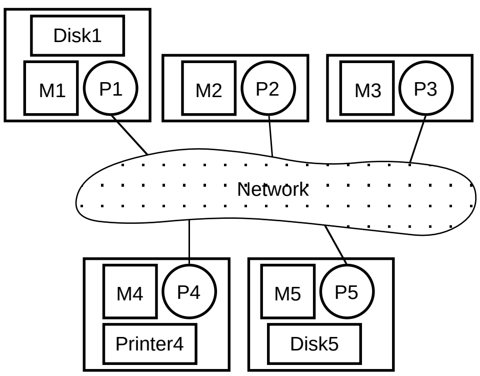
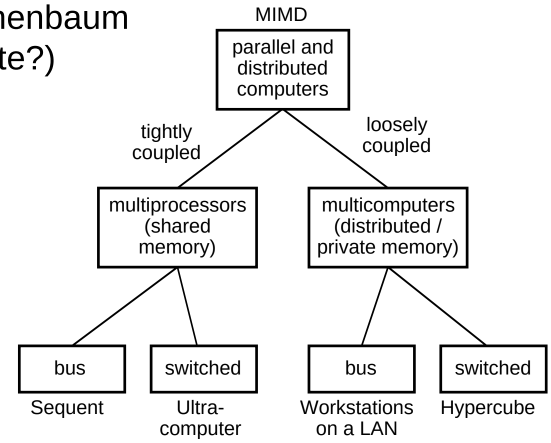
Classification of Operating Systems (Review)

- "True" 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



Classification of MIMD Architectures (Review)

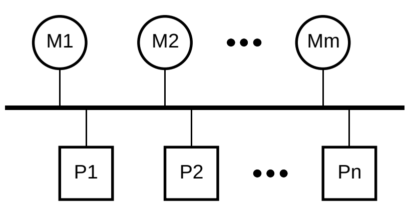
- Tanenbaum (date?)



- 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

Classification of Multiprocessors, Based on Interconnection Network

- Three main types of interconnection:
  - Bus
  - Switch (crossbar, multistage switch)
- Bus-based interconnection



✔ Simple

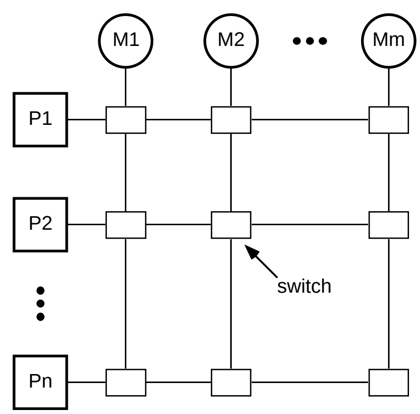
✔ No need for routing — just broadcast

✘ Contention for access to bus (does not scale well)

✘ Complicates caches (need *snoopy* cache)

Classification of Multiprocessors, Interconnection Network (cont.)

- Crossbar switch



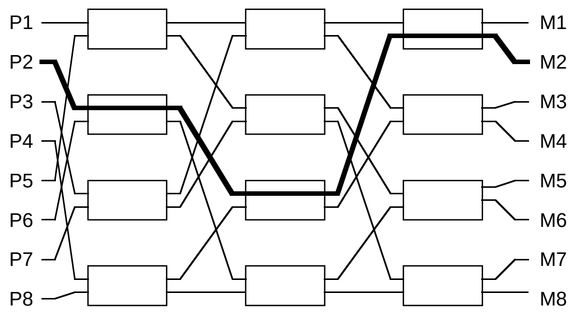
✔ Usually no contention for memory access — multiple memories can be accessed in parallel

✔ Simple routing

✘ Number of crossbar switches grows quadratically

Classification of Multiprocessors, Interconnection Network (cont.)

