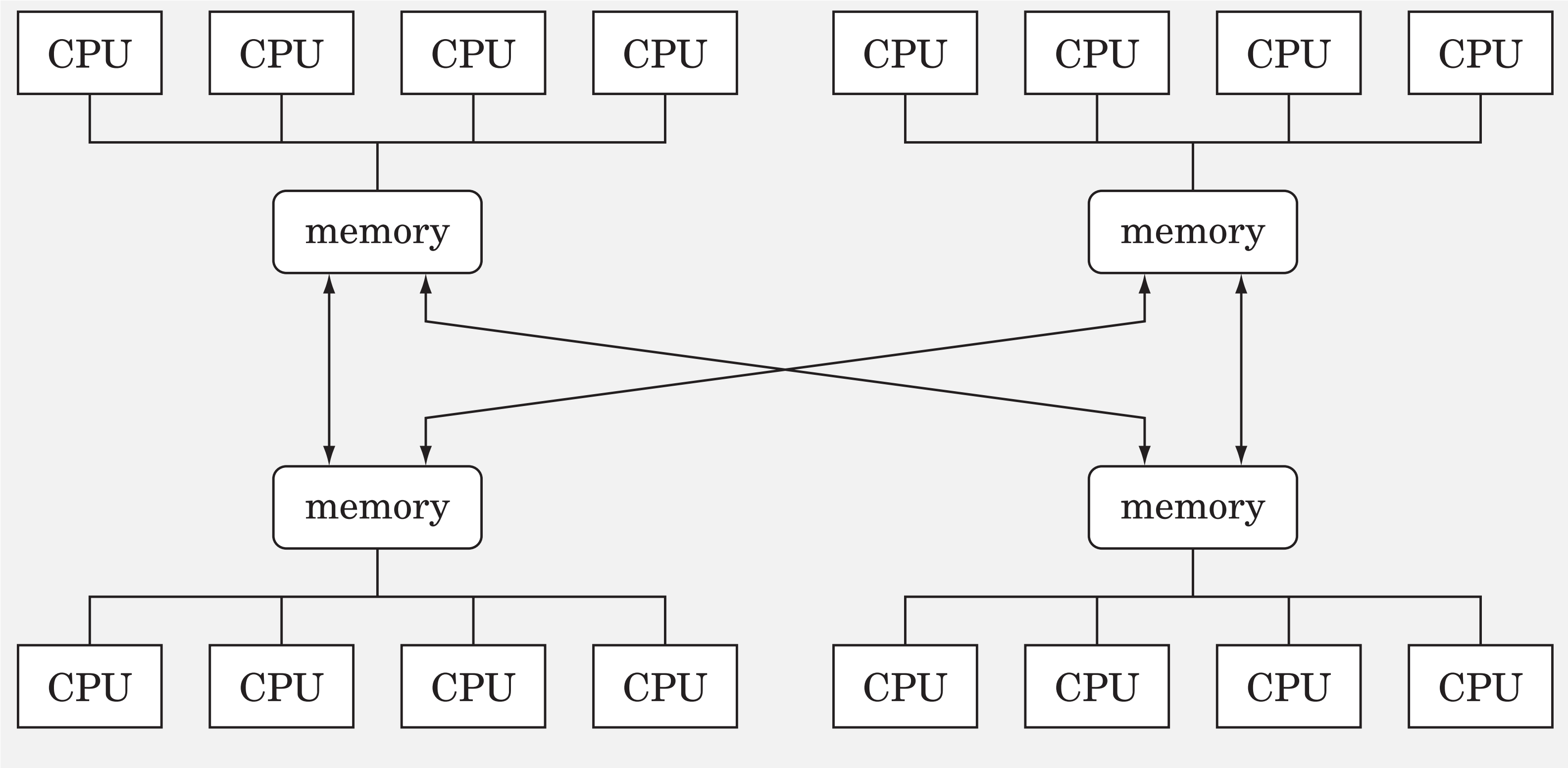


Image from: Mattson T., Sanders B., Massingill B.; Patterns for Parallel Programming; Addison-Wesley(2004).

Parallel Architectures

- Nonuniform memory access (NUMA) architect.

