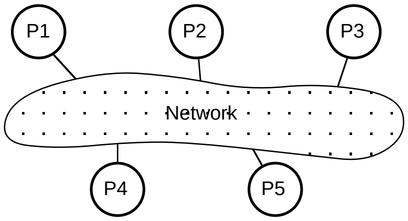
What is a Distributed System?

- A *distributed system* is a set of physically separate processors connected by one or more communication links



P1
P2
P3
Network
P4
P5

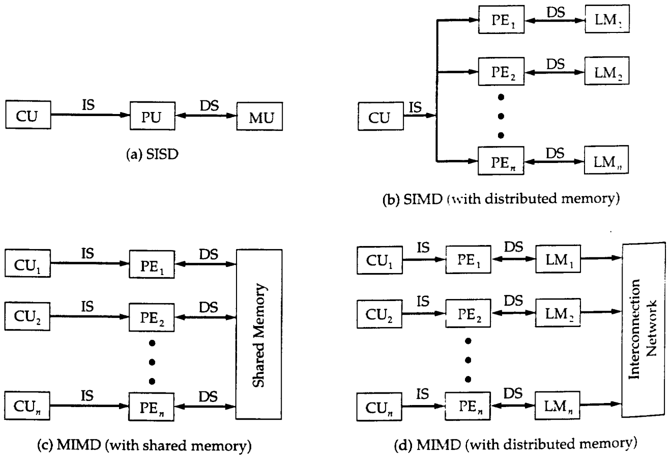
  - Workstation = computer = machine = processor = host = site = node

- Is every system with >2 computers a distributed system??
  - File server, printer server, web server
  - Beowulf-style cluster of workstations
  - 16-processor Cray SV1 at OSC
  - How does a distributed system differ from a parallel system?

Two Taxonomies for Classifying Computer Systems

- Michael Flynn (1966)
  - SISD — single instruction, single data
  - SIMD — single instruction, multiple data
  - MISD — multiple instruction, single data
  - MIMD — multiple instruction, multiple data

- More recent (Stallings, 1993)



(a) SISD

(b) SIMD (with distributed memory)

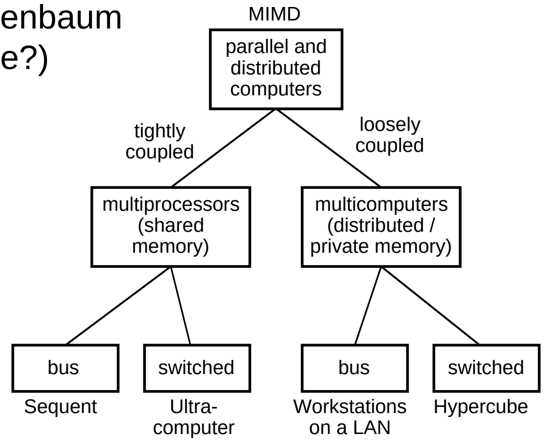
(c) MIMD (with shared memory)

(d) MIMD (with distributed memory)

FIGURE 16.16. Alternative Computer Organizations

Classification of MIMD Architectures

- Tanenbaum (date?)



MIMD
parallel and distributed computers
tightly coupled
loosely coupled
multiprocessors (shared memory)
multicomputers (distributed / private memory)
bus
switched
bus
switched
Sequent
Ultra-computer
Workstations on a LAN
Hypercube

- Tightly coupled ≈ *parallel processing*
  - Processors share clock and memory, run one OS, communicate frequently

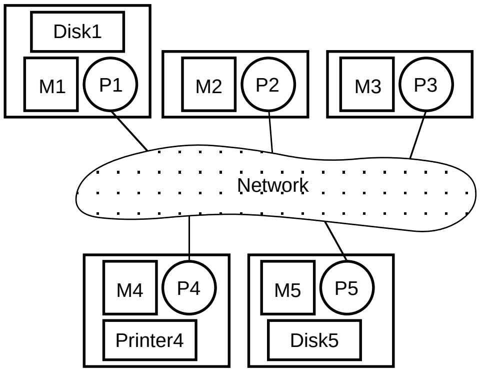
- Loosely coupled ≈ *distributed computing*
  - Each processor has its own memory, runs its own OS (?), communicates infrequently

Distributed Operating System

- Loosely-coupled hardware
  - No shared memory, but provides the "feel" of a single memory

