EECS 489
Computer Networks

Winter 2025

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Material with thanks to Aditya Akella, Sugih Jamin, Philip Levis, Sylvia Ratnasamy, Peter Steenkiste, and many other colleagues.

Recap

- Delay refers to the time to send data from src to dst
  - It has four components: transmission, propagation, queueing, and processing
- Bandwidth is the characteristics of a link
- Throughput is the rate at which a src and dst can communicate
  - Bounded by the bottleneck link on the path

Agenda

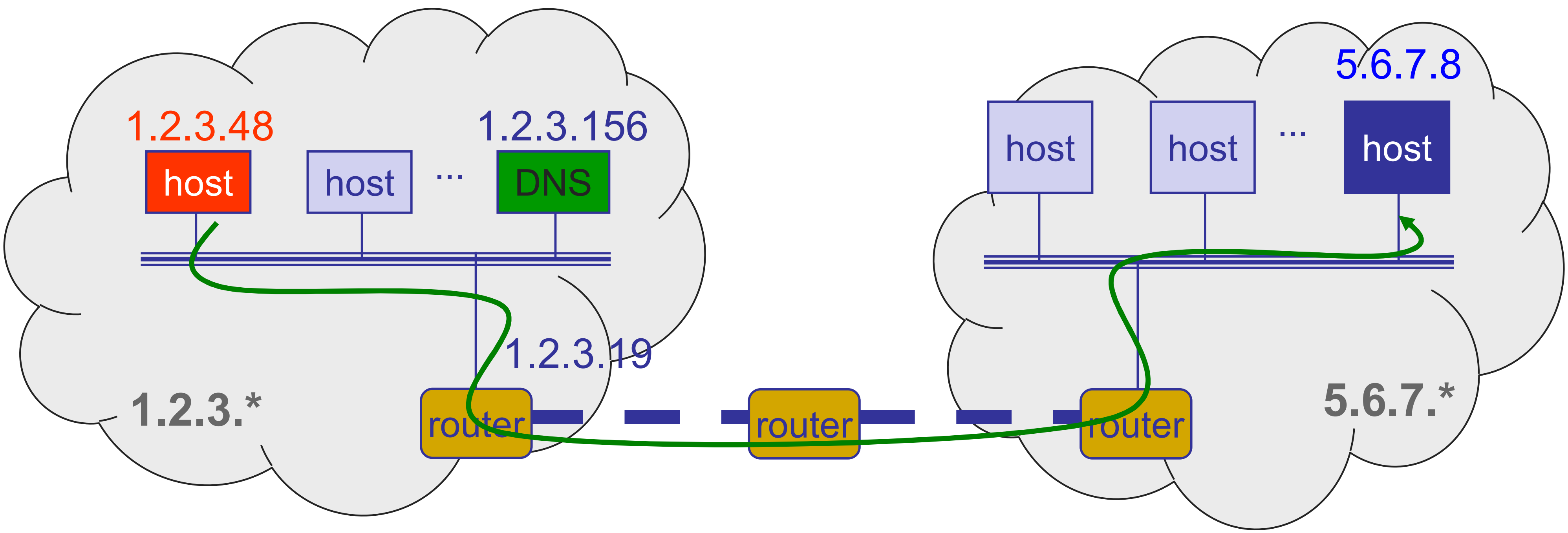
- How is communication organized?

What we want

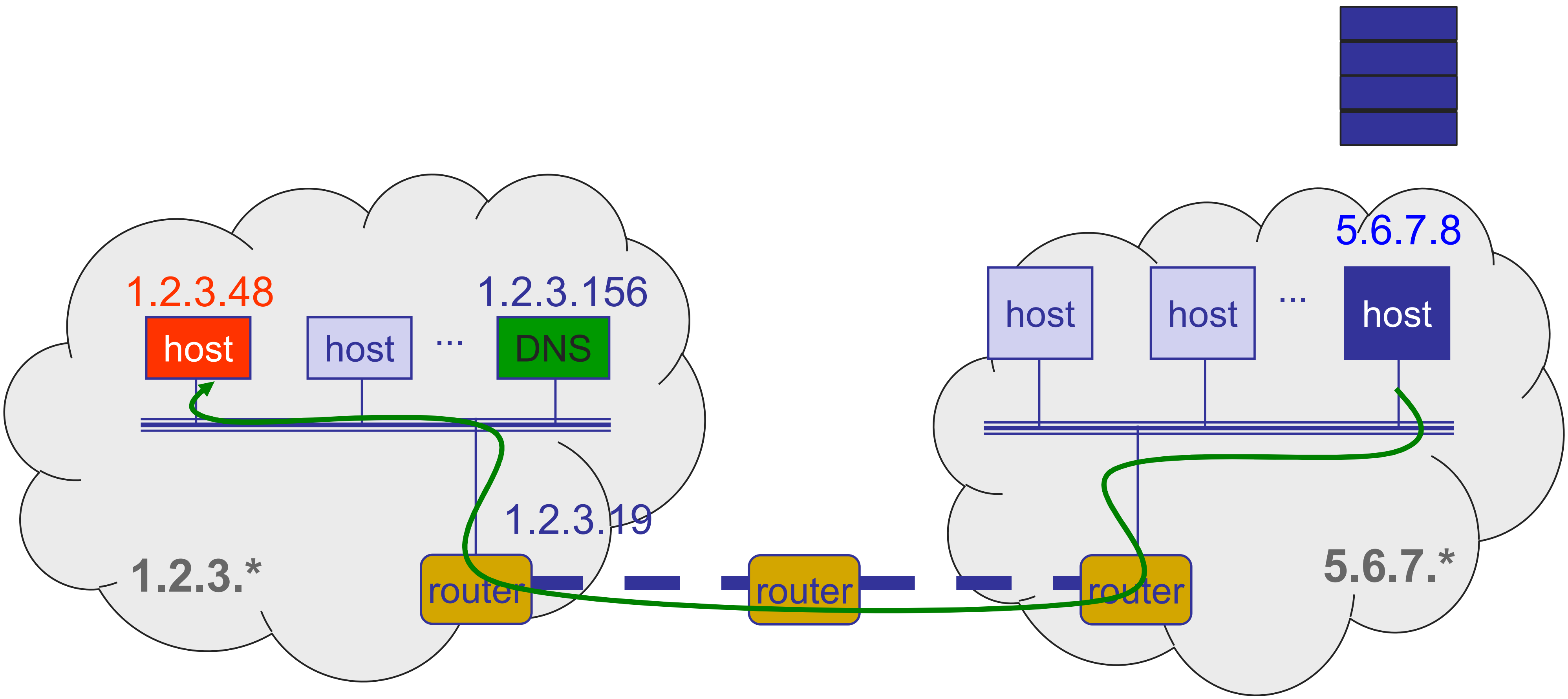
http://123.xyz

123.xyz server

(Some of) What happens...

