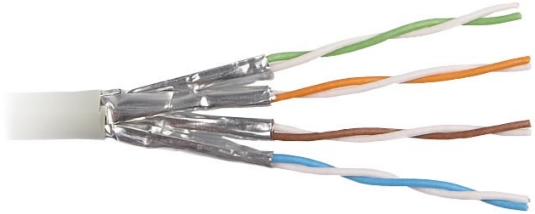
Lecture 23: Networking

CS 105

Fall 2023

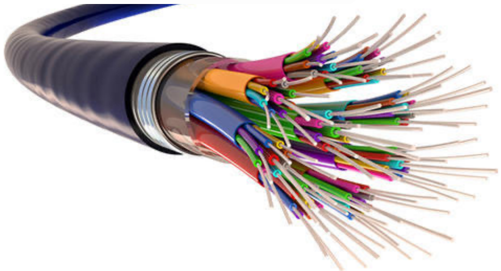
Physical Layer

- Twisted Pair



- Coaxial

- Fiber

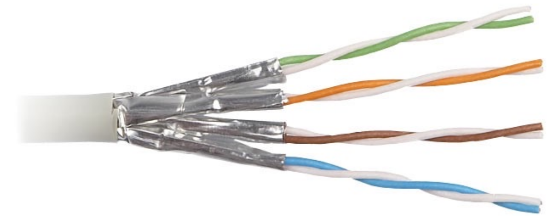


- Radio

Data Link Layer

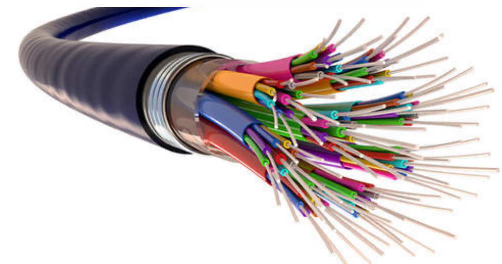
- DSL
- Ethernet
- WiFi (802.11)
- 3G
- LTE
- 5G

Twisted Pair

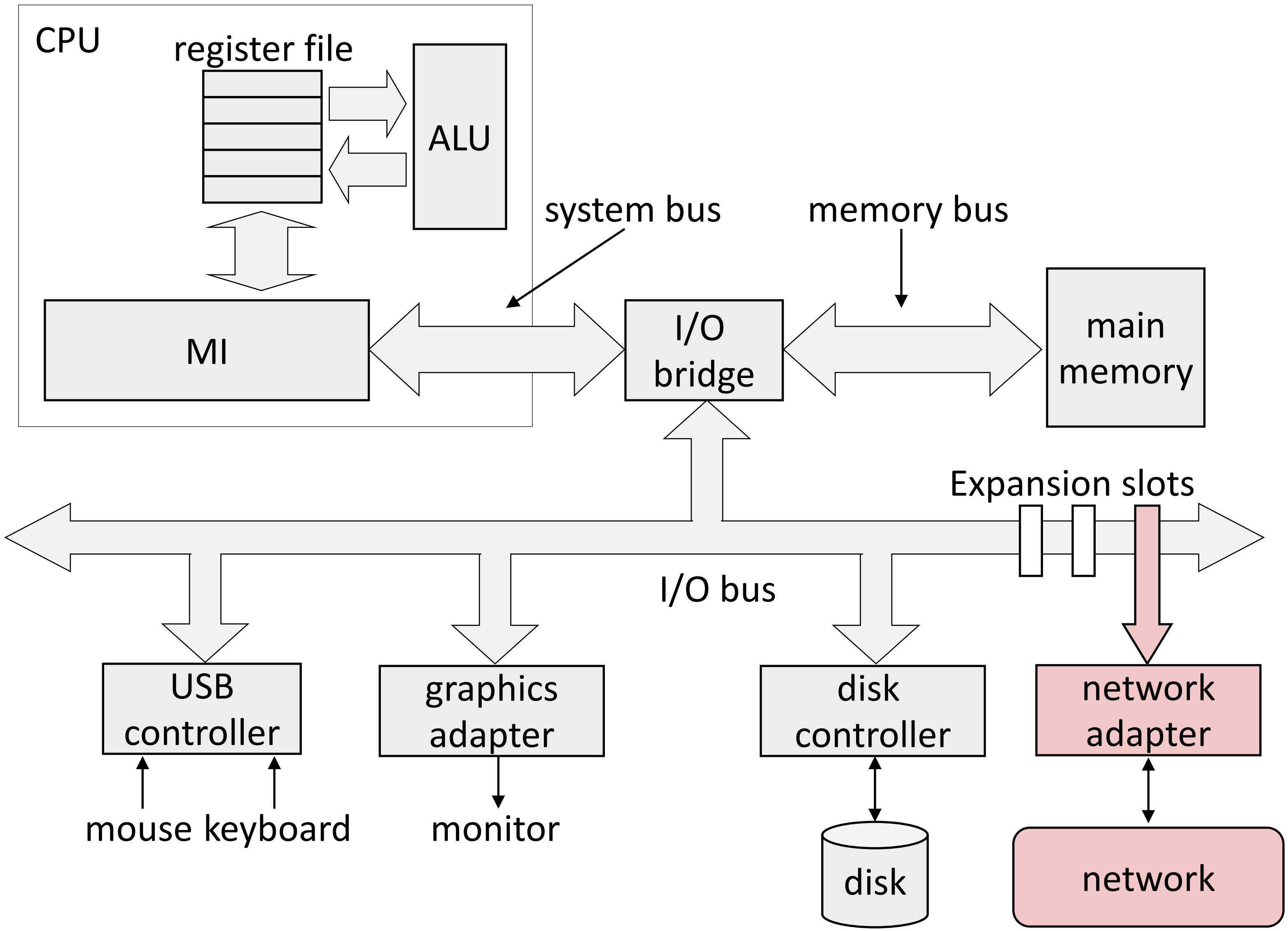


Coaxial

Fiber



Radio


CPU
register file
ALU
MI
system bus
memory bus
I/O bridge
main memory
Expansion slots
I/O bus
USB controller
graphics adapter
disk controller
network adapter
mouse keyboard
monitor
disk
network

Data Link Layer

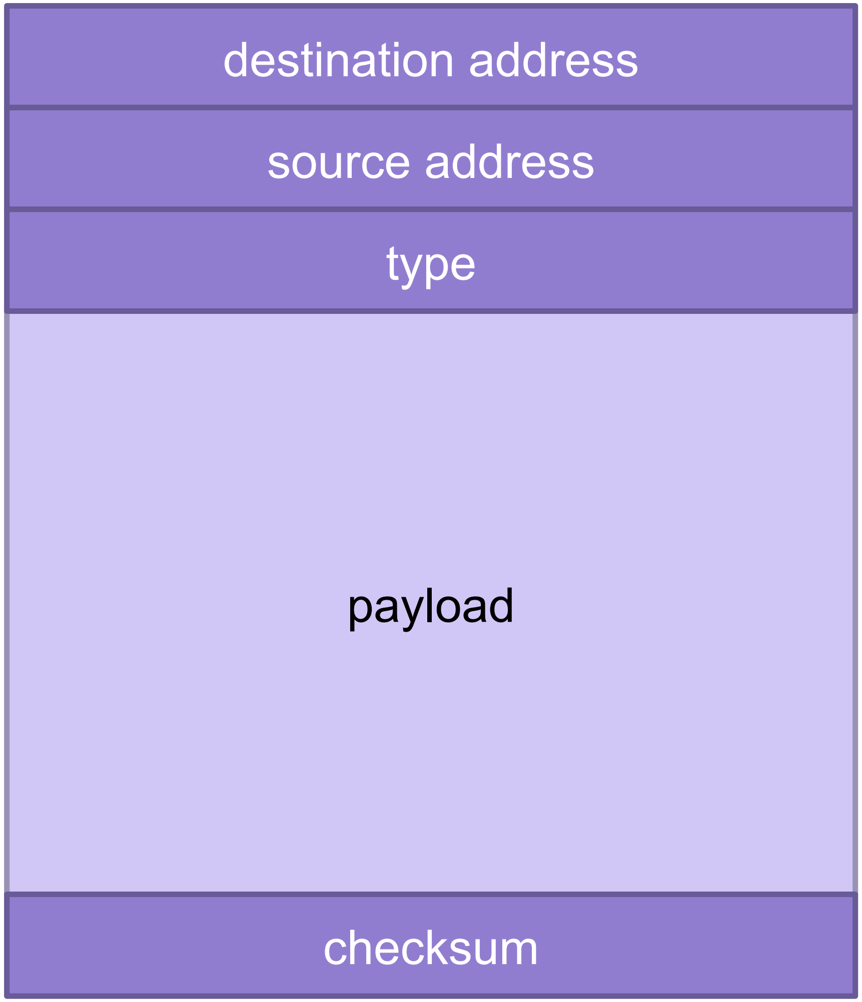
- Each host has one or more network adapter (aka NIC)
  - handles particular physical layer and protocol
- Each network adapter has a media access control (MAC) address
  - unique to that network instance
- Messages are organized as packets

Example: Ethernet

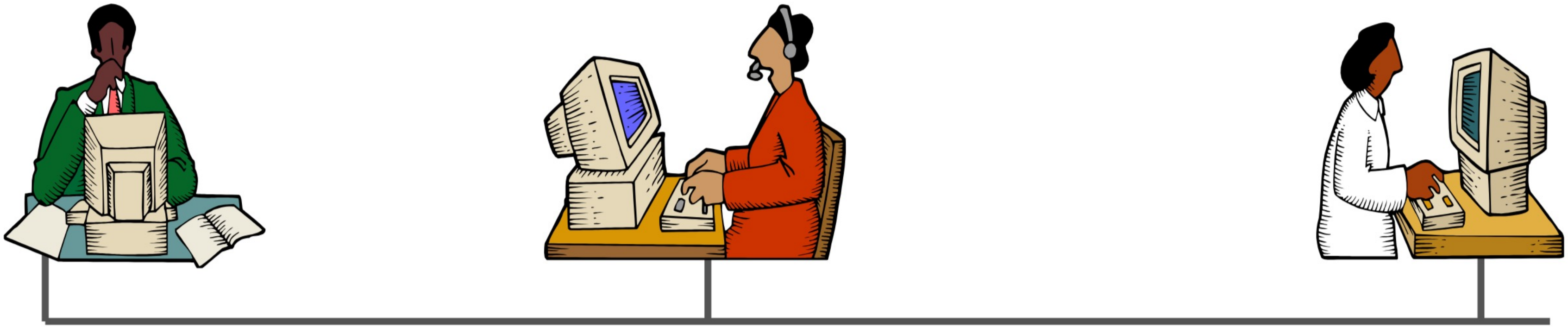
- Developed 1976 at Xerox
- Simple, scales pretty well
- Very successful, still in widespread use

- Example address: b8:e3:56:15:6a:72

- **Carrier sense:** listen before you speak
- **Multiple access:** multiple hosts on network
- **Collision detection:** detect and respond to cases where two messages collide



Example: Ethernet



- Carrier sense: broadcast if wire is available
- In case of collision: stop, sleep, retry
  - sleep time is determined by collision number
  - abort after 16 attempts

Example: Ethernet

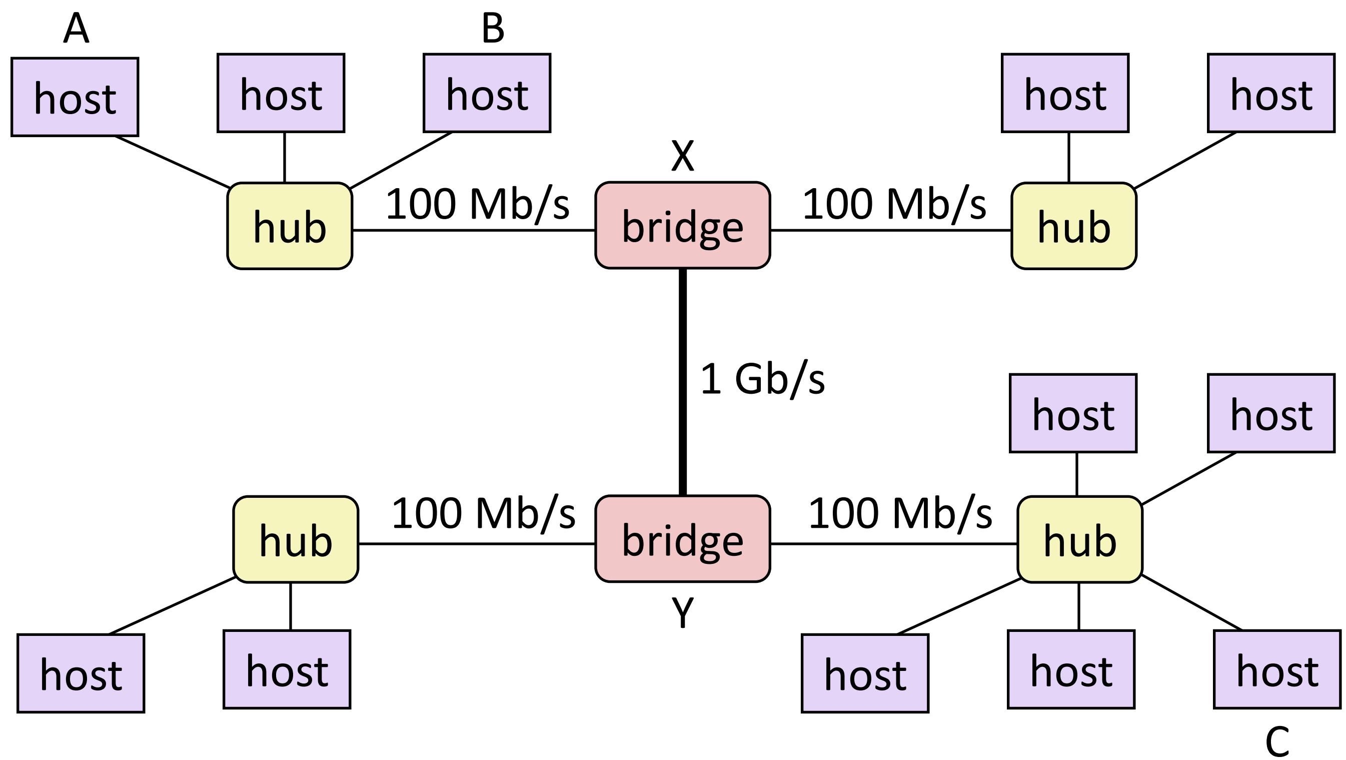
Advantages

- completely decentralized
- inexpensive
  - no state in the network
  - no arbiter
  - cheap physical links

Disadvantages

- data is available for all to see
  - can place ethernet card in promiscuous mode and listen to all messages
- endpoints must be trusted
- In large/high-traffic networks, many collisions

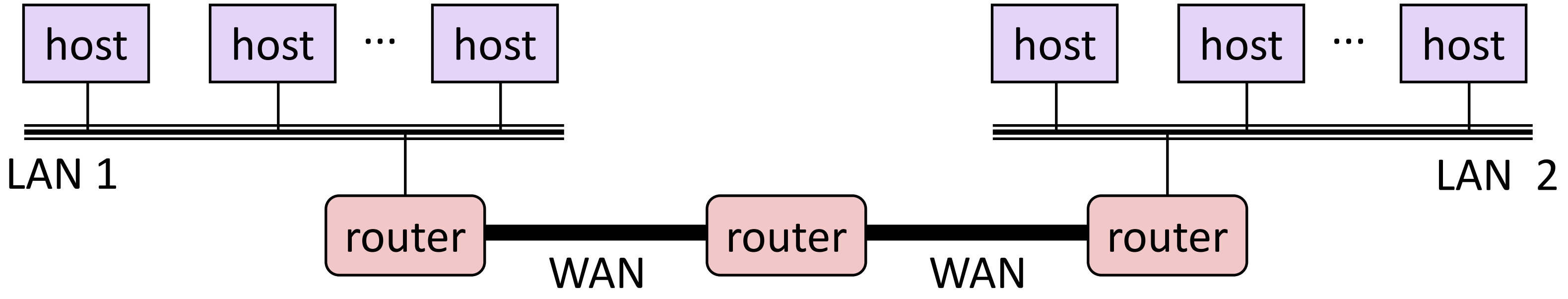
Bridged Ethernet



- Spans building or campus
- Bridges cleverly learn which hosts are reachable from which ports and then selectively copy frames from port to port

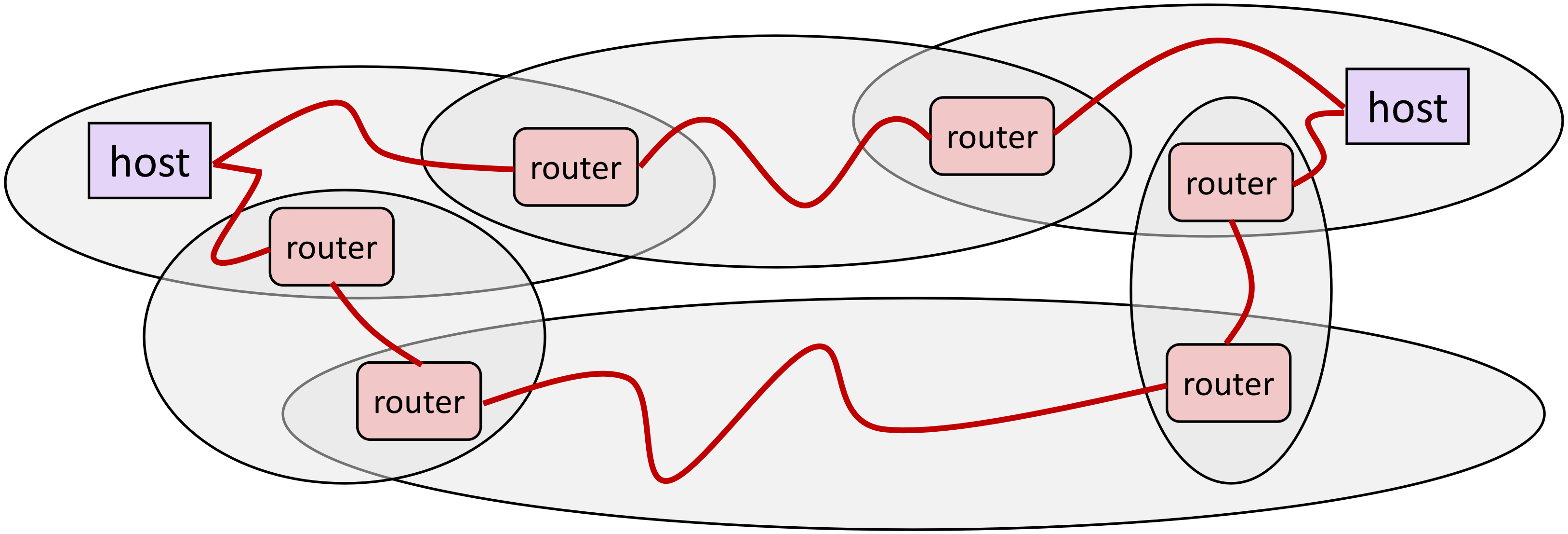
Network Layer

- There are lots of lots of local area networks (LANs)
  - each determines its own protocols, address format, packet format
- What if we wanted to connect them together?
  - physically connected by specialized computers called routers
  - routers with multiple network adapters can translate
  - standardize address and packet formats



- This is a internetwork
  - aka wide-area network (WAN)
  - aka internet

Logical Structure of an internet



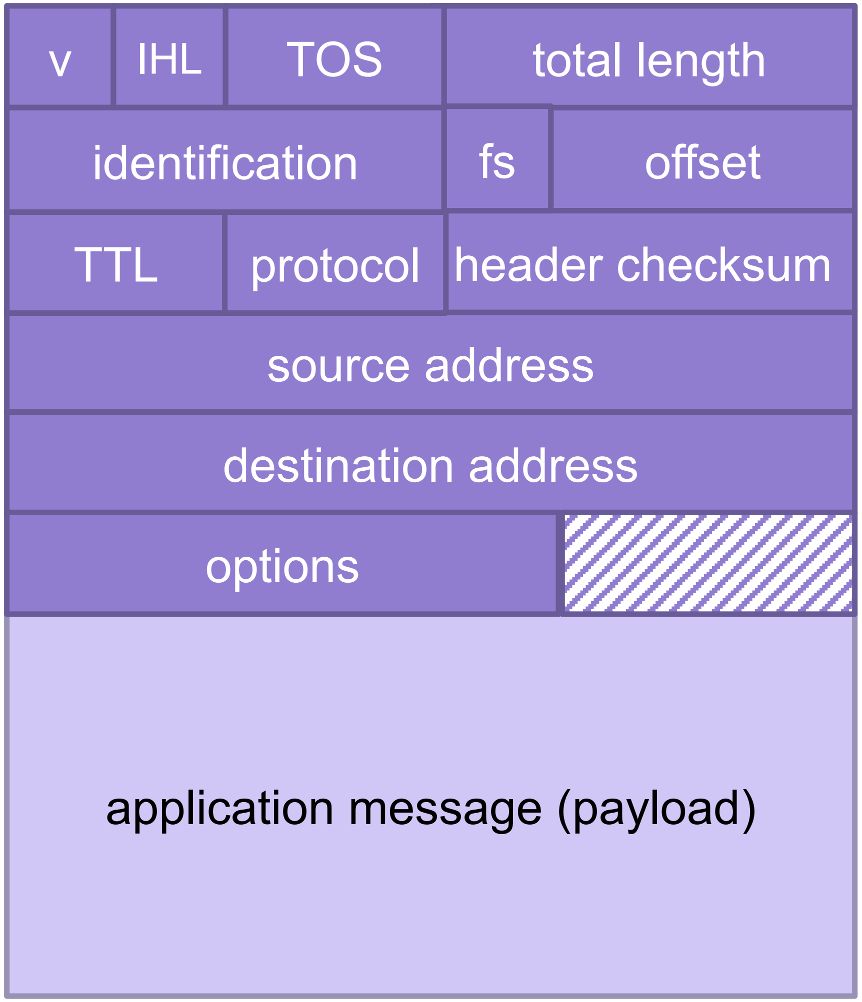
- Ad hoc interconnection of networks
  - No particular topology
  - Vastly different router & link capacities
- Send packets from source to destination by hopping through networks
  - Router forms bridge from one network to another
  - Different packets may take different routes

Internet Protocol (IP)

- Initiated by the DoD in 60s-70s
- Currently transitioning (very slowly) from IPv4 to IPv6

- Example address: 128.84.12.43

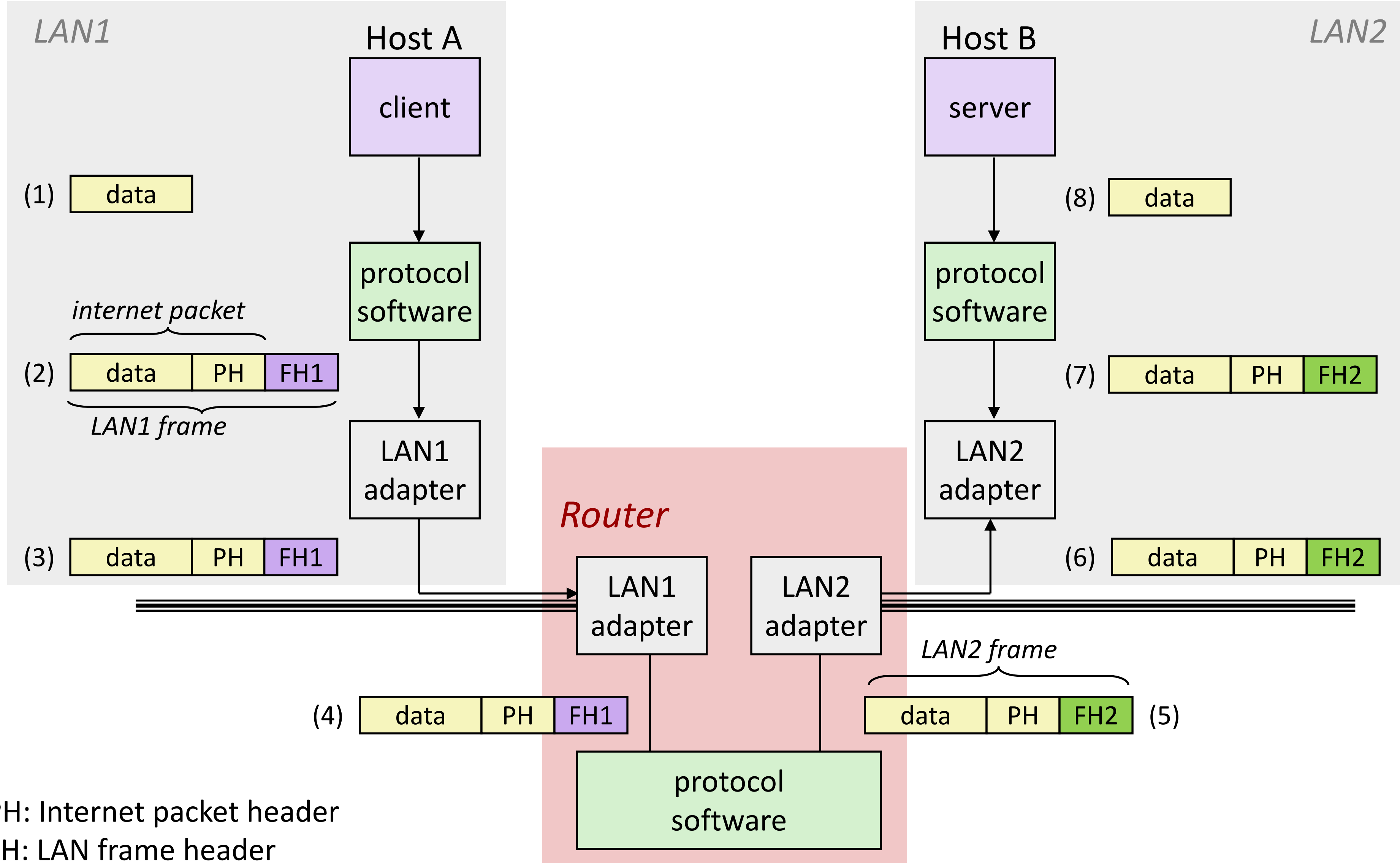
- interoperable
- network dynamically routes packets from source to destination



Aside: IPv4 and IPv6

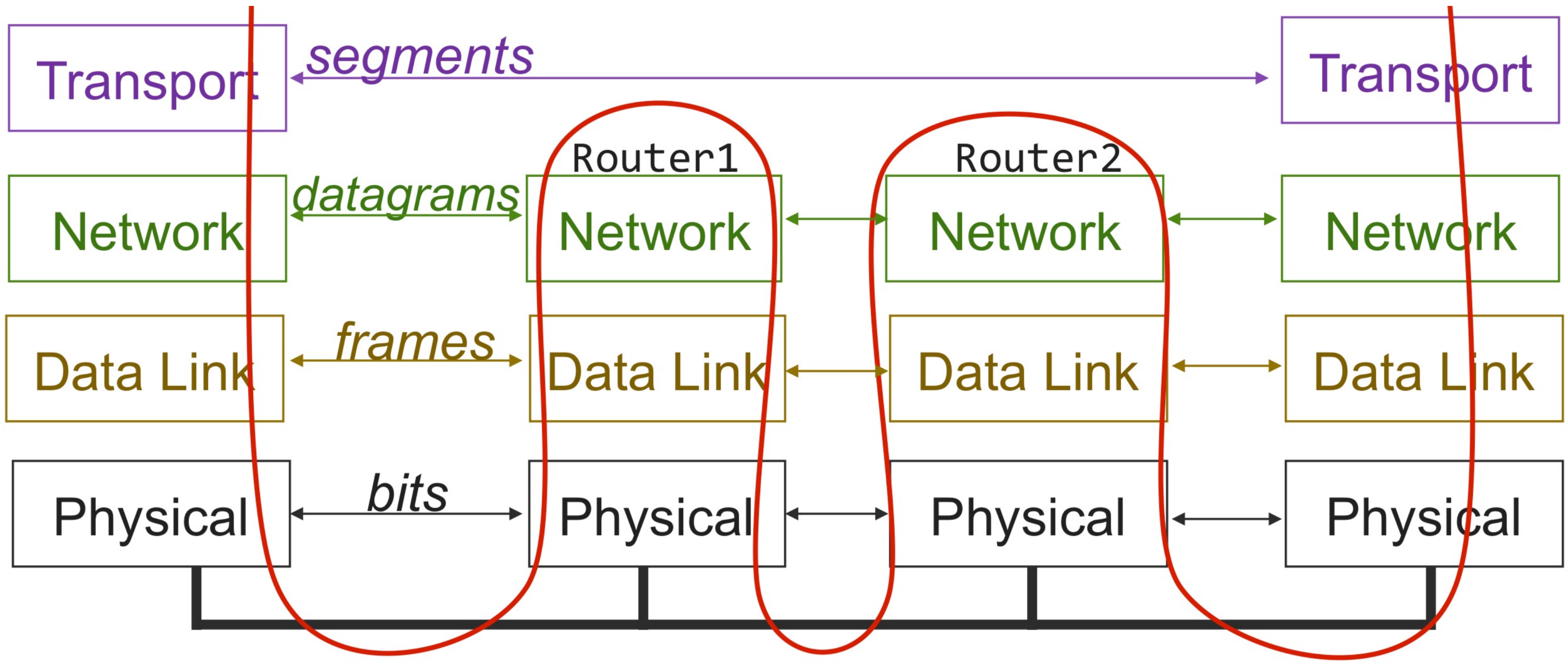
- The original Internet Protocol, with its 32-bit addresses, is known as *Internet Protocol Version 4* (IPv4)
- 1996: Internet Engineering Task Force (IETF) introduced *Internet Protocol Version 6* (IPv6) with 128-bit addresses
  - Intended as the successor to IPv4
- As of April 2023, majority of Internet traffic still carried by IPv4
  - 38-44% of users access Google services using IPv6.
- We will focus on IPv4, but will show you how to write networking code that is protocol-independent.

Transferring internet Data Via Encapsulation



PH: Internet packet header
FH: LAN frame header

Transport Layer



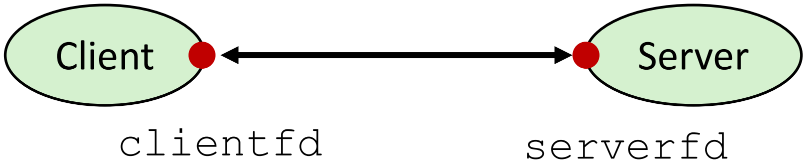
Transport Layer

- Clients and servers communicate by sending streams of bytes over a **connection**.

- A transport layer endpoint is identified by an **IP address** and a **port**, a 16-bit integer that identifies a process
  - Ephemeral port: Assigned automatically by client kernel when client makes a connection request.
  - Well-known port: Associated with some service provided by a server (e.g., port 80 is associated with Web servers)

Sockets

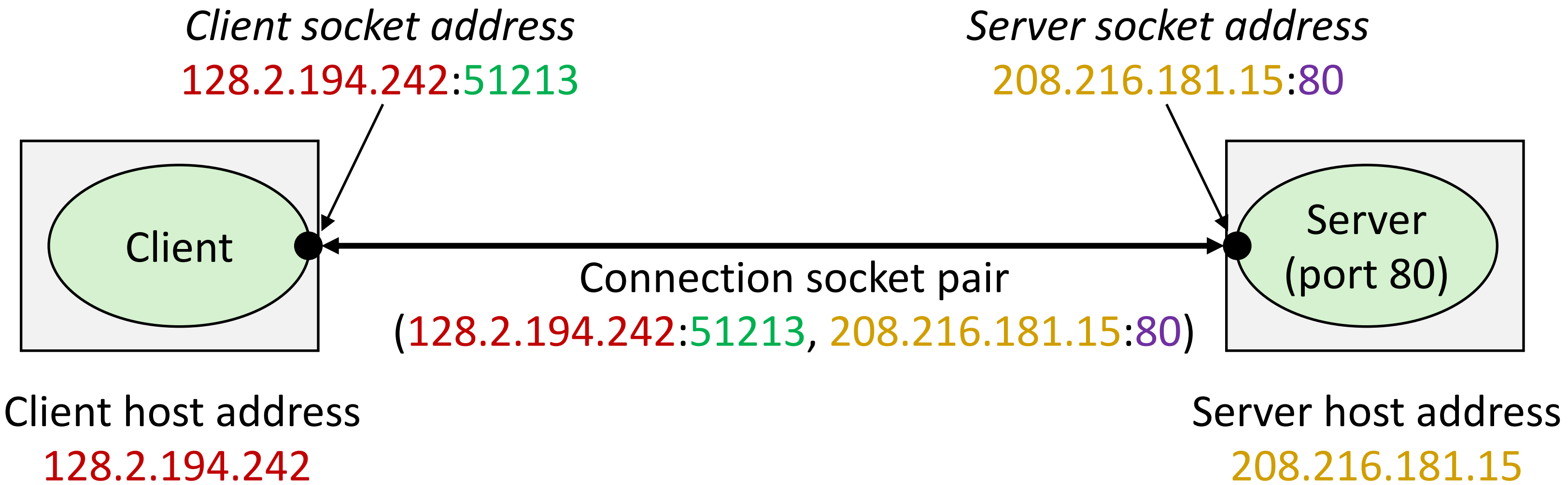
- What is a socket?
  - IP address + port
  - To the kernel, a socket is an endpoint of communication
  - To an application, a socket is a file descriptor that lets the application read/write from/to the network
    - ***Note:*** All Unix I/O devices, including networks, are modeled as files
- Clients and servers communicate with each other by reading from and writing to socket descriptors



- The main distinction between regular file I/O and socket I/O is how the application “opens” the socket descriptors

Anatomy of a Connection

- A connection is uniquely identified by the socket addresses of its endpoints (*socket pair*)
  - `(cliaddr:cliport, servaddr:servport)`



51213 is an ephemeral port allocated by the kernel

80 is a well-known port associated with Web servers

Well-known Ports and Service Names

- Popular services have permanently assigned **well-known ports** *and* corresponding ***well-known service names***:
  - echo server: 7/echo
  - ssh servers: 22/ssh
  - email server: 25/smtp
  - Web servers: 80/http

- Mappings between well-known ports and service names is contained in the file `/etc/services` on each Linux machine.

Should the transport layer guarantee packet delivery?

Transport Layer Protocols

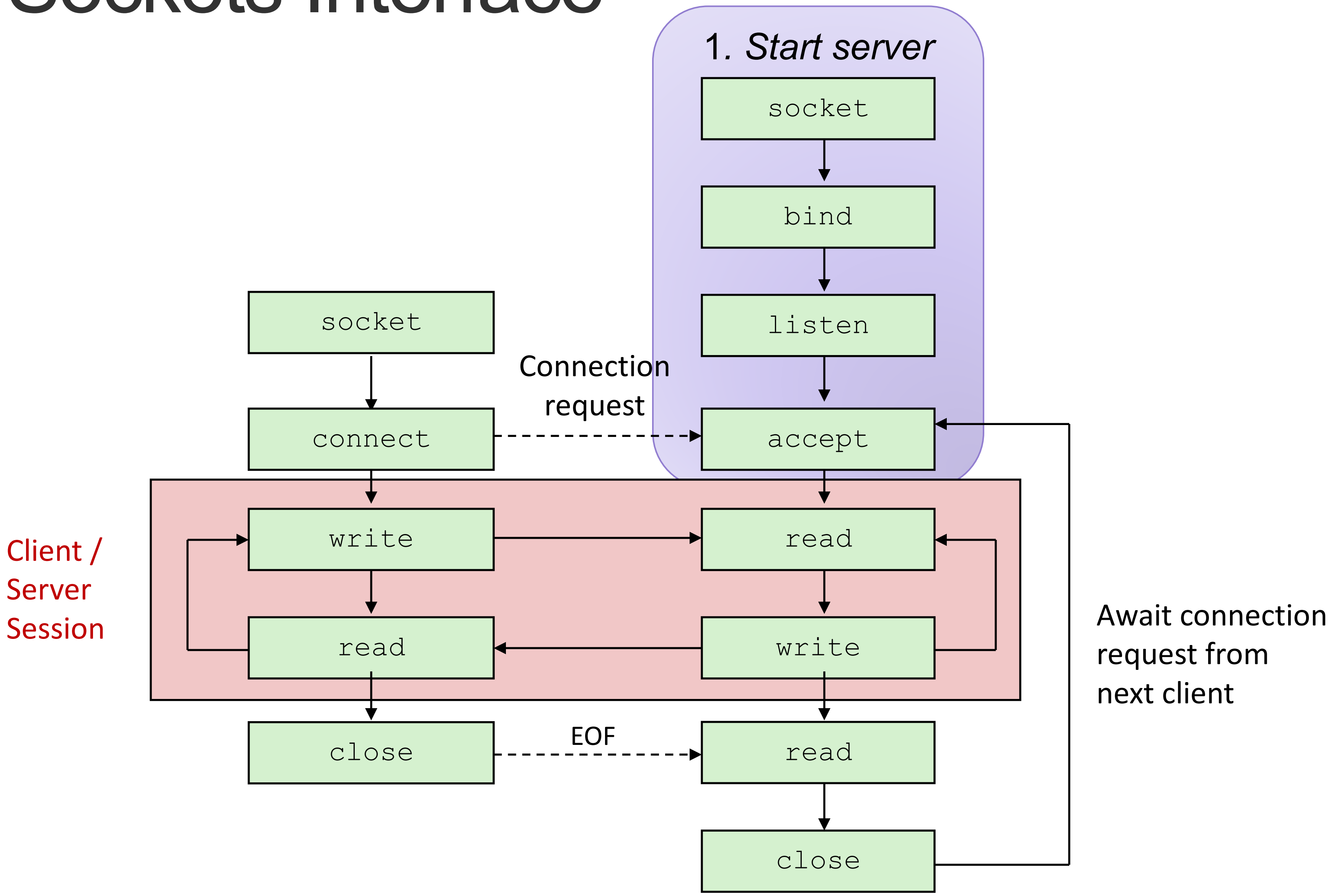
User Datagram Protocol (UDP)

- **unreliable, unordered delivery**
- connectionless
- best-effort, segments might be lost, delivered out-of-order, duplicated
- reliability (if required) is the responsibility of the app

Transmission Control Protocol (TCP)

- **reliable, in-order delivery**
- connection setup
- flow control
- congestion control

Sockets Interface



Sockets Interface: `socket`

- Clients and servers use the `socket` function to create a *socket descriptor*:

```
int socket(int domain, int type, int protocol)
```

- Example:

```
int clientfd = socket(AF_INET, SOCK_STREAM, 0);
```

Indicates that we are using 32-bit IPV4 addresses

Indicates that the socket will be the end point of a TCP connection

Protocol specific! Best practice is to use `getaddrinfo` to generate the parameters automatically, so that code is protocol independent.

