CMSC 714
High Performance Computing
Lecture 1 - Introduction

https://www.cs.umd.edu/class/fall2023/cmsc714

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Introduction

- Class is an introduction to parallel computing
  - Seminar style, on history and recent advances
  - topics include: programming models, hardware, applications, compilers, system software, and tools
- Qualifying course for MS/PhD: Computer Systems
- Work required
  - small programming assignments (two) – MPI and OpenMP
  - Midterm exam
  - classroom participation
    - Everyone will have to prepare questions for the readings for several classes (3 students per class with readings), and help explain the papers
  - group project (3 students per group)

Course Topics

- Introduction to parallel computing – 1 week
- Programming Models – 3 weeks
- Parallel Architectures and Networks – 3 weeks
- Debugging and Instrumentation – 1 week
- Performance Tools – 2 weeks
- OS, Runtime Systems, and Parallel I/O – 2 weeks
- Commercial and Scientific Applications – 2 weeks

Additional class info

- Syllabus, lecture slides, project descriptions on course web site:
  - https://www.cs.umd.edu/class/fall2023/cmsc714/
- Project submissions via ELMS
- In-class midterm – date TBD soon
- Cluster accounts on university resource (zaratan) will be coming soon
  - You will log in with your UMD directory ID and password
  - Further instructions with first project

Introductions

- Name
- MS or PhD, and department
- Area of research
- Why this course?
- Something interesting /unique about yourself

What is Parallel Computing?

- Does it include:
  - super-scalar processing (more than one instruction at once)?
  - vector processing (same instruction to several values)?
  - collection of PC's **not** connected to a (fast) network?
  - cloud computing?
  - Accelerators (GPUs, FPGAs)?

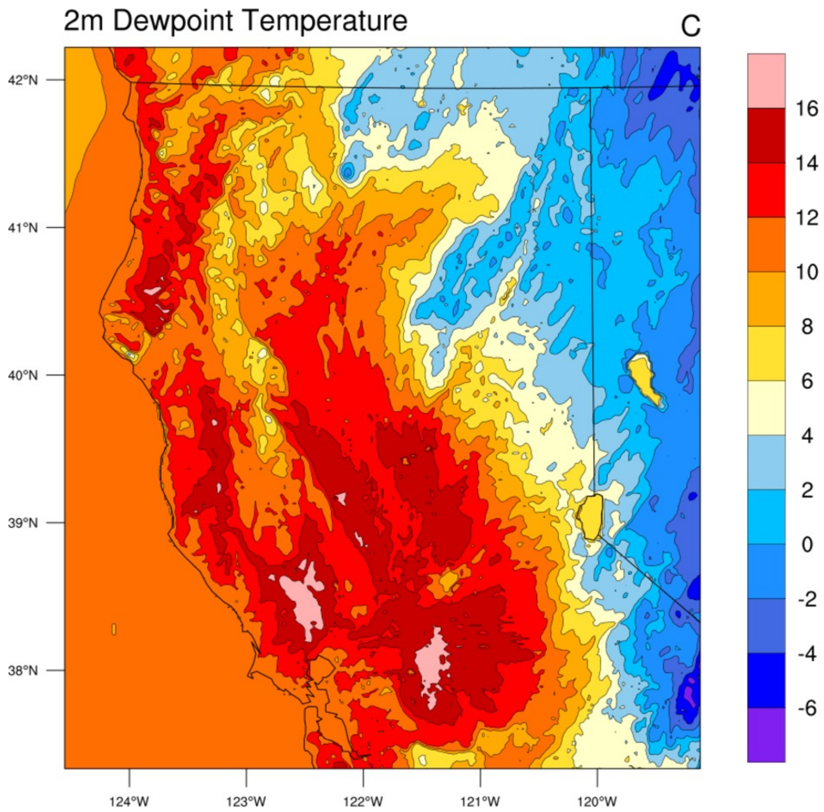
- For this class, parallel computing requires:
  - – more than one processing element/core
  - – nodes (with one or more cores) connected to a communication network
  - – nodes working together to solve a single problem
    - –Sometimes a single node is enough

Why Parallelism

- Speed
  - need to get results faster than possible with sequential
    - a weather forecast that is late is useless
  - could come from
    - more processing elements (P.E.'s)
    - more memory (or cache)
    - more disks/secondary storage
  - example is speeding up scientific simulations
  - another reason is to get results in (near) realtime
- Cost: cheaper to buy many smaller machines
  - this has been true for the last ~20 years due to
    - VLSI
    - commodity parts