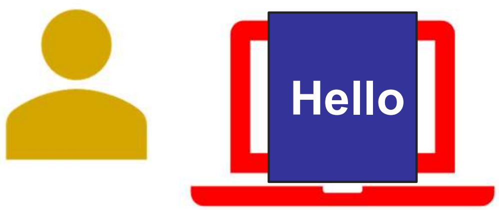


(More of) What happens



What we get

http://123.xyz



123.xyz server

Inspiration…

- CEO A writes letter to CEO B

Dear John,

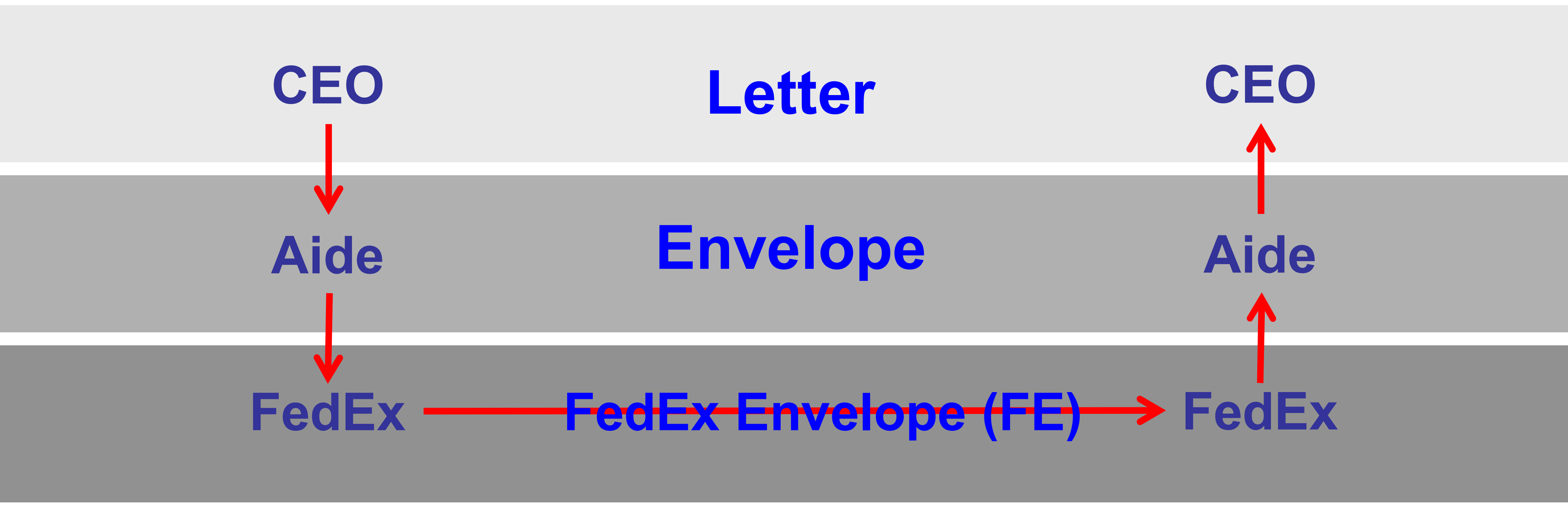
Your days are numbered.

--Pat

Inspiration…

- CEO A writes letter to CEO B
  - Folds letter and hands it to administrative aide
- Aide:
  - Puts letter in envelope with CEO B's full name
  - Takes to FedEx
- FedEx Office
  - Puts letter in larger envelope
  - Puts name and street address on FedEx envelope
  - Puts package on FedEx delivery truck
- FedEx delivers to other company

The path of the letter



The path of the letter

- "Peers" in same layer understand each other
- No one else needs to
- Lowest level has most packaging

CEO	Semantic Content	CEO
Aide	Identity	Aide
FedEx	Location	FedEx

Three steps

- Decompose the problem into tasks
- Organize these tasks
- Assign tasks to entities (who does what)

Back to the Internet: Decomposition

Applications

in built on

Reliable or unreliable transport

in built on

Best-effort global packet delivery

in built on

Best-effort local packet delivery

in built on

Physical transfer of bits

Communication organization

Applications

in built on

Reliable or unreliable transport

in built on

Best-effort global packet delivery

in built on

Best-effort local packet delivery

in built on

Physical transfer of bits

L7	Application
L4	Transport
L3	Network
L2	Data link
L1	Physical

OSI layers

OSI stands for Open Systems Interconnection model

- Developed by the ISO

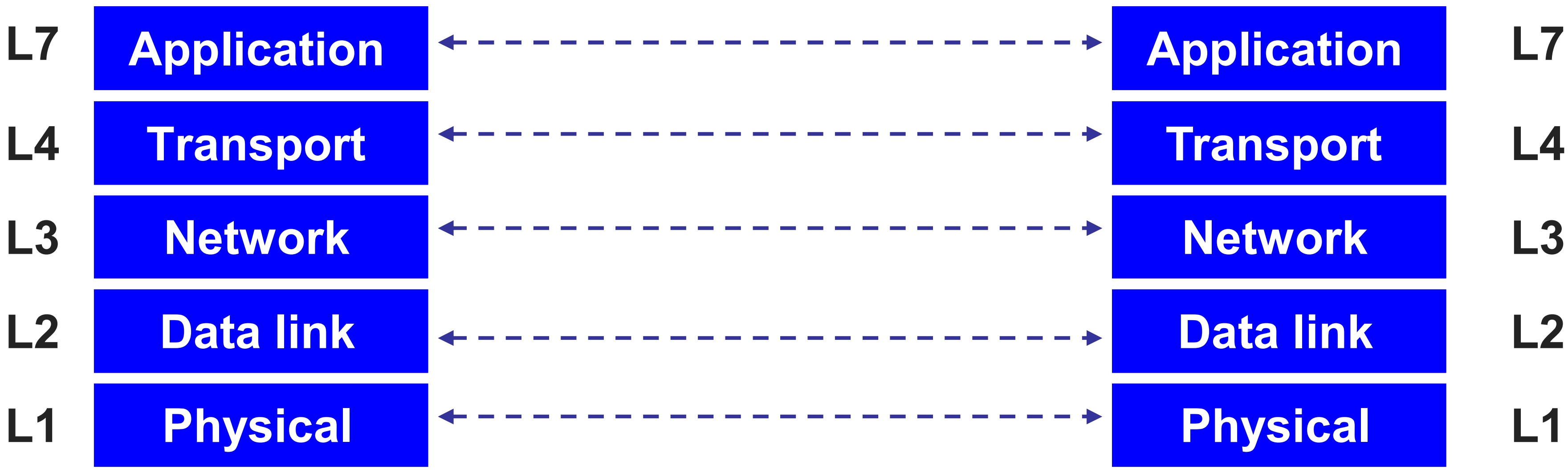
Session and presentation layers are often implemented as part of the application layer

L7	Application
L6	Presentation
L5	Session
L4	Transport
L3	Network
L2	Data link
L1	Physical

Layers

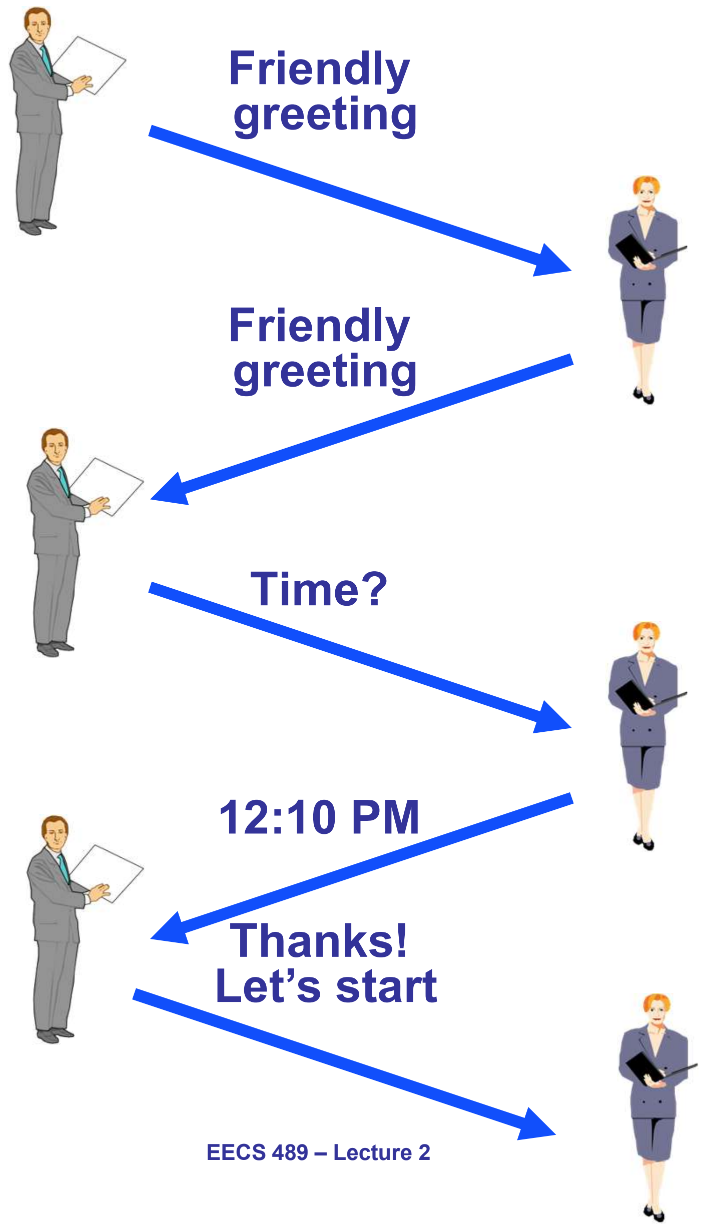
- Layer: a part of a system with well-defined interfaces to other parts
- One layer interacts only with layer above and layer below
- Two layers interact only through the interface between them

Layers and protocols



- Communication between peer layers on different systems is defined by protocols

What is a Protocol?



What is a Protocol?

- An agreement between parties (in the same later) on how to communicate
- Defines the syntax of communication
  - Header → instructions on how to process payload
  - Each protocol defines the format of its headers
    - e.g., “the first 32 bits carry the destination address”

What is a Protocol?

- An agreement between parties on how to communicate
- Defines the syntax of communication
- And semantics
  - “First a hello, then a request…”
  - We will study many protocols later in the semester
- Protocols exist at many levels, hardware, and software
  - Defined by standards bodies like IETF, IEEE, ITU

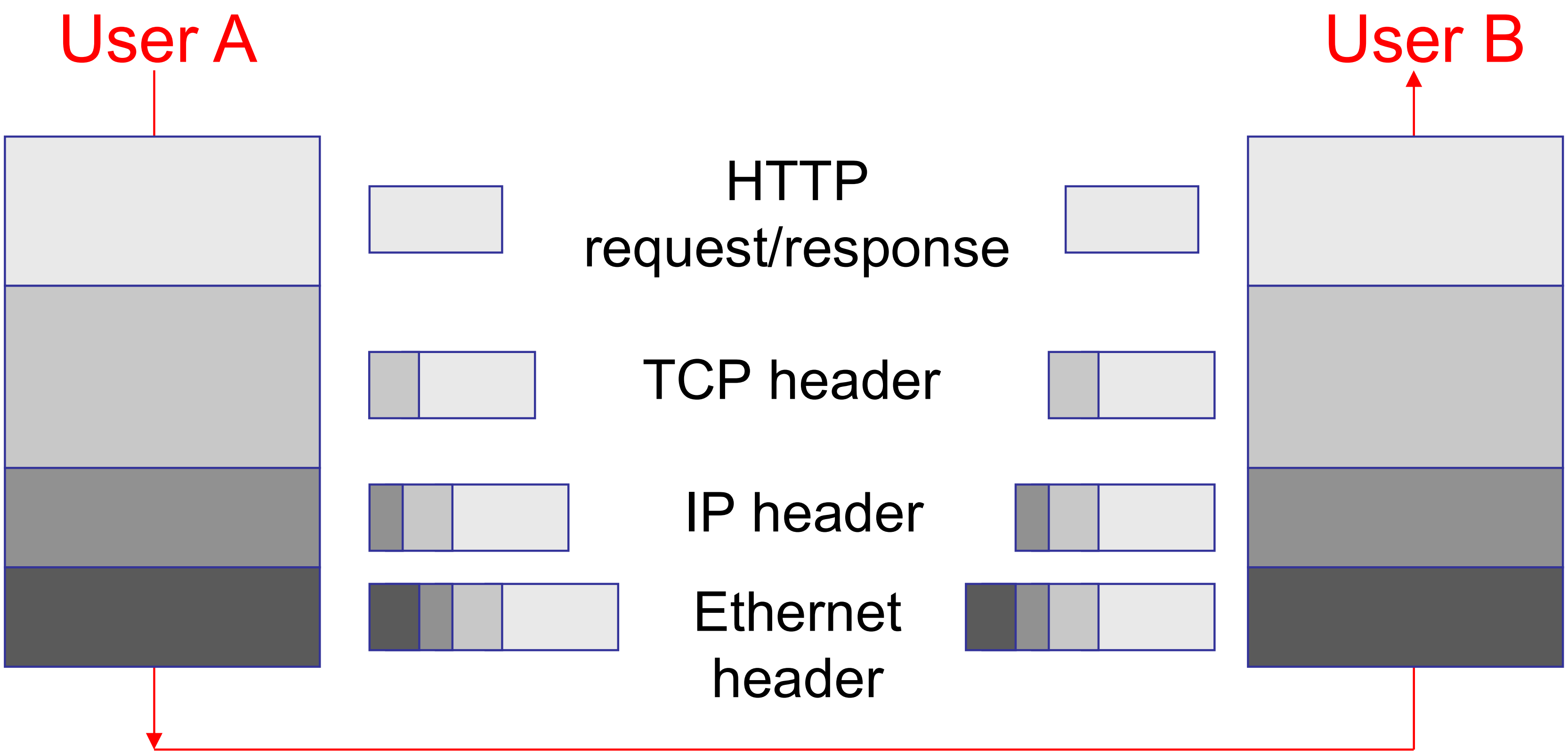
Protocols at different layers

L7	Application	SMTP, HTTP, DNS, NTP
L4	Transport	TCP, UDP
L3	Network	IP
L2	Data link	Ethernet, FDDI, PPP
L1	Physical	Optical, Copper, Radio, PSTN

ONE network layer protocol

L7	Application	SMTP HTTP DNS NTP
L4	Transport	TCP UDP
L3	Network	IP
L2	Data link	Ethernet FDDI PPP
L1	Physical	Optical Copper Radio PSTN

Layer encapsulation: Protocol headers



5-MINUTE BREAK!

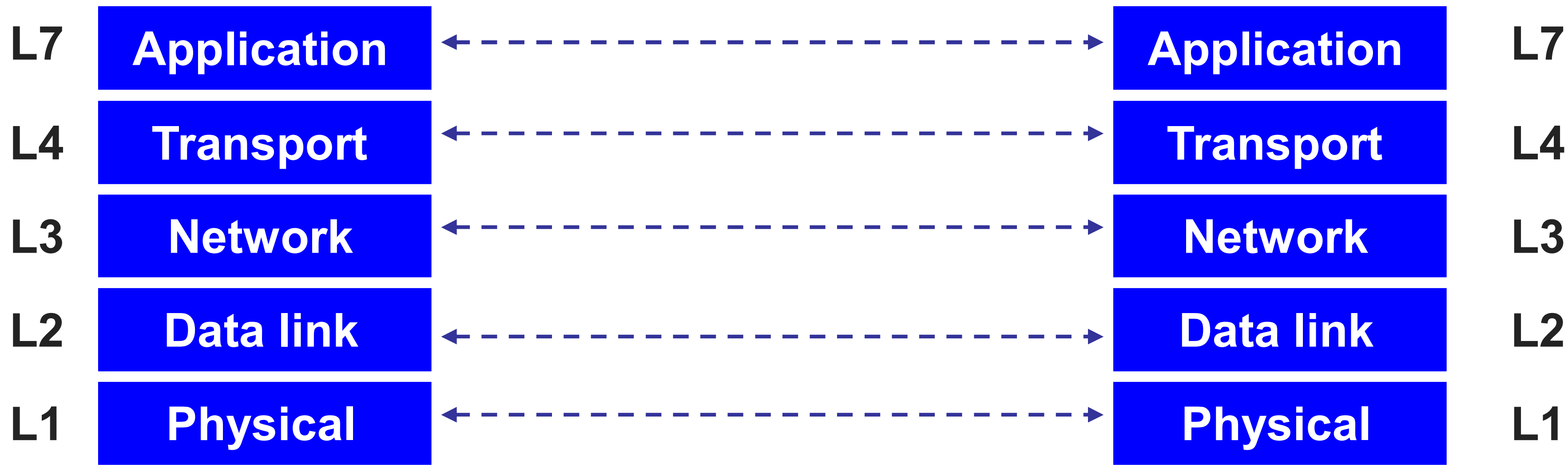
Announcements

- Assignment 1 is out today!

Three steps

- Decompose the problem into tasks
- Organize these tasks
- Assign tasks to entities (who does what)

What gets implemented where?



What gets implemented at the end systems?