- Tightly-coupled software
  - One single OS, or at least the feel of one

- Machines are somewhat, but not completely, autonomous



Disk1
M1
P1
M2
P2
M3
P3
Network
M4
P4
Printer4
M5
P5
Disk5

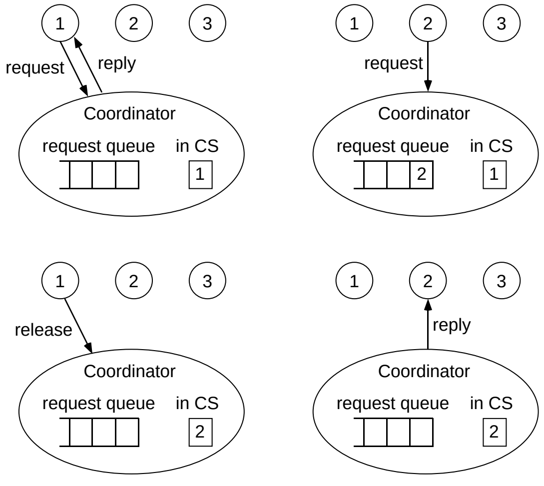
Why Use Distributed Systems? What are the Advantages?

- Natural programming model
  - Some applications (database in large company) are inherently distributed
- Resource sharing
  - Expensive (scarce) resources need not be replicated for each processor
- Price / performance
  - Network of workstations provides more MIPS for less $ than a mainframe does
- Reliability
  - Replication of processors and resources yields fault tolerance
- Scalability
  - Modular structure makes it easier to add or replace processors and resources

Central Coordinator

- To enter the critical section, a thread sends a *request* message to the central coordinator, and waits for a reply
- When the coordinator receives a request:
  - If **no** other thread is in the critical section, it sends back a *reply* message
  - If another thread **is** in the critical section, the coordinator adds the request to the tail of its queue, and does not respond
- When the requesting thread receives the *reply* message from the coordinator, it enters the critical section
  - When it leaves the critical section, it sends a *release* message to coordinator
  - When the coordinator receives a *release* message, it removes the request from the head of the queue, and sends a *reply* message to that thread

Central Coordinator (cont.)



- Evaluation:
  - 3 messages required to enter CS
    - release, request, reply
  - ✘ Coordinator is a performance bottleneck
  - ✘ Coordinator is a single point of failure
  - ✘ Delay is unconstrained

Lamport's Algorithm (1978)

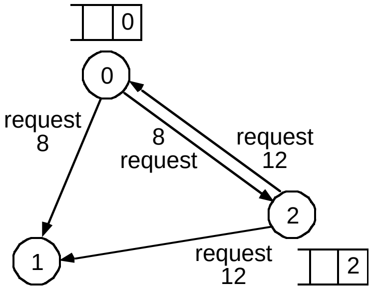
- Each process maintains a request queue, ordered by timestamp value
- Requesting the critical section (CS):
  - When a thread wants to enter the CS, it:
    - Adds the request to its own request queue
    - Sends a timestamped *request* message to all threads in that CS's request set
  - When a thread receives a *request* message, it:
    - Adds the request to its own request queue
    - Returns a timestamped *reply* message
- Executing the CS:
  - A thread enters the CS when **both**:
    - Its own request is at the top of its own request queue (its request is earliest)
    - It has received a *reply* message with a timestamp larger than its request from all other threads in the request set

Lamport's Algorithm (cont.)

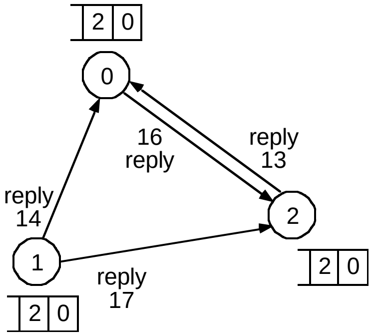
- Releasing the CS:
  - When a thread leaves the CS, it:
    - Removes its own (satisfied) request from the top of its own request queue
    - Sends a timestamped *release* message to all threads in the request set
  - When a thread receives a *release* message, it:
    - Removes the (satisfied) request from its own request queue
    - (Perhaps raising its own message to the top of the queue, enabling it to finally enter the CS)
- Evaluation:
  - 3(N–1) messages required to enter CS
    - (N–1) release, (N–1) request, (N–1) reply
  - ✘ Later…

Lamport's Algorithm (cont.)

- Both threads 0 and 2 request the CS:



- Everyone replies, thread 0 enters the CS since its request was first:



Lamport's Algorithm (cont.)

- Thread 0 releases the CS, thread 2 enters it: