How to make sense of all this?

Study of networks can be divided into three aspects:

- architecture

  → system design or blueprint

- algorithms

  → how do the components work

- implementation

  → how are the algorithms implemented

Architecture

- hardware
  - communication or data link technology (e.g., Ethernet, SONET, CDMA/DSSS, TDMA)
  - hardware interface standards (e.g., EIA RS 232C—serial communication between DTE and DCE)
- software
  - conceptual organization (e.g., ISO/OSI 7 layer reference model, ATM network model)
  - protocol standards (e.g., IAB RFC—TCP, UDP, IP, Mobile IP; ISO MPEG)

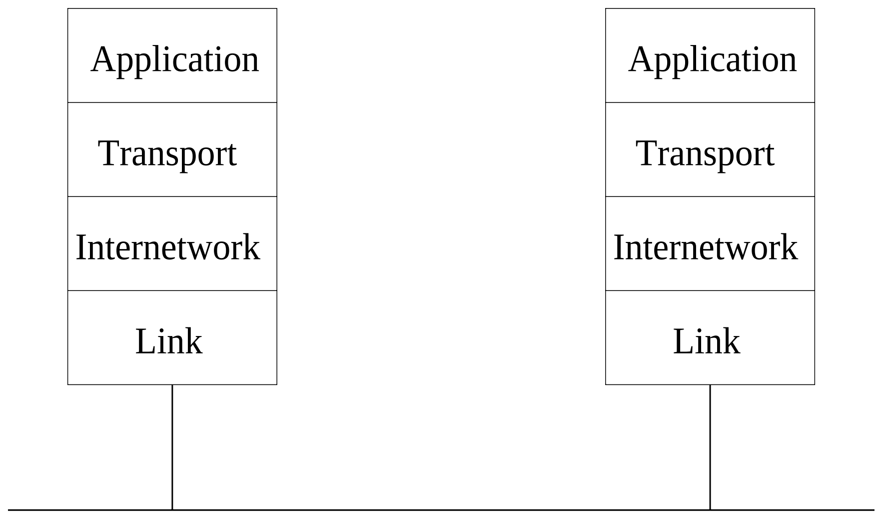
$\longrightarrow$ the *what* over *how*

Provides the "skeleton" for everything else.

... speaking of *standards*,

- ISO (International Standards Organization). ISO/OSI 7-layer reference model.
- ITU (International Telecommunications Union). Successor of CCITT (used to be parent organization), U.N.-chartered.
- IEEE. Professional society, LAN standards; e.g., IEEE 802.3 (Ethernet), IEEE 802.11 (WLAN), IEEE 802.5 (token ring).
- IETF (Internet Engineering Task Force). Internet protocol standardization body.
- W3C. World Wide Web consortium. Application layer web protocols and representations.
- ATM Forum. Industry organization (defunct).
- many others . . .