Bits arrive on wire, must make it up to application

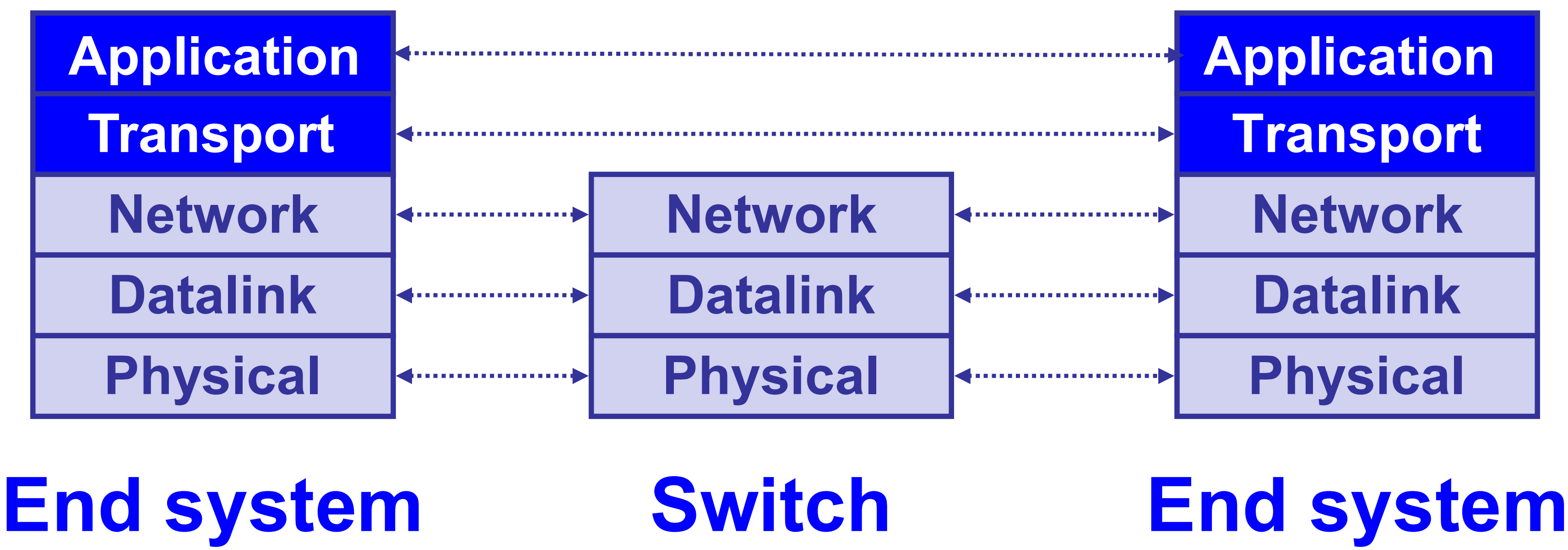
Therefore, all layers must exist at host!

What gets implemented in the network?

- Bits arrive on wire → physical layer (L1)
- Packets must be delivered across links and local networks → datalink layer (L2)
- Packets must be delivered between networks for global delivery → network layer (L3)
- The network does not support reliable delivery
  - Transport layer (and above) not supported

Simple Diagram

- Lower three layers implemented everywhere
- Top two layers implemented only at hosts



A closer look: End system

Application

- Web server, browser, mail, game

Transport and network layer

- typically part of the operating system

Datalink and physical layer

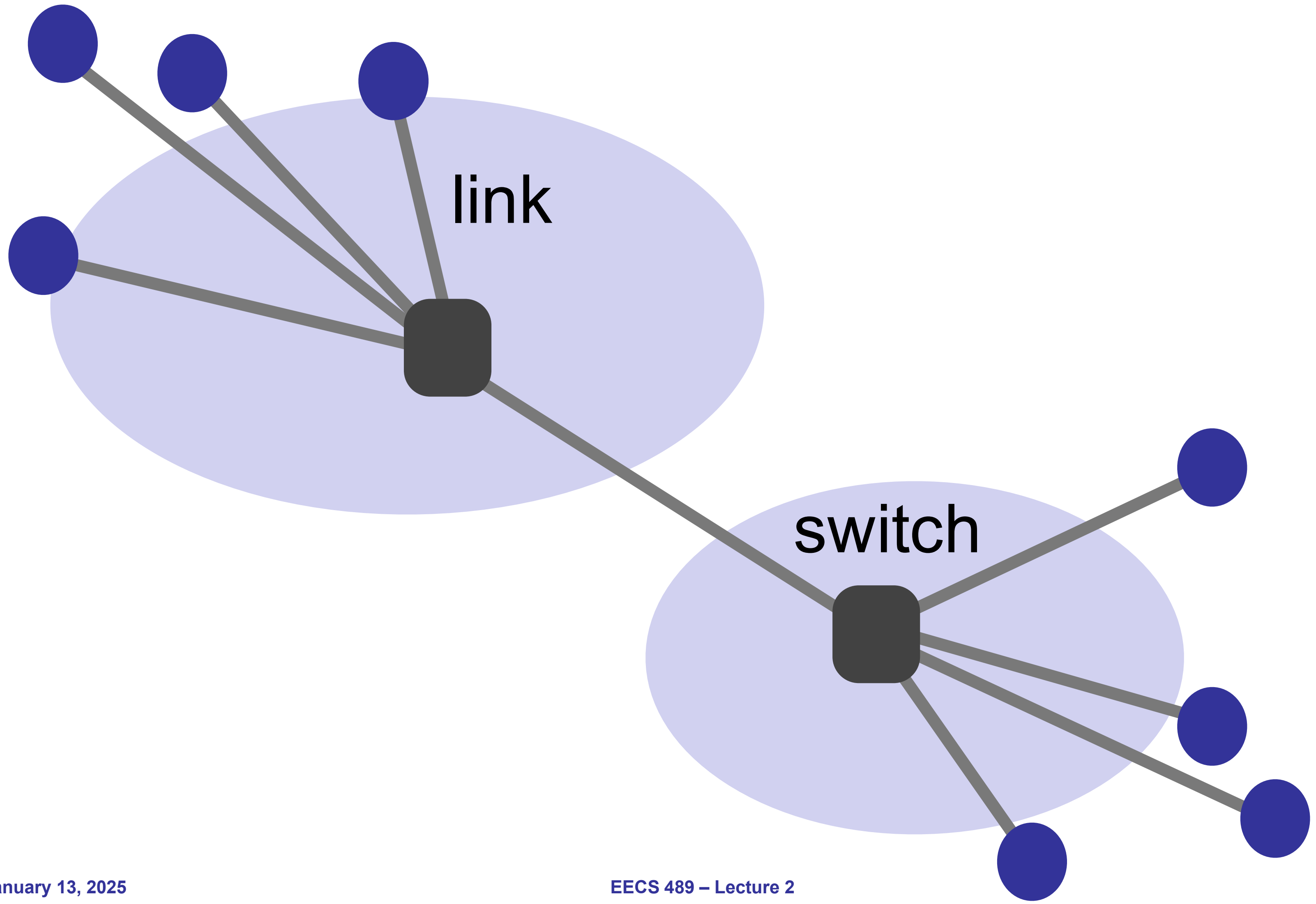
- hardware/firmware/drivers

What gets implemented in the network?