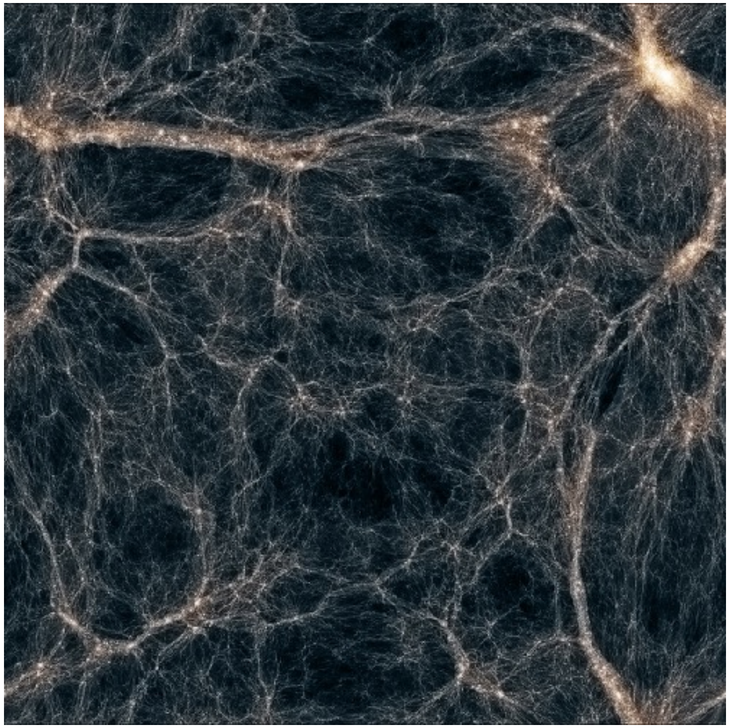
HPC is needed for real applications

Weather forecasting



https://www.ncl.ucar.edu/Applications/wrf.shtml

Cosmology studies



https://www.nas.nasa.gov/SC14/demos/demo27.html

Parallel Architecture

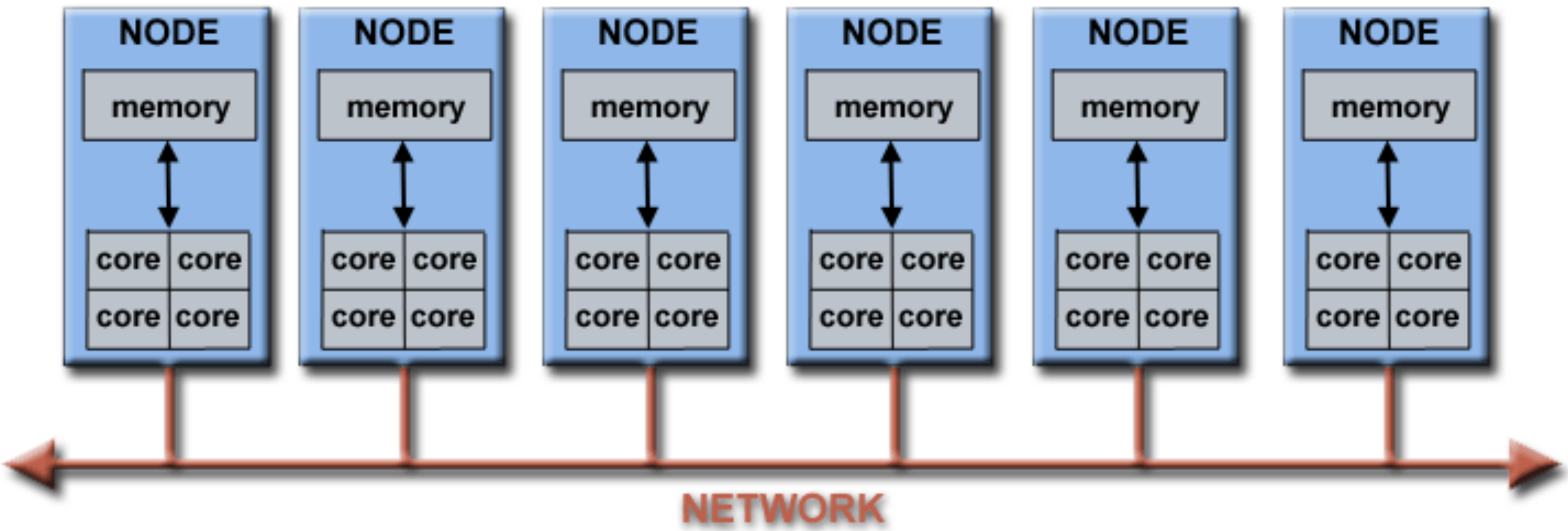
What Does a Parallel Computer Look Like?