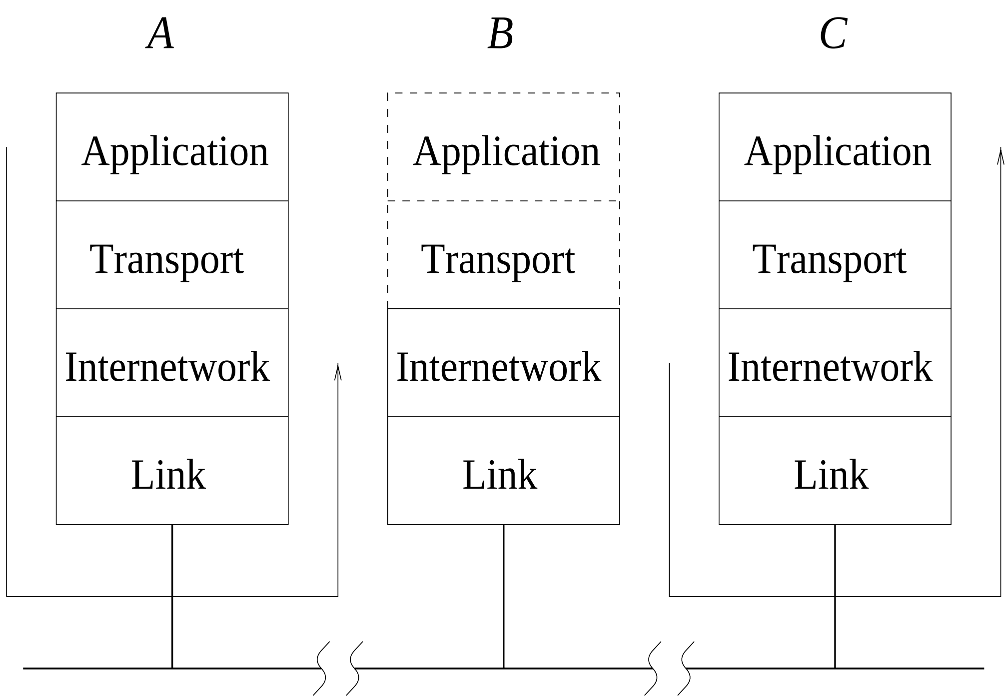
Layering: protocol stack



Achieves abstraction, modularization; two types of interfaces:

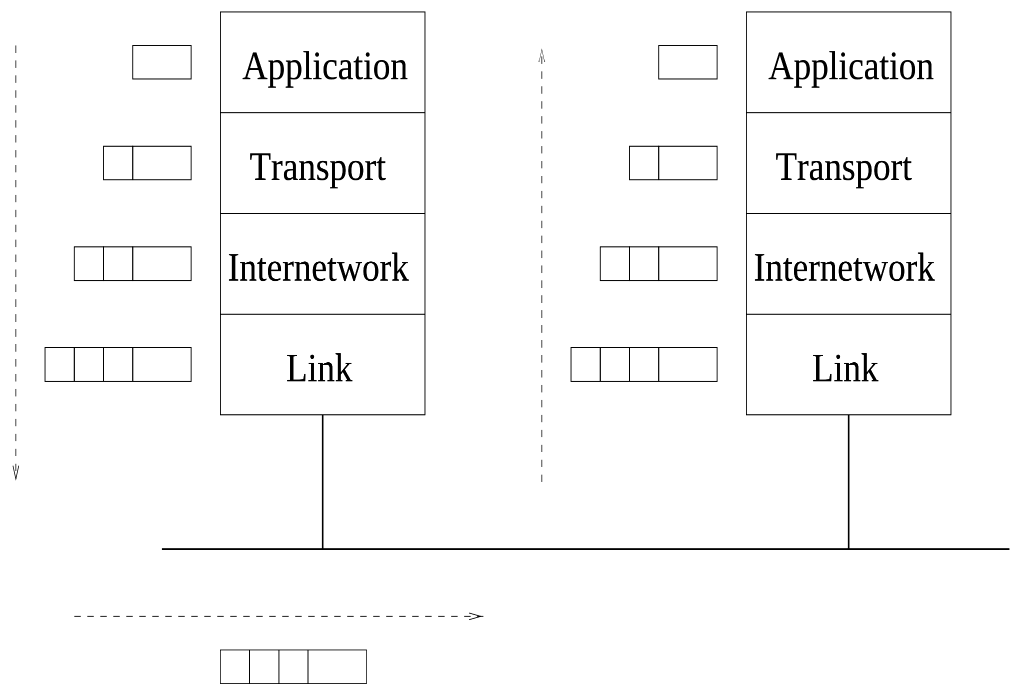
- vertical: inter-layer communication
  - SAP (service access point)
  - PDU (protocol data unit)
- horizontal: peer-to-peer

Internetworking example:



⟶ note processing of packet at B

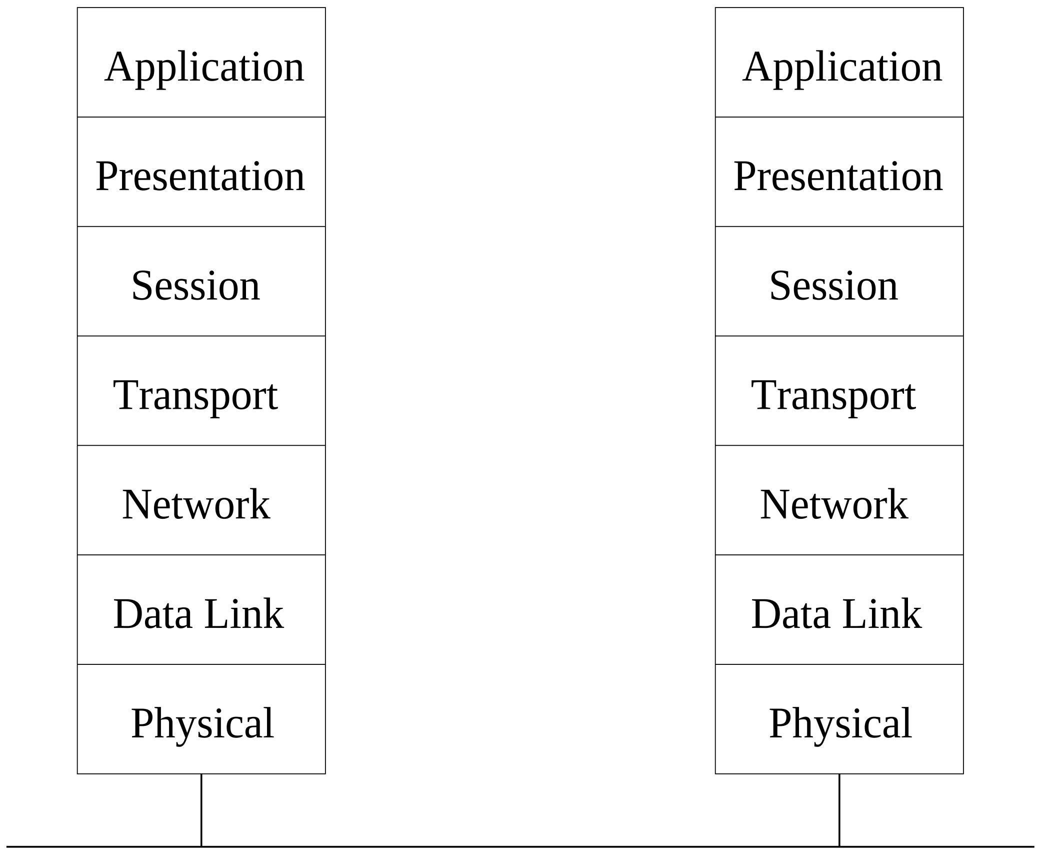
Encapsulation:



- protocol stack (push/pop)
- header/trailer overhead

  → e.g., addressing, error detection
- segmentation/fragmentation and reassembly

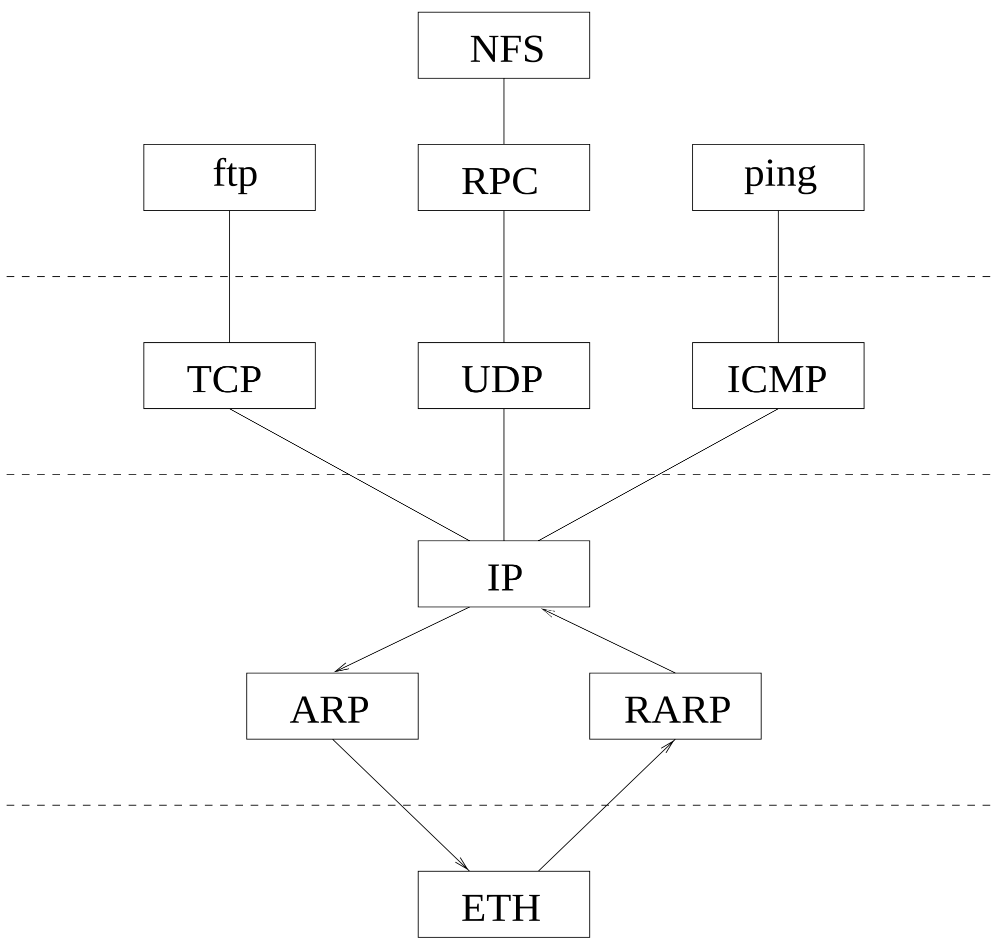
ISO/OSI 7-layer reference model:



Outdated; still semi-useful as historical reference point.

Protocol graph:

Shows logical relationship between protocol modules in the protocol stack.



Algorithms

- error detection and correction (e.g., checksum, CRC)
- medium access control (e.g., CSMA/CD, token ring, CSMA/CA)
- routing (e.g., shortest path—Dijkstra, Bellman & Ford; policy based)
- congestion control (e.g., TCP window control, multimedia rate control)
- scheduling (e.g., FIFO, priority, WFQ)
- traffic shaping and admission control
- packet filtering (e.g., firewalls)
- overlay networks (e.g., VPNs)

$\longrightarrow$ *how* aspect of computer networks

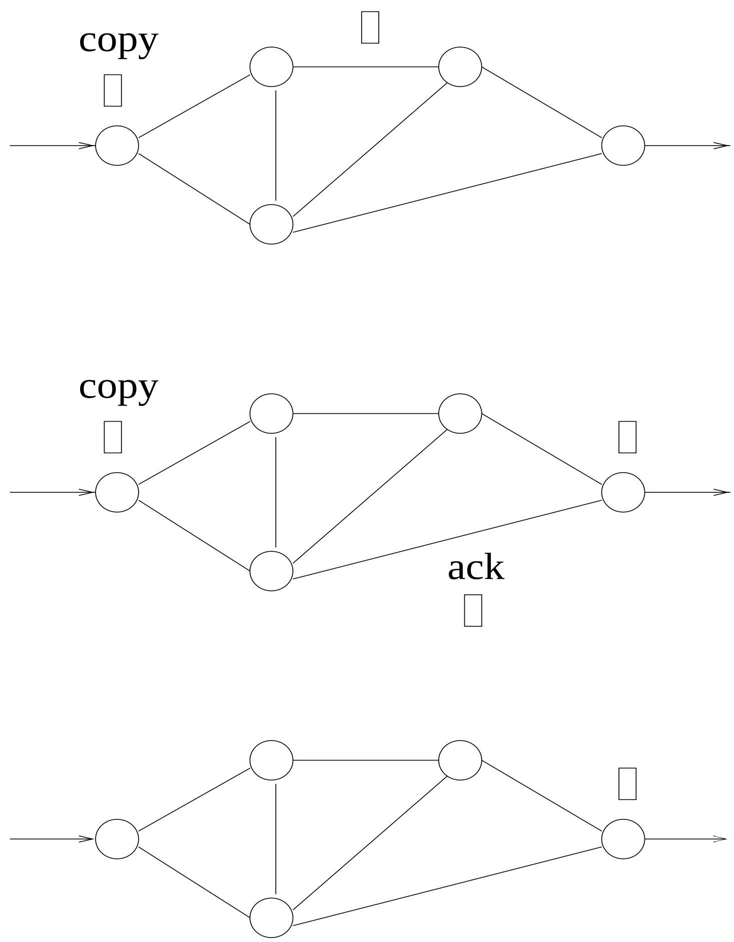
Impacts network performance by controlling the underlying resources provided by the network architecture.