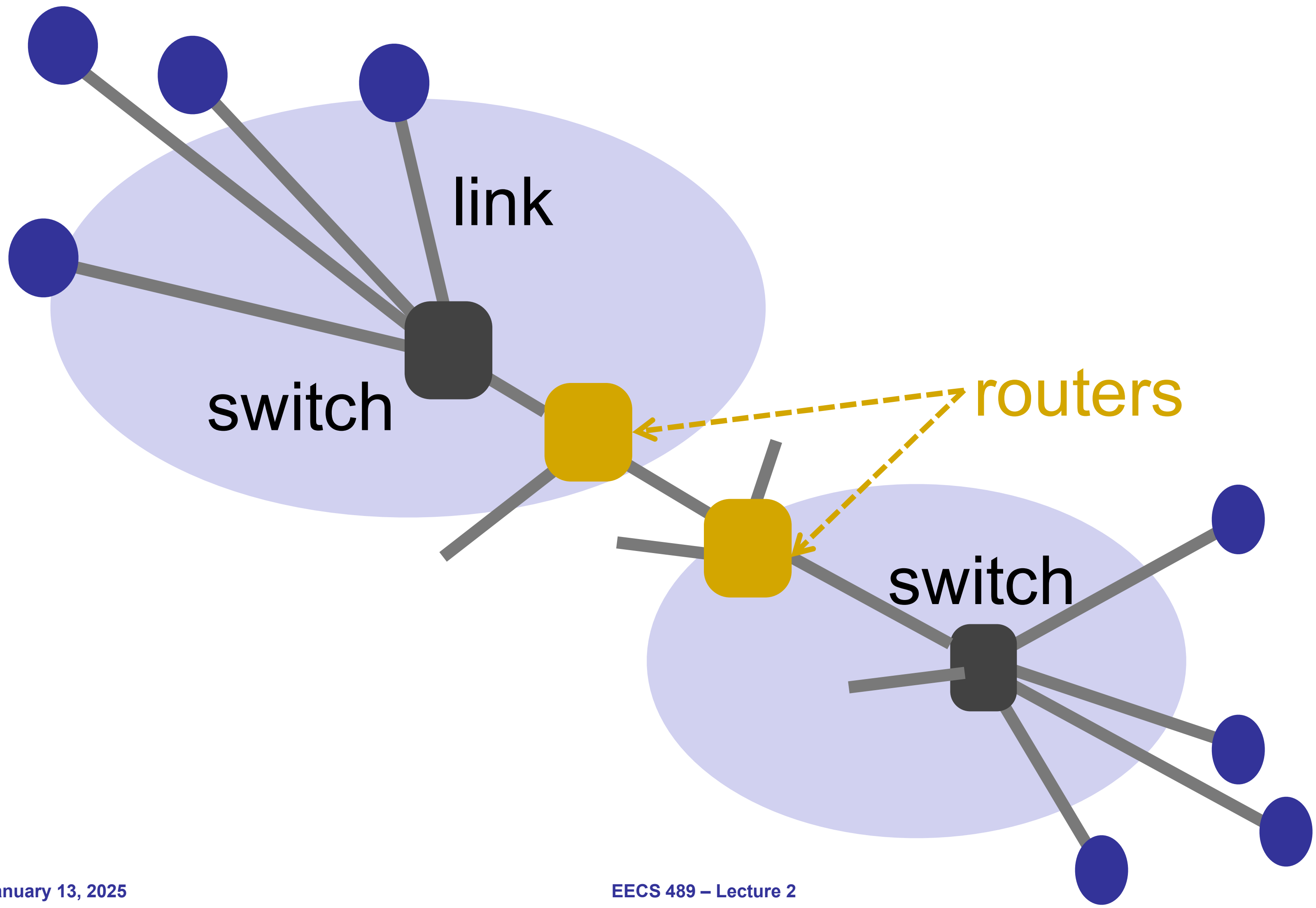
- Bits arrive on wire → physical layer (L1)
- Packets must be delivered across links and local networks → datalink layer (L2)
- Packets must be delivered between networks for global delivery → network layer (L3)

- Switches implement only physical and datalink layers (L1, L2)
- Routers implement the network layer too (L1, L2, L3)

A closer look at the network



A closer look at the network



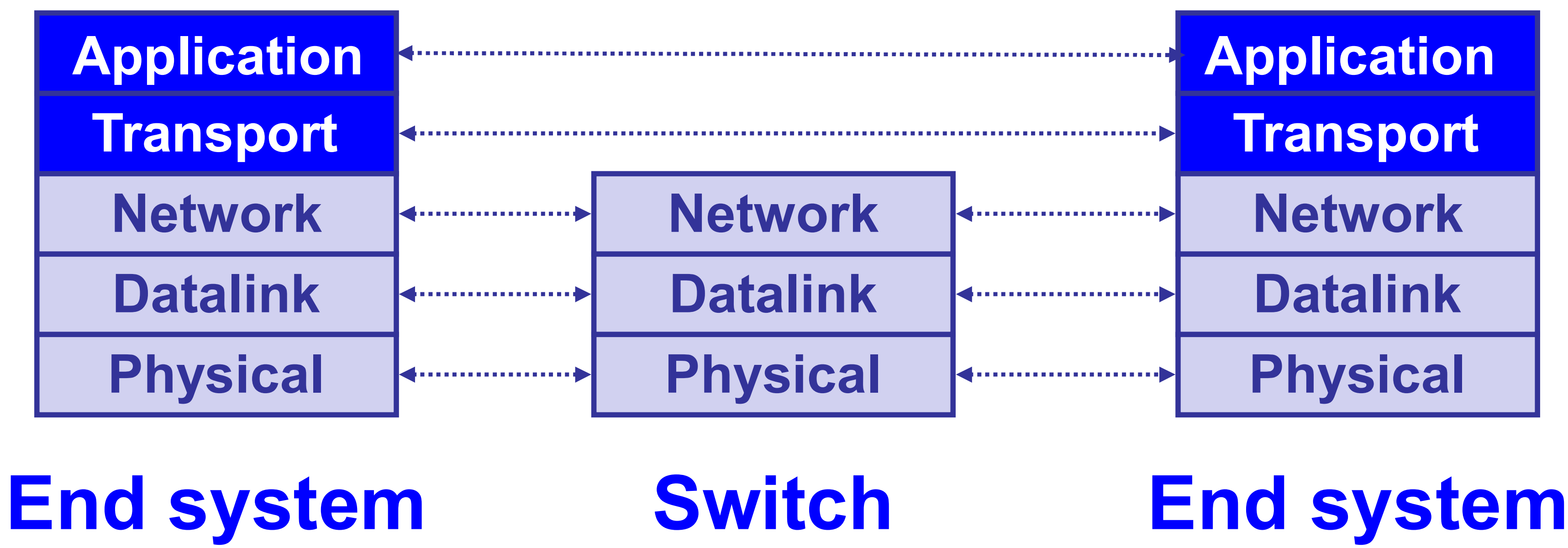
Switches vs. Routers

- Switches do what routers do but don't participate in global delivery, just local delivery
  - Switches only need to support L1, L2
  - Routers support L1-L3

