Inter-computer communication

Without shared memory, computers need to communicate

… they need a communication link

Direct links aren't practical – they don't scale to lots of computers:
you need a transceiver for each connection
Connecting computers

Communication network
– Share the infrastructure
– Multiple access problem
  • How do you coordinate multiple senders?
  • Collision: when two nodes transmit at the same time, same channel
    ⇒ Both signals get damaged
Modes of connection

**Circuit switching (virtual circuit)**
- Dedicated path (route) – established at setup
- Guaranteed (fixed) bandwidth – routers commit to resources
- Typically fixed-length packets (cells) – each cell only needs a virtual circuit ID
- Constant latency

**Packet switching (datagram)**
- Shared connection; competition for use with others
- Data is broken into chunks called packets
- Each packet contains a destination address
- Available bandwidth \( \leq \) channel capacity
- Variable latency

The Internet Protocol (IP) uses packet switching.
Packet switching relies on random access to the network
- Statistical multiplexing – packets from different sources may be intermixed randomly
- No timeslots
- Anyone can transmit when ready
- But be prepared for collisions or dropped packets
Network Protocol Layering

Most popular model of guiding (not specifying) protocol layers is the **OSI reference model**

Adopted and created by ISO

Specifies 7 layers of protocols

**OSI = Open Systems Interconnection**

From the ISO = International Organization for Standardization
OSI Reference Model: Layer 1

1. **Physical**

- Transmits and receives raw data to communication medium
- Does not care about contents
- Media, voltage levels, speed, connectors

Examples: USB, Bluetooth, 1000BaseT, Wi-Fi radios
OSI Reference Model: Layer 2

Organizes data into frames before passing it down to the hardware.

Detects and corrects errors

Accepts acknowledgements from immediate receiver

Examples: Ethernet MAC, PPP
An ethernet switch is an example of a device that works on layer 2

It forwards ethernet frames from one host to another as long as the hosts are connected to the switch (switches may be cascaded)

This set of connected hosts and switches defines the local area network (LAN)
Ethernet

- Packet-based protocol
- Originally designed for shared (bus-based) links
- Each endpoint has a unique ethernet address
  - MAC address: 48-bit number

Created by Bob Metcalfe in 1973
Ethernet

- Packet-based protocol
- Originally designed for shared (bus-based) links
- Each endpoint has a unique ethernet address
  - MAC address: 48-bit number
  - Assigned by the manufacturer of the hardware
- Service guarantees
  - Each packet (frame) contains a CRC checksum
    - The recipient will drop a received frame if it is bad
  - No acknowledgment of packet delivery
  - Ethernet provides unreliable, in-order delivery
    - Packet loss is possible

Created by Bob Metcalfe in 1973
OSI Reference Model: Layer 3

Relay and route information to destination

Manage journey of datagrams and figure out intermediate hops

Examples: IP, X.25
Provides an interface for end-to-end (application-to-application) communication: sends & receives segments of data. Manages flow control. May include end-to-end reliability.

Allows an application to set up a message stream to another application.

Examples: TCP, UDP
OSI Reference Model: Layer 5

- **Session**: Services to coordinate dialogue and manage data exchange
- **Transport**: Software implemented switch
- **Network**: Manage multiple logical connections
- **Data Link**: Keep track of who is talking: establish & end communications
- **Physical**: Deals with data streams

Examples: HTTP 1.1, SSL
Data representation

- Concerned with the meaning of data bits
- Convert between machine representations

Examples: XDR, ASN.1, MIME, JSON, XML
OSI Reference Model: Layer 7

Collection of application-specific protocols

Examples:
- web (HTTP)
- email (SMTP, POP, IMAP)
- file transfer (FTP)
- directory services (LDAP)
Network Protocols

1. Physical
   - Define 0, 1, transmission

2. Data Link
   - Packet format, network access

3. Network
   - Packet format, routing, reassembly

4. Transport
   - Sequencing, retransmission, …

5. Session
   - Coordinating requests and responses

6. Presentation
   - Data representation

7. Application
   - Application-specific interactions
A layer communicates only with its counterpart.
IP protocol layers vs. OSI layers

Internet protocol stack:
- Application
- Middleware (libraries/languages)
- Transport (TCP, UDP)
- Network (IP)
- Data Link
- Physical

OSI protocol stack:
- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical
Protocol Encapsulation

At any layer:
- The higher-level protocol headers are just treated like data
- Lower-level protocol headers can be ignored

An ethernet switch or ethernet driver sees this:

A router or IP driver sees this:

A TCP driver sees this:

An application sees this:
The End