- Hardware
  - processors
  - communication
  - memory
  - coordination

- Software
  - programming model
  - communication libraries
  - operating system

Parallel architecture – the current answer

- A set of nodes or processing elements connected by a network.



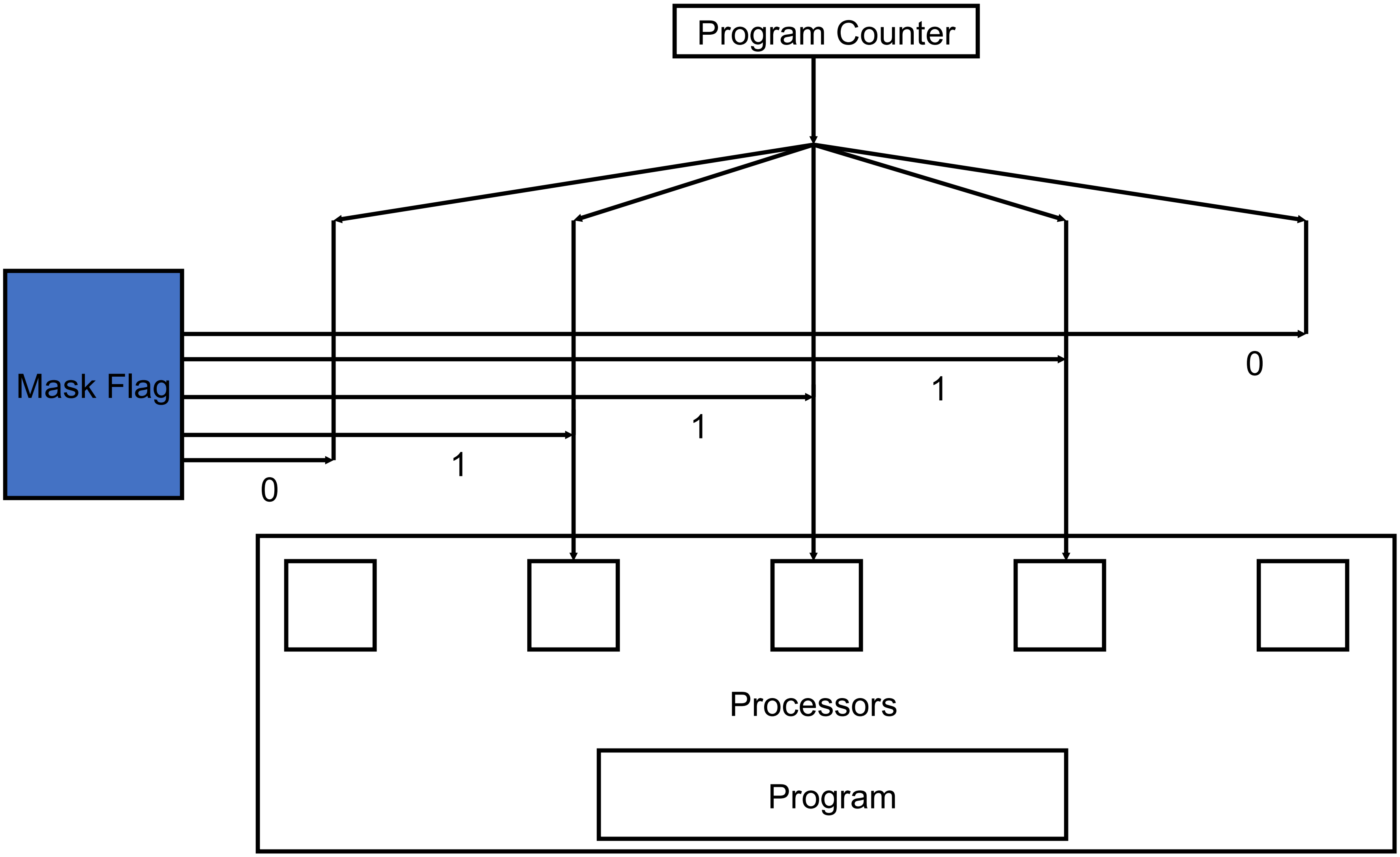
https://computing.llnl.gov/tutorials/parallel_comp

Processing Elements (PE)