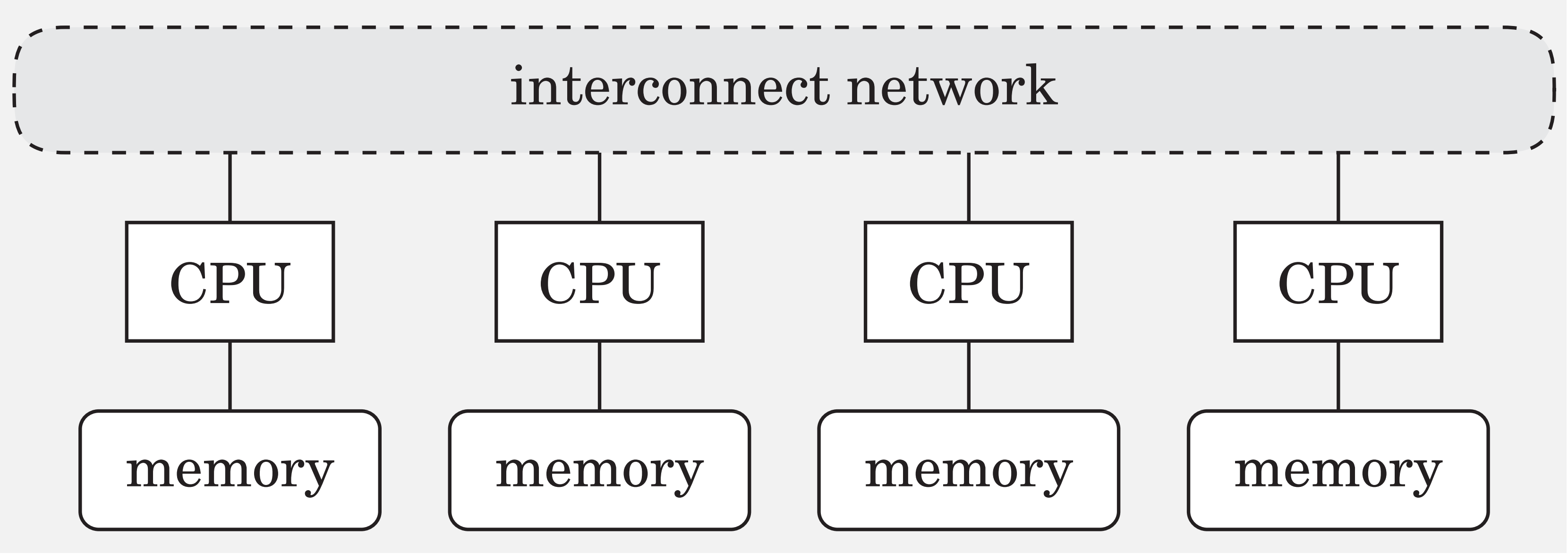


Image from: Mattson T., Sanders B., Massingill B.; Patterns for Parallel Programming; Addison-Wesley(2004).

Software Taxonomies

- Data Parallel (SIMD)
  - Parallelism that is a result of identical operations being applied concurrently on different data items; e.g., many matrix algorithms
  - Difficult to apply to complex problems
- Single Program, Multiple Data (SPMD)
  - A single application is run across multiple processes/threads on a MIMD architecture
  - Most processes execute the same code but do not work in lock-step
  - Dominant form of parallel programming

Shared Memory (SM)

- Attributes:
  - Global memory space
  - Each processor will utilize its own cache for a portion of global memory; consistency of the cache is maintained by hardware
- Advantages:
  - User-friendly programming techniques (OpenMP and OpenACC)
  - Low latency for data sharing between tasks
- Disadvantages:
  - Global memory space-to-CPU path may be a bottleneck
  - Non-Uniform Memory Access
  - Programmer responsible for synchronization

Distributed Memory (DM)

- Attributes:
  - Memory is shared amongst processors through message passing
- Advantages:
  - Memory scales based on the number of processors
  - Access to a processor's own memory is fast
  - Cost effective
- Disadvantages:
  - Error prone; programmers are responsible for the details of the communication
  - Complex data structures may be difficult to distribute

Hardware/Software Models

- **Software and hardware models do not need to match**
- DM software on SM hardware:
  - Message Passing Interface (MPI) - designed for DM Hardware but available on SM systems
- SM software on DM hardware
  - Remote Memory Access (RMA) included within MPI-3
  - Partitioned Global Address Space (PGAS) languages
    - Unified Parallel C (extension to ISO C 99)
    - Coarray Fortran (Fortran 2008)

Difficulties

- Serialization causes bottlenecks
- Workload is not distributed
- Debugging is hard
- Serial approach doesn't parallelize

The END