- Multistage switch



✔ Reduced number of switches

✘ Increased communication delay

✘ Increased contention for memory access

✘ Complex network

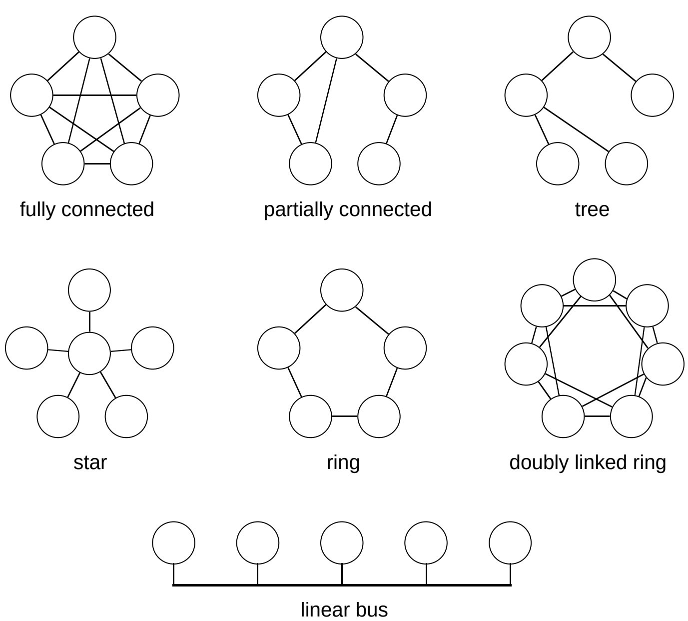
Classification of Multicomputers, Based on Interconnection Network

- Two main types of interconnection:
  - Switching network
  - LAN (local area network)

- Switching network
  - Grid
    - n^2 nodes arranged as an n x n grid
    - ✘ Maximum route proportional to n^2
    - ✘ Most messages take multiple hops
  - Hypercube
    - A n-degree hypercube (n-cube) consists of 2^n nodes (processors) arranged in an n-dimensional cube, where each node is connected to n other nodes
    - ✓ Maximum route proportional to n
    - ✘ Most messages take multiple hops

Classification of Multicomputers, Based on Interconnection Network

- LAN-based interconnection



Classification of Multiprocessors and Multicomputers, Based on Memory Access

- UMA — Uniform Memory Access
  - Main memory is at a central location

- NUMA — Non-Uniform Memory Access
  - Main memory is physically partitioned, with each partition attached to a different processor
  - Each processor can access its own memory (fast), or the memory of another processor (slow)

- NORMA — No Remote Memory Access
  - Main memory is physically partitioned, with each partition attached to a different processor
  - A processor can not access the memory of another processor

Distributed System Models

- Minicomputer model
  - Several minicomputers connected to a network, each with several terminals
- Workstation-server model
  - Specialized workstations running servers: file server, print server, etc.
  - Good resource sharing (printers, etc.), cheap workstations (don't need big disks)
- Workstation model
  - Many workstations on a network
  - System automatically transfers processes to idle workstations (process migration)
- Processor-pool model
  - Terminals connect to network, pool of processors connect to network

Goals of a Distributed System: Transparency

- *Access* transparency
  - User is unaware whether a resource is local or remote
- *Location* transparency
  - User is unaware of physical location of hardware or software resources
- *Migration* transparency
  - User is unaware if OS moves processes or resources (e.g., files) move to a different physical locations
- *Replication* transparency
  - Resource duplication is invisible to users
- *Concurrency* transparency
  - Resource sharing is invisible to users

Other Goals of a Distributed System

- *Reliability*
  - Must avoid, tolerate, detect, and recover from *faults* — mechanical or algorithmic defects that can generate an error
- *Flexibility*
  - System should be easy to modify and enhance (use microkernel and user-level processes providing services)
- *Performance*
  - Cache data, minimize copying data, minimize network traffic, use threads to take advantage of parallelism
- *Scalability*
  - System should adapt well to increased load (avoid central control, do as much work locally as possible)

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