Sockets Interface: `bind`

- A server uses `bind` to ask the kernel to associate the server's socket address with a socket descriptor:

```
int bind(int sockfd, SA* addr, socklen_t addrlen);
```

- The process can read bytes that arrive on the connection whose endpoint is `addr` by reading from descriptor `sockfd`.
- Similarly, writes to `sockfd` are transferred along connection whose endpoint is `addr`.

Best practice is to use `getaddrinfo` to supply the arguments `addr` and `addrlen`.

Sockets Interface: `listen`

- By default, kernel assumes that descriptor from socket function is an active socket that will be on the client end of a connection.
- A server calls the listen function to tell the kernel that a descriptor will be used by a server rather than a client:

```
int listen(int sockfd, int backlog);
```

- Converts `sockfd` from an active socket to a **listening socket** that can accept connection requests from clients.

- `backlog` is a hint about the number of outstanding connection requests that the kernel should queue up before starting to refuse requests.

Sockets Interface: `accept`

- Servers wait for connection requests from clients by calling `accept`:

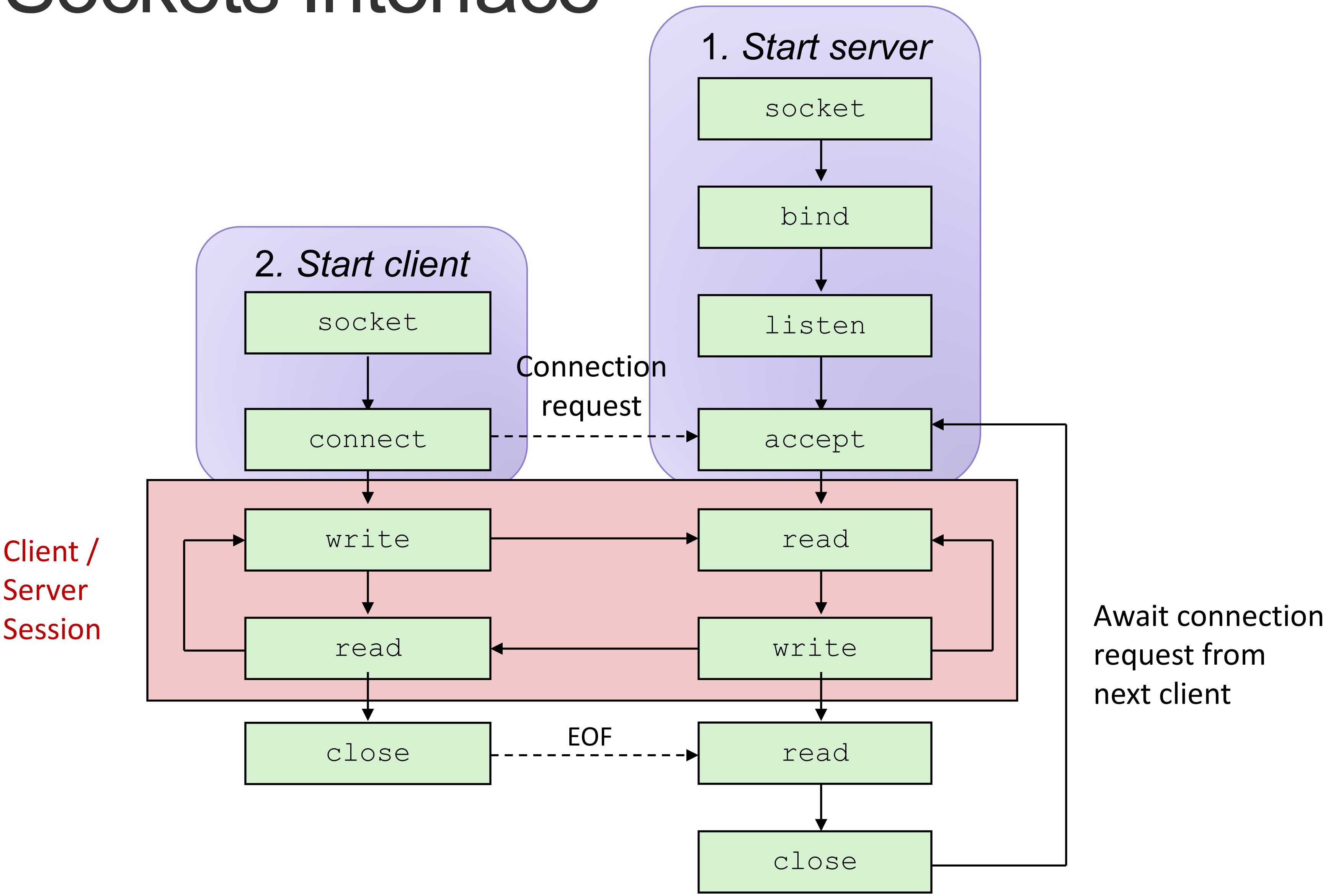
```
int accept(int listenfd, SA *addr, int *addrlen);
```

- Waits for connection request to arrive on the connection bound to `listenfd`, then fills in client's socket address in `addr` and size of the socket address in `addrlen`.
- Returns a **connected descriptor** that can be used to communicate with the client via Unix I/O routines.

Connected vs. Listening Descriptors

- Listening descriptor
  - End point for client connection requests
  - Created once and exists for lifetime of the server
- Connected descriptor
  - End point of the connection between client and server
  - A new descriptor is created each time the server accepts a connection request from a client
  - Exists only as long as it takes to service client
- Why the distinction?
  - Allows for concurrent servers that can communicate over many client connections simultaneously
    - E.g., Each time we receive a new request, we fork a child to handle the request

Sockets Interface



Sockets Interface: `connect`

- A client establishes a connection with a server by calling connect:

```
int connect(int clientfd, SA* addr, socklen_t addrlen);
```

- Attempts to establish a connection with server at socket address `addr`
  - If successful, then `clientfd` is now ready for reading and writing.
  - Resulting connection is characterized by socket pair

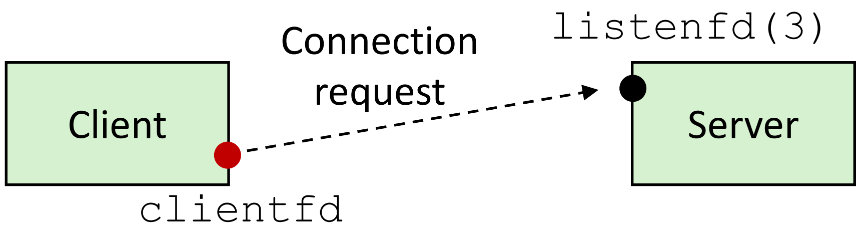
    `(x:y, addr.sin_addr:addr.sin_port)`

    - `x` is client address
    - `y` is ephemeral port that uniquely identifies client process on client host

Best practice is to use `getaddrinfo` to supply the arguments `addr` and `addrlen`.