Example: reliable communication

Packets may get

- corrupted due to errors (e.g., noise)
- dropped due to buffer overflow
- dropped due to aging or outdatedness—TTL (time-to-live field in IP)
- lost due to link or host failures

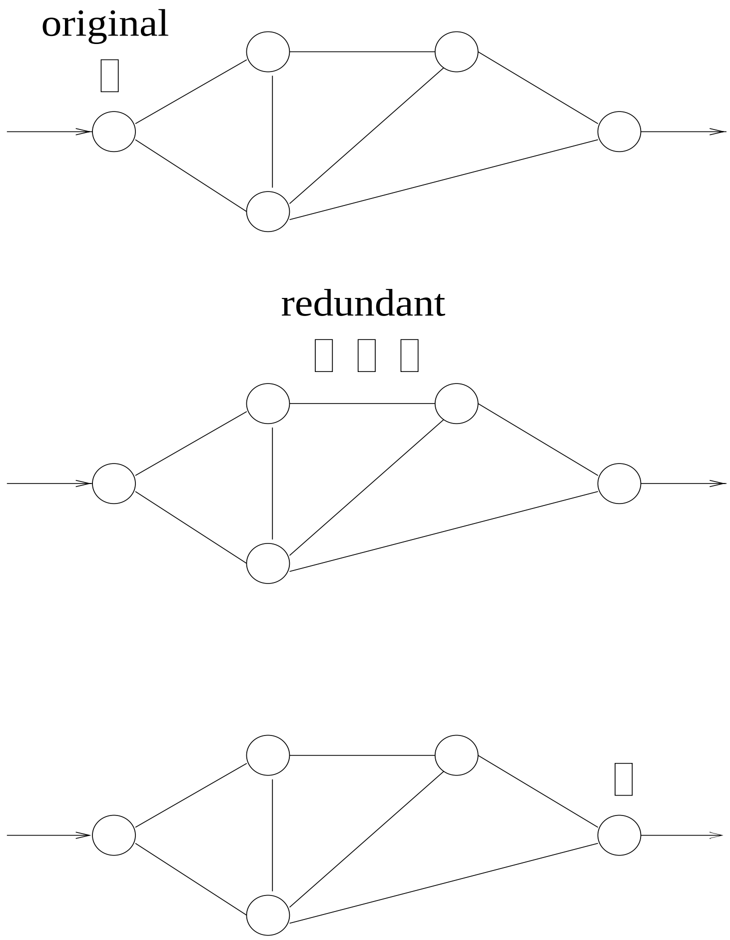
Internet philosophy: reliable transport (TCP) over unreliable internetwork (IP). Use retransmission and acknowledgment (ACK).



- acknowledge receipt (positive ACK)
- absence of ACK indicates probable loss

... or vice versa (negative ACK); when to use which ...

Forward error-correction (FEC):



. . . works if at most two out of every three packets get dropped.