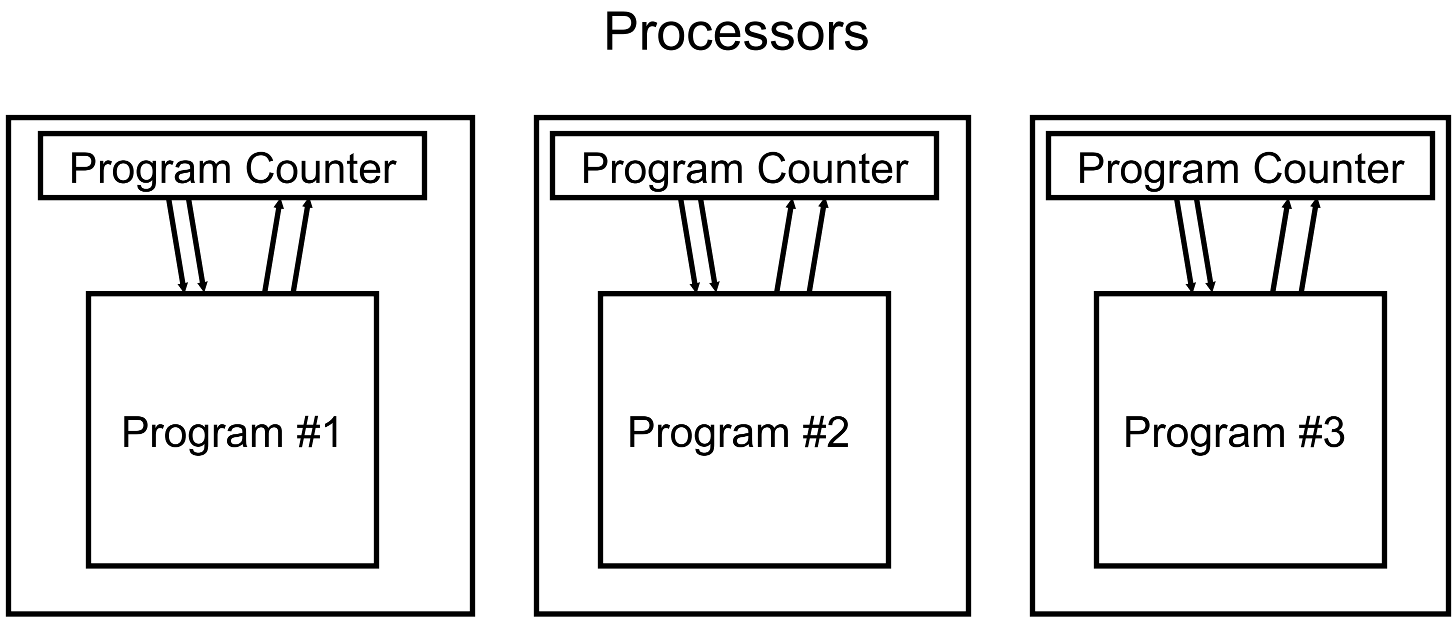
- Key Processor/Core Choices
  - How many?
  - How powerful?
  - Custom or off-the-shelf?

- Major Styles of Parallel Computing
  - SIMD - Single Instruction Multiple Data
    - one master program counter (PC)
  - MIMD - Multiple Instruction Multiple Data
    - separate code for each processor
  - SPMD - Single Program Multiple Data
    - same code on each processor, separate PC's on each
  - Dataflow – instruction (or code block) waits for operands
    - "automatically" finds parallelism

