• Distributed File Systems
• Distributed Operating Systems
• Distributed Services (email, web, telnet)
• Networking Basics

The Next Few Classes
- Communication should be less frequent
- Each processor runs an independent OS
- Each processor has its own memory

**Loosely-coupled systems:** "distributed computing"
- Frequent communication
- Processes share disk, memory, and run one OS

**Tightly-coupled systems:** "parallel processing"

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**Parallel versus Distributed Systems**

- Email, file servers, network printers, remote backup, world wide web

Nearly all systems today are distributed in some way.

**Distributed system**: a set of physically separate processors connected by one or more communication links
For example, mail, transaction processing systems like airlines and banks, WWW.

- Communication:
  The server caches, none of the workstations are useful.
  Example: If in Eklab workstation crashes, you can use another workstation. If the
  recovery is centrally, a single point of failure.
  However, if some component of the system is centralized, a single point of failure.
  Performance will degrade, but system remains operational.
  For example, if one node crashes, the user can work on another.
  Replication of resources yields fault tolerance.

Reliability:

Advantages of Distributed Systems

- Exchange of results is needed.
- Coordination and communication between cooperating processes (synchronization).
- Problems must be decomposable into subproblems
- A process potentially gives you more than the computational power

Computational Speedup:

- Keeping files on a file server
- Each processor can represent the same environment to the user (for example, by
  Each processor can present the environment to the user (for example, printers)
- Expensive (scarce) resources can be shared (for example, printers)
- Resources need not be replicated at each processor (for example, shared files)

Resource Sharing:

Advantages of Distributed Systems
Typical bandwidth: 1.544 Mbps (T1), 45 Mbps (T3)
- WANs are typically slower and less reliable than LAN (e.g., Ethernet)
- and need to be fast and reliable (e.g., Ethernet).

Wide Area Network (WAN)
- connects nodes across the state, country,
or planet.

Local Area Network (LAN)
- usually connects nodes in a single building

Networks

What do we need to consider when building these systems?
- Be distributed

Modern work environments are distributed distributed systems need to
- WANs typically use this structure:
  - Routing algorithms.
  - Sending a message to a node may have to go through several other nodes.
  - Less expensive, but less tolerant to failures. A single failure can partition the network.

  **Partially Connected:** links between some, but not all nodes

![Partially Connected](image)

- **Point-to-Point Network Topologies**

- Expensive, especially with lots of nodes, not practical for WANs.
- Failure of any one node does not affect communication between other nodes.
- Going through any other node is inefficient, i.e., goes directly to the destination without
- Each message takes only a single hop, i.e., goes directly to the destination without

  **Fully Connected:** all nodes connected to all other nodes

![Fully Connected](image)
- Expensive, and sometimes used for LAN
- If one piece of hardware fails, that disconnects the entire network.
- Each message takes only two hops.
- The central site is generally dedicated to network traffic.

**Star** - All nodes connect to a single central node

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**Tree-Structured Network**

- Not tolerant of failures. If any interior node fails, the network is partitioned.
- Some corporate networks use this topology, since it matches a hierarchical world.
- Must go up to a common ancestor and then back down.
- All messages between direct descendants are fast, but messages between "cousins" are slow.
Doubly connected ring nodes connected to neighbors and one way.

Ring Networks Topologies

- More expensive, but more tolerant of failures.
- A message takes at most \( n/4 \) hops.

- Neighbors

- Doubly Labeled Ring

Ring Networks Topologies

- Partition the network.
- If a single failure, a single failure by increasing message hop, two failures.
- With \( n \) nodes, a message needs to go at most \( n/2 \) hops.

- Bi-directional Ring - nodes can send in either direction.

- One directional ring - nodes can only send in one direction.

Ring Networks Topologies
Principles of Network Communication

**Analogies:**
- **Shared Link - Bridge:**
  - Shared resources can lead to contention (traffic jams).
- **Analogy:** cars/road/pollce - packets/network/computer
  - Computers at the switching points control the packet flow.
- **Analogy:** cars/road/pollce - packets/network/computer
  - Packets are sent through the network.
- **Analogy:** cars/road/pollce - packets/network/computer
  - Data sent into the network is chopped into "packets", the network's basic transmission unit.

**Bus Network Topologies**

**Ring Bus** - Single shared circular link
- Ethernet LAN use this structure.
- Inexpensive (linear in the number of nodes) and tolerant of node failures.
- Nodes connect directly to each other using multilaccecess bus technology.

**Linear Bus** - Single shared link
- Bus nodes connect to a common network.
**ISO Network Protocol Stack**

- **Physical Layer**
  - Deals with timing issues.
- **Data Link Layer**
  - Reliable point-to-point communication of packets over an unreliable channel. Sometimes implemented in hardware, sometimes in software (PPP).
- **Network Layer**
  - Routing and congestion control. Usually implemented in OS.
- **Transport Layer**
  - Reliably end-to-end communication between any set of nodes.
- **Session Layer**
  - Provides a UI.
- **Presentation Layer**
  - Applies various escapes on the input to the network
- **Application Layer**
  - Provides a UI.

*(ISO OSI)*

Example: International Standards Organization / Open Systems Interconnection

- The interface to the N-1 Layer
- Each Layer N provides a service to Layer N+1 by using its own Layer N procedures

**Protocol Stack**: Networking software is structured into layers

**Protocols**: a set of rules for communication that are agreed to by all parties.
- The data segment of the packet contains headers for higher protocol layers and actual application data.

- Each packet contains all the information needed to recreate the original message.

- Each message is chopped into packets.

- Ethernet Packet Contents:
  - To put them back into order.
  - For example, packets may arrive out of order and the destination node must be able to put them back into order.

Networks make tradeoffs between speed, reliability, and expense.

Networks hook them together.

Virtually all computer systems contain distributed components.

Summary