- send redundant information
- need to know properties of how losses occur
- appropriate for real-time contrained data

$\longrightarrow$ FEC vs. BEC (backward error-correction)

Pros/cons vis-à-vis retransmission ...

Implementations

Same algorithm can be implemented in different ways.

Key issue: *efficiency*.

- reduce copying operation

  $\longrightarrow$ pass pointers instead of value

  $\longrightarrow$ in-place processing

- locality of reference

  $\longrightarrow$ packet trains

- multi-threading to reduce context-switch overhead
- multi-threading to hide communication latency

Although at times ugly, a *must* to squeeze the most out of performance.

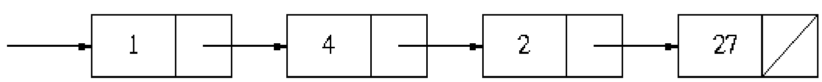
$\longrightarrow$ OO and modularity: secondary to performance

Software clock:

$\longrightarrow$ single hardware clock to emulate multiple clocks

$\longrightarrow$ timer for keeping track of events

Example: want to be notified at time 1 sec, 5 sec, 7 sec, 34 sec from now.



Hardware clock interrupt handling routine:

$\longrightarrow$ kept minimal

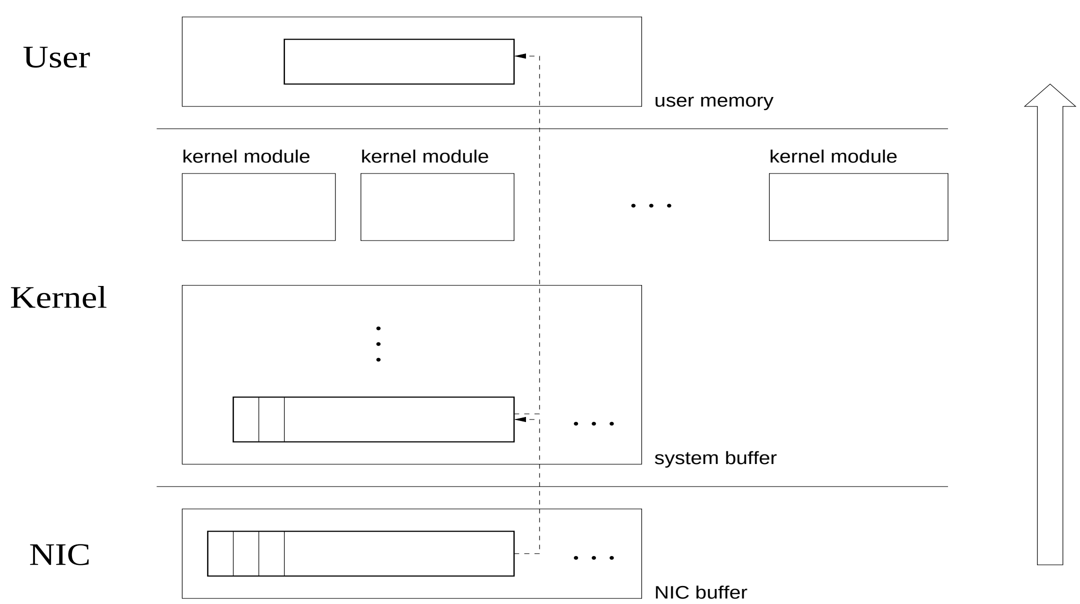
$\longrightarrow$ house-keeping chores through software clock

Vertical & horizontal design:

- keep copy operation to minimum
- use shared memory with pointers

  $\longrightarrow$ vertical design
- use horizontal design to achieve parallelism

  $\longrightarrow$ multi-threading



User space memory management.

$\longrightarrow$ data structure: e.g., trie, hashing for IP table

$\longrightarrow$ 300,000+ route entries

$\longrightarrow$ garbage collection

Keep number of system calls small.

$\longrightarrow$ system call is costly

$\longrightarrow$ stay in user space, if possible

Disk I/O.