`accept` Illustrated

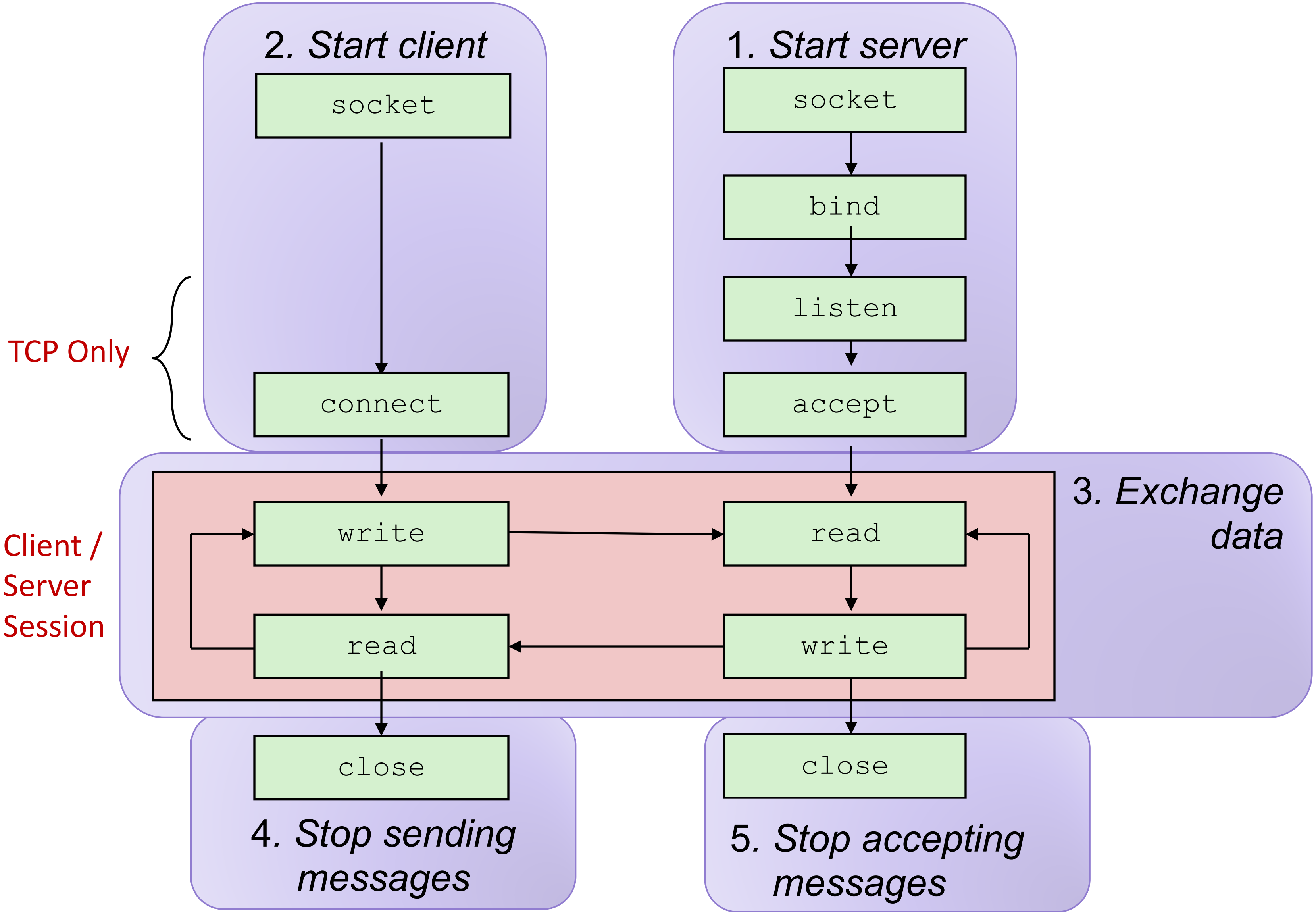
1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`



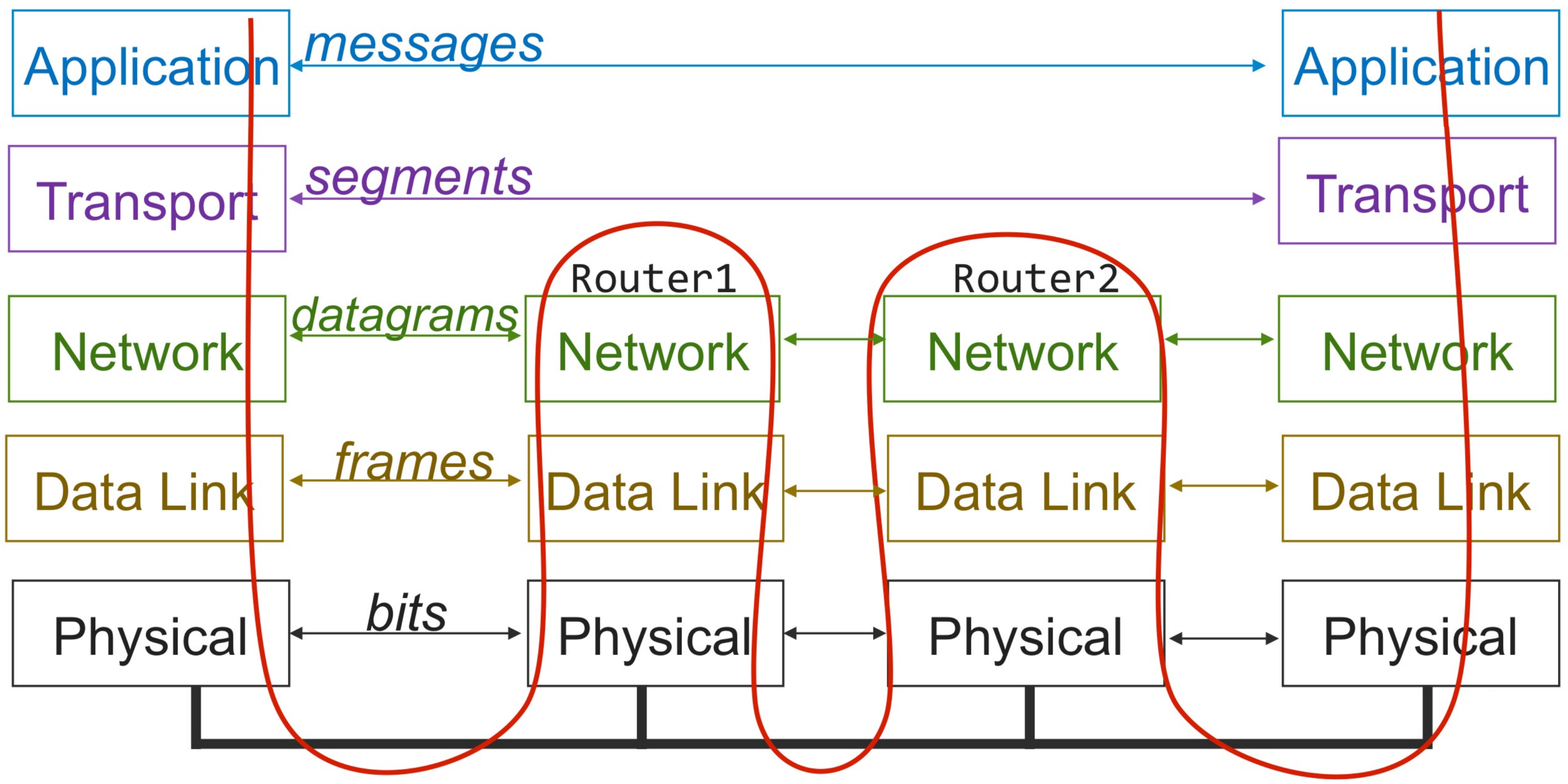
2. Client makes connection request by calling and blocking in `connect`