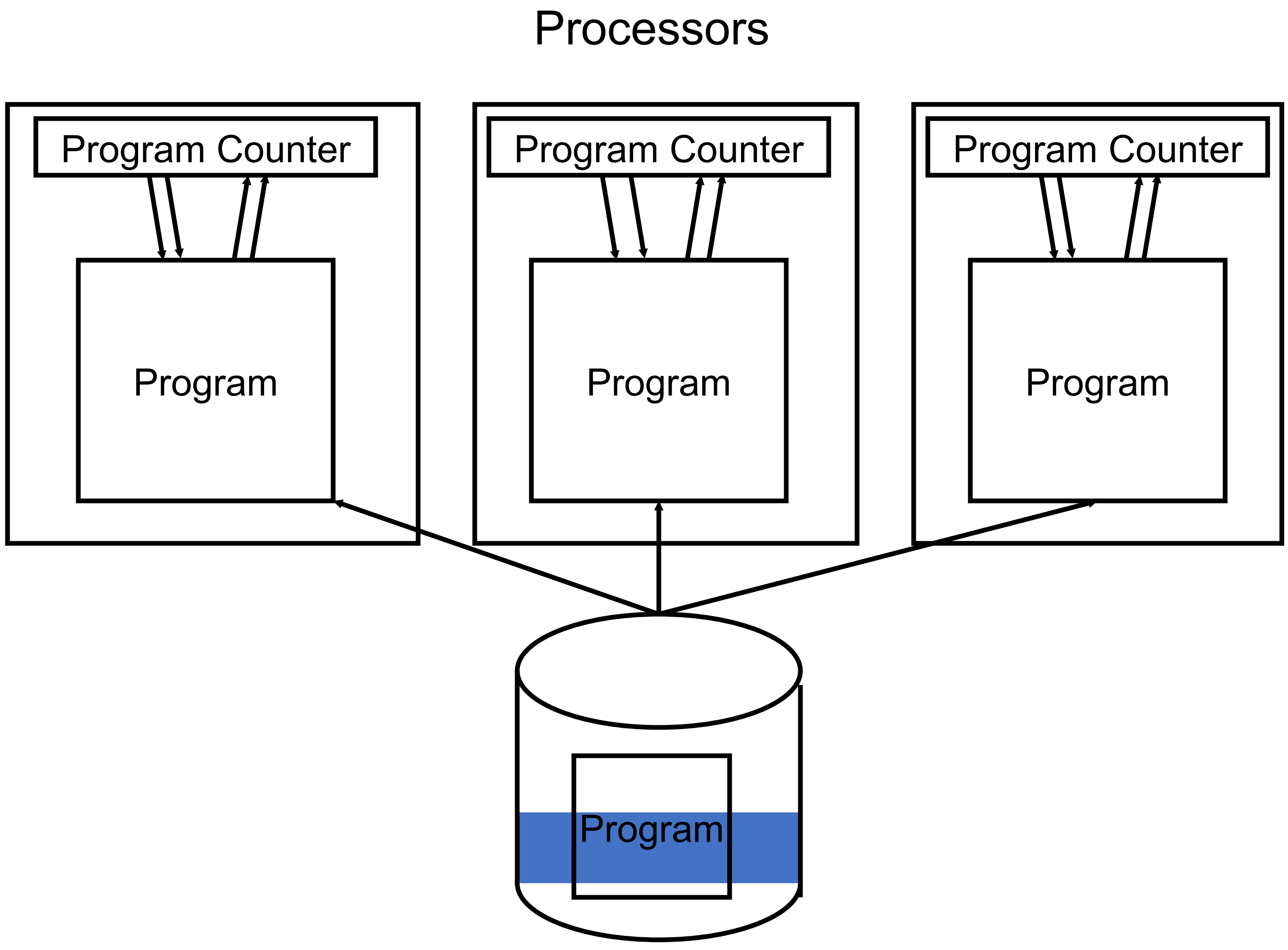
SIMD



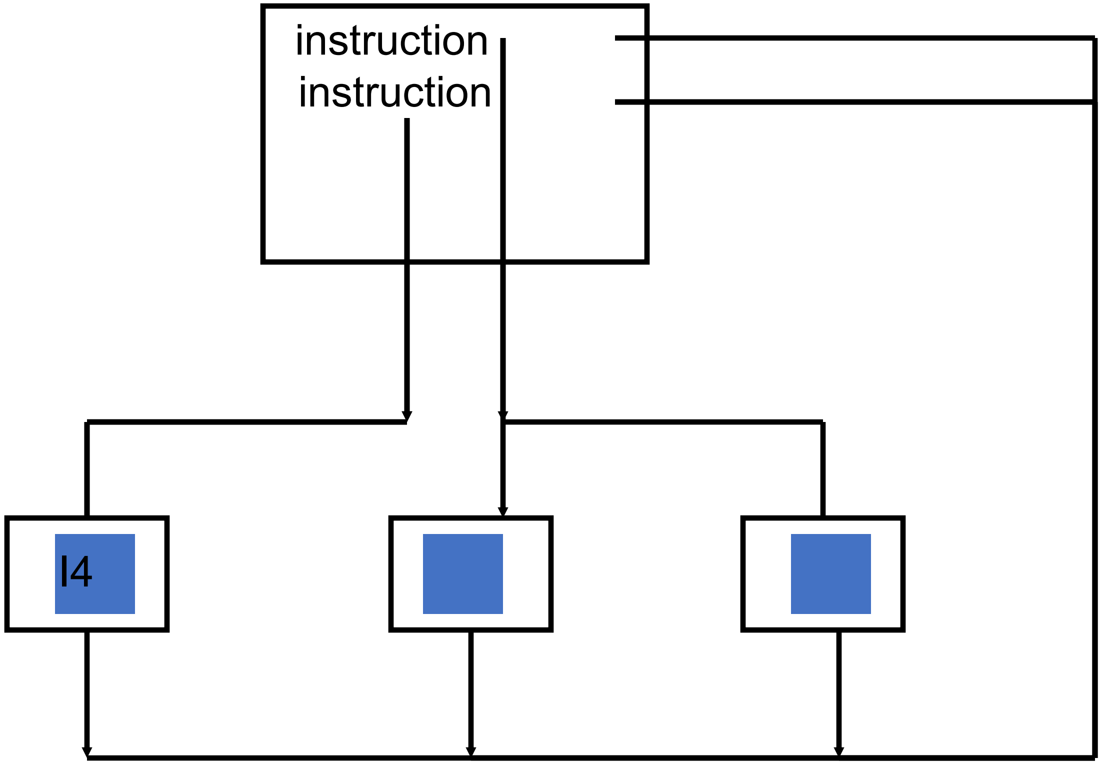
MIMD


Processors
Program Counter
Program #1
Program Counter
Program #2
Program Counter
Program #3

SPMD

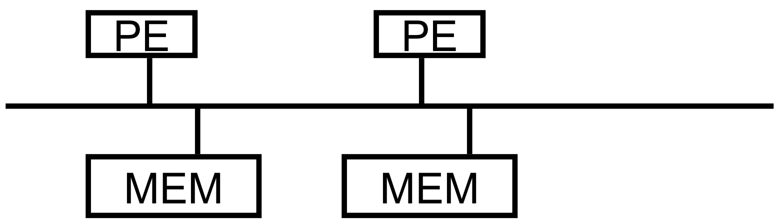

Processors
Program Counter
Program
Program Counter
Program
Program Counter
Program
Program

Dataflow

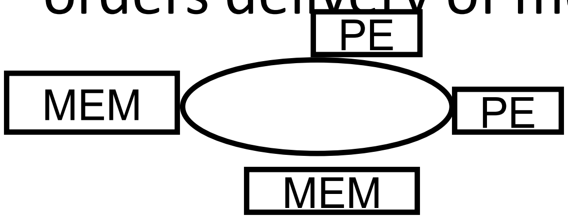


Communication Networks

- Connect
  - PE's, memory, I/O
- Key Performance Issues
  - latency: time for first byte
  - throughput: average bytes/second
- Possible Topologies
  - bus - simple, but doesn't scale

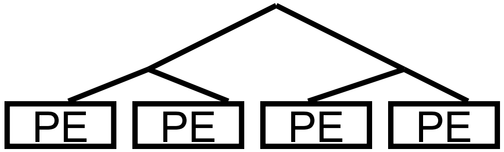


  - ring - orders delivery of messages

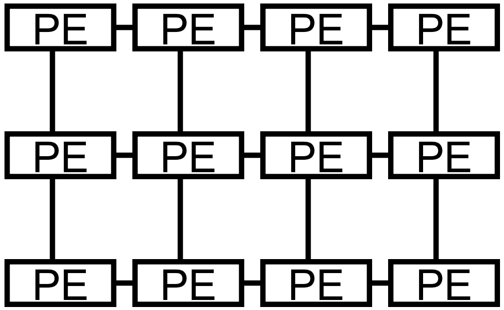


Topologies (cont)

- tree - need to increase bandwidth near the top (fat-tree)

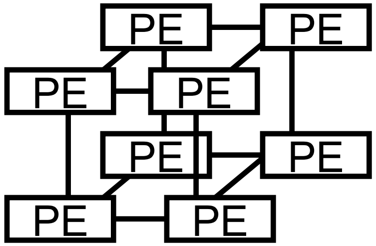


  – Mesh/torus - two or three dimensions



Current state of the art is dragonfly network – local groups with mesh + global links between groups

  – hypercube - needs a power of (2) number of nodes



Memory Systems

- Key Performance Issues
  - latency: time for first byte
  - throughput: average bytes/second
- Design Issues
  - Where is the memory
    - divided among each node
    - centrally located (on communication network)
  - Access by processors
    - can all processors get to all memory?
    - is the access time uniform?
      - UMA vs. NUMA