- Won't focus on the router/switch distinction
  - Almost all boxes support network layer these days

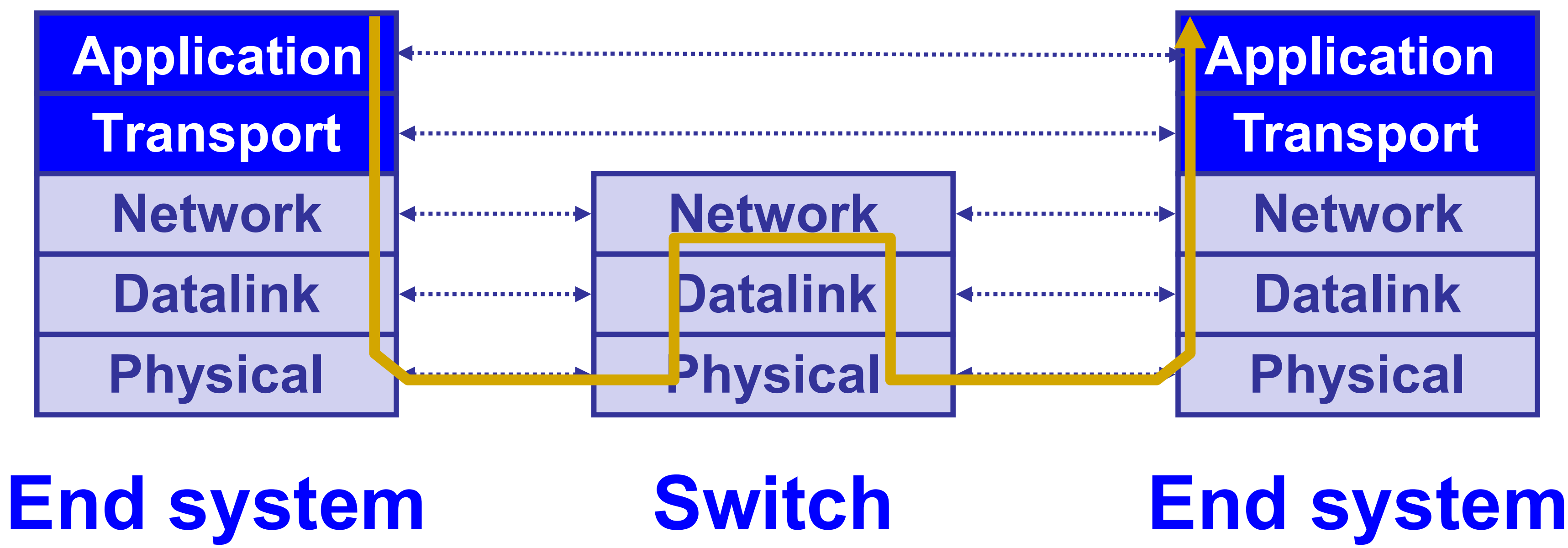
Logical communication

- A layer interact with its peers corresponding layer

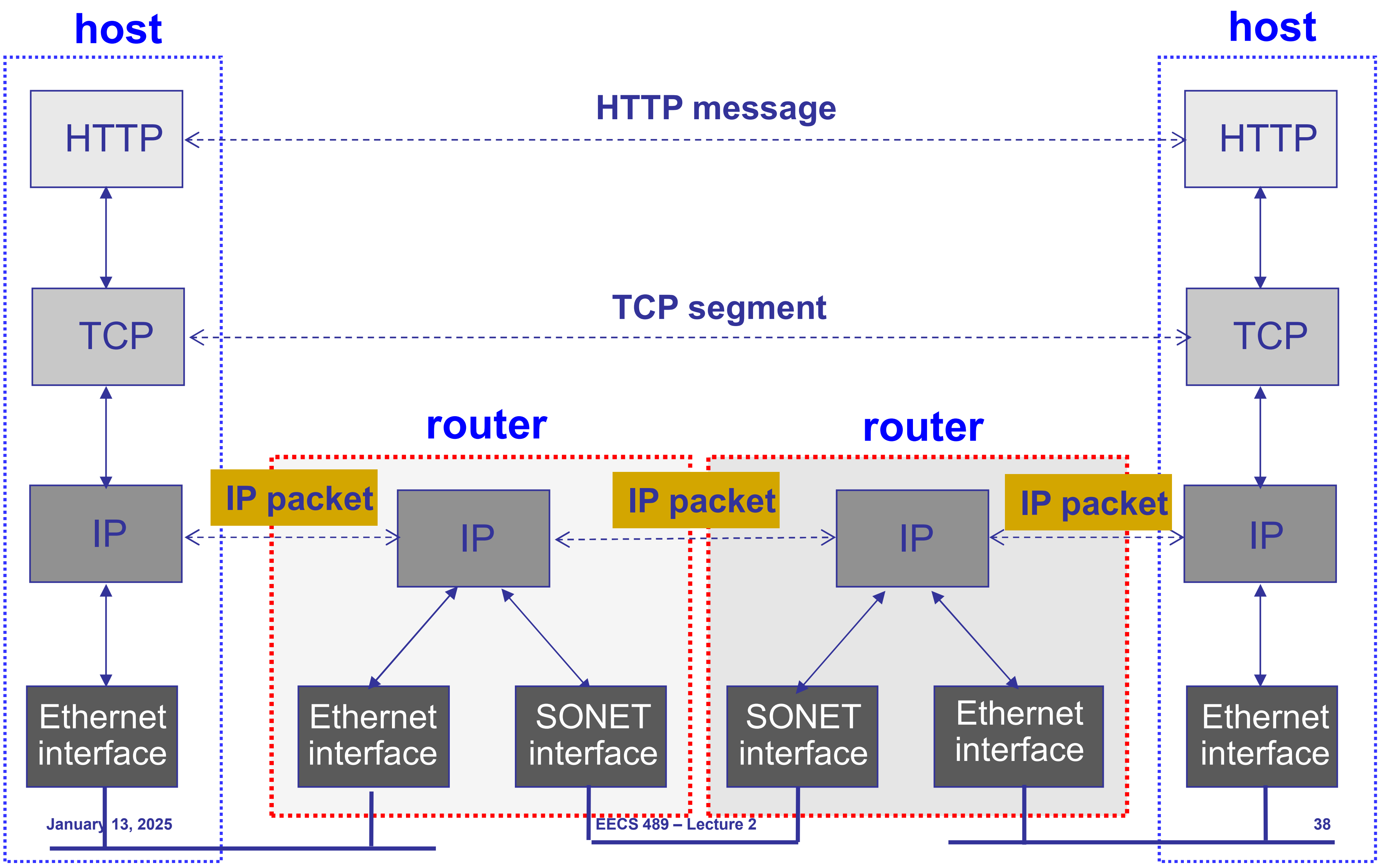


Physical communication

- Communication goes down to physical network
- Then up to relevant layer



A protocol-centric diagram



Pros and cons of layering

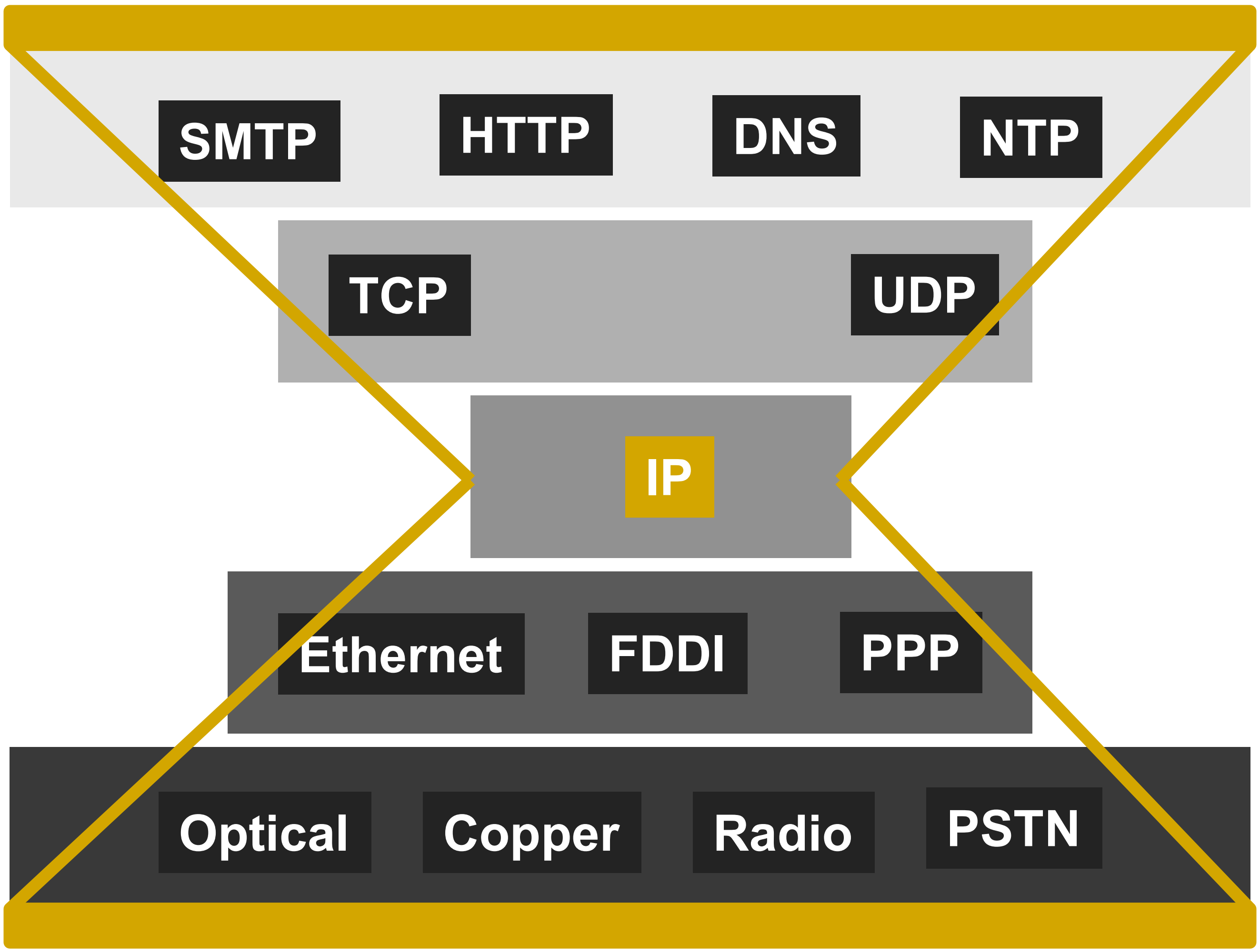
Why layers?

- Reduce complexity
- Improve flexibility
- Better manageability

Why not?

- Higher overheads
- Cross-layer information is often useful

IP is the narrow waist of the layering hourglass



Implications of hourglass

- Single network-layer protocol (IP)
- Allows arbitrary networks to interoperate
  - Any network that supports IP can exchange packets
- Decouples applications from low-level networking technologies
  - Applications function on all networks
- Supports simultaneous innovations above and below IP
- But changing IP itself is hard (e.g., IPv4 → IPv6)

Placing network functionality

- End-to-end arguments by Saltzer, Reed, and Clark
  - Dumb network and smart end systems
  - Functions that can be *completely* and *correctly* implemented *only* with the knowledge of application end host, should not be pushed into the network
  - Sometimes necessary to break this for performance and policy optimizations
  - Fate sharing: fail together or don't fail at all

Fate sharing

Fail together or don't fail at all

- "it is acceptable to lose the state information associated with an entity if, at the same time, the entity itself is lost"
- e.g., state information (like browser session data) is kept only at the endpoints of a communication system (i.e., browser and server), rather than within the network itself
  - » If a failure occurs, it affects only the endpoints and not the entire network

Summary

- Layering is a good way to organize networks
- Unified Internet layer decouples applications from networks
- E2E argument encourages us to keep IP simple