3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`

Sockets Interface

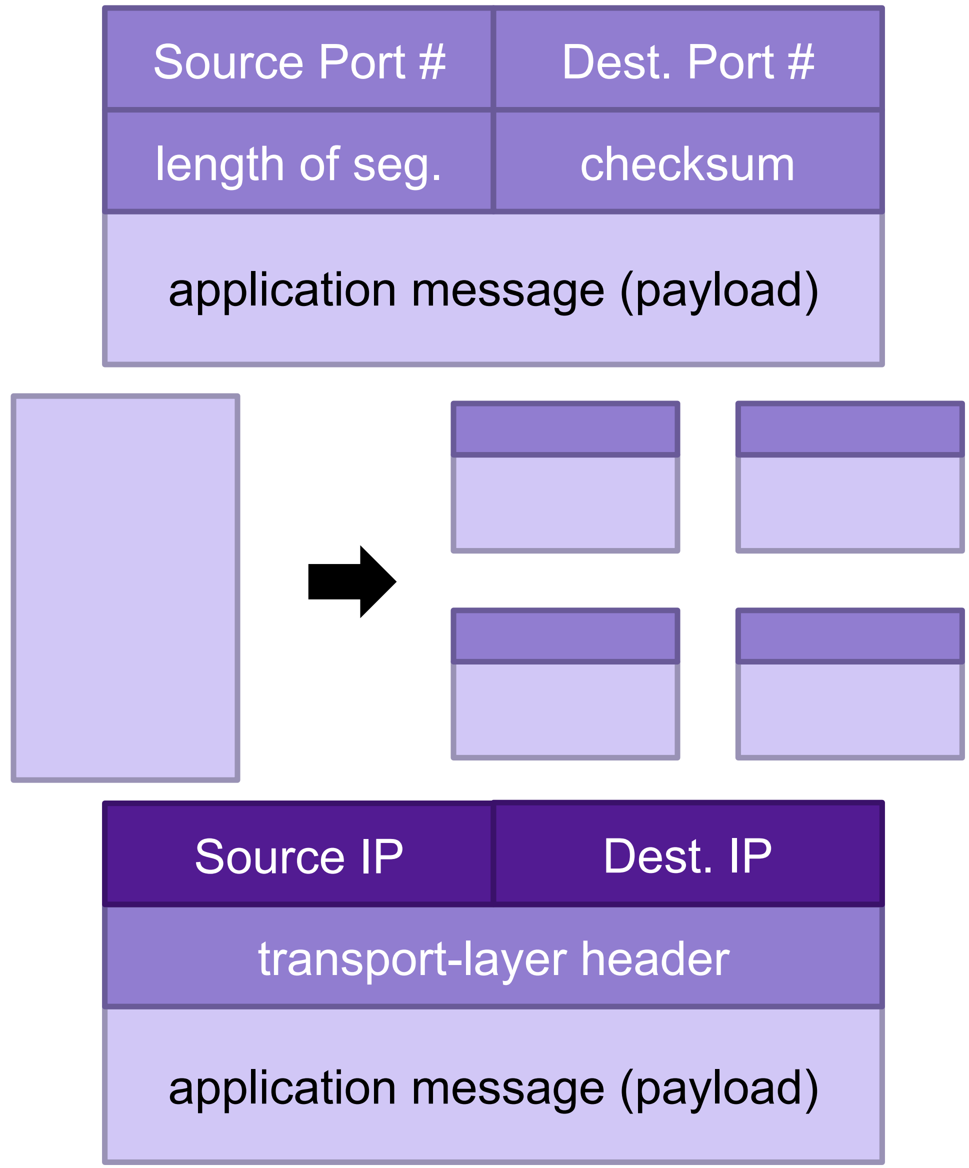


The Big Picture

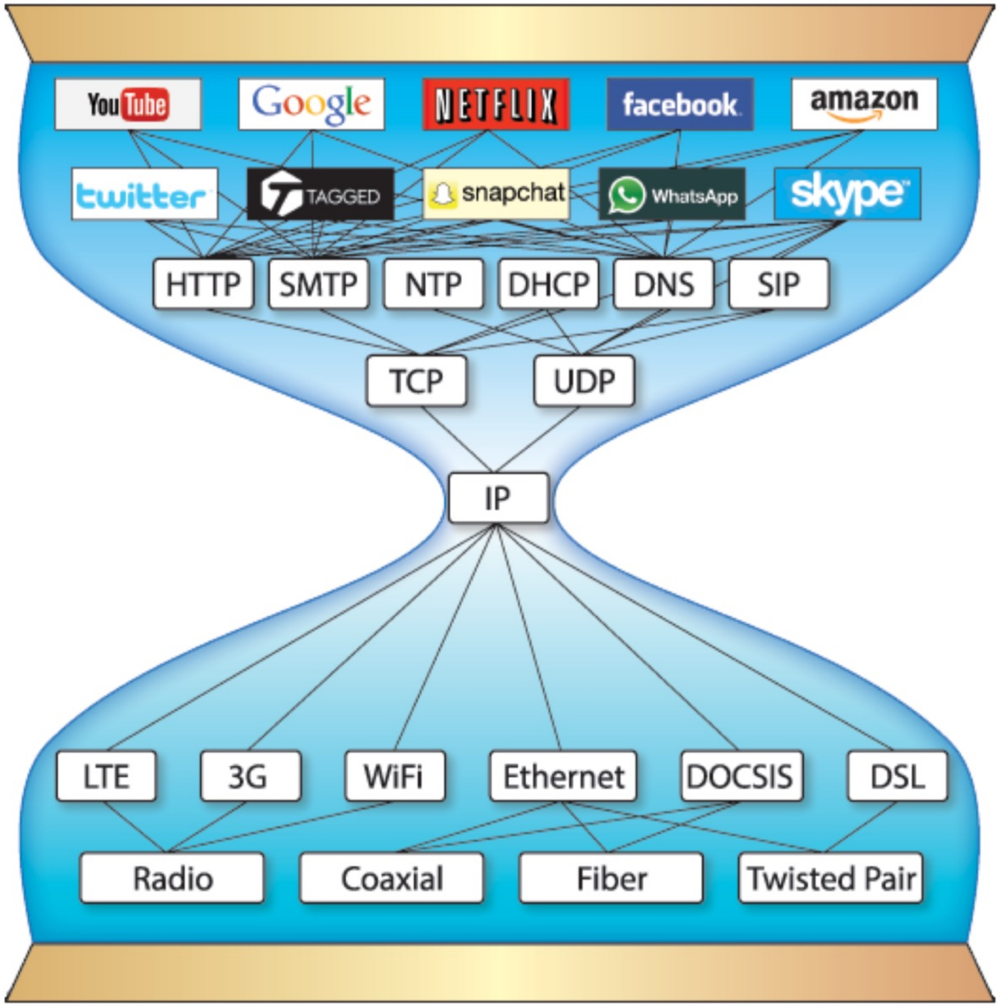


The Big Picture

- Sending application:
  - specifies IP address and port
  - uses socket bound to source port
- Transport Layer:
  - breaks application message into smaller chunks
  - adds transport-layer header to each message to form a segment
- Network Layer (IP):
  - adds network-layer header to each datagram



The Big Picture



Application

Transport

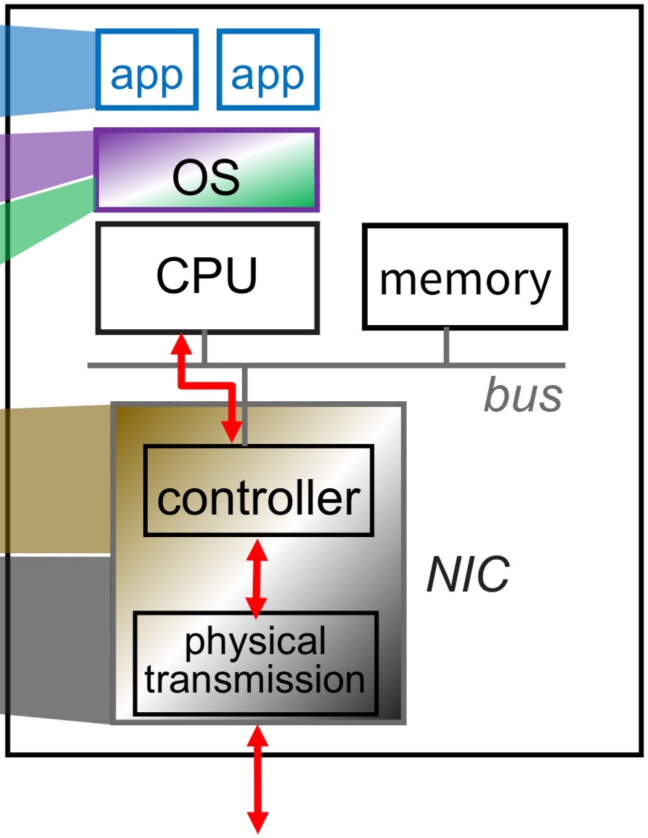
Network

Data Link

Physical

Hardware and Software Interfaces

Application	HTTP, FTP, DNS (*these*^ are usually in libraries)
Transport	TCP, UDP
Network	IP, ICMP (ping)
Link	Ethernet, WiFi
Physical	wires, signal encoding



(Hard to draw firm lines here)