EN.601.414/614
Computer Networks

Protocol Layering

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JOHNS HOPKINS
U N I V E R S I T Y

https://github.com/xinjin/course-net

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Agenda

- **How is communication organized?**

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

CEO → Aide → FedEx → **FedEx Envelope** → FedEx → Aide → CEO

Letter

Envelope

FedEx Envelope
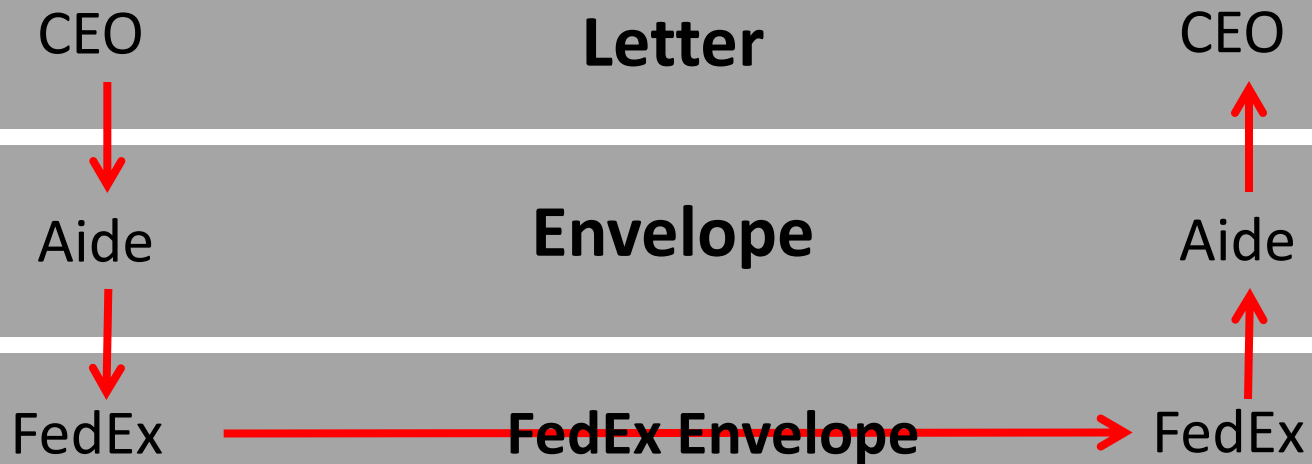
The path of the letter

- "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

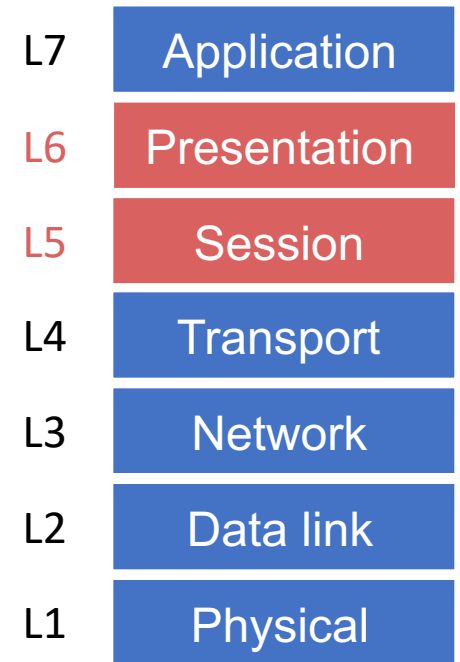|	
L7	Application
L4	Transport
L3	Network
L2	Data link
L1	Physical

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

L7	Application	Application	L7
L4	Transport	Transport	L4
L3	Network	Network	L3
L2	Data link	Data link	L2
L1	Physical	Physical	L1
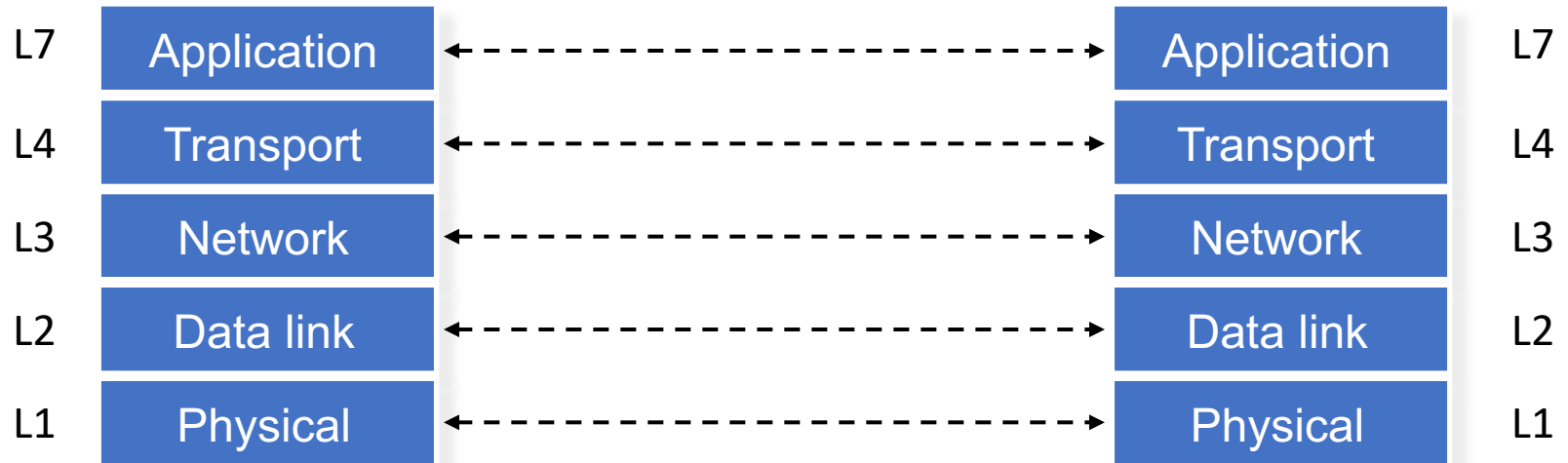
- **Communication between peer layers on different systems is defined by protocols**

What is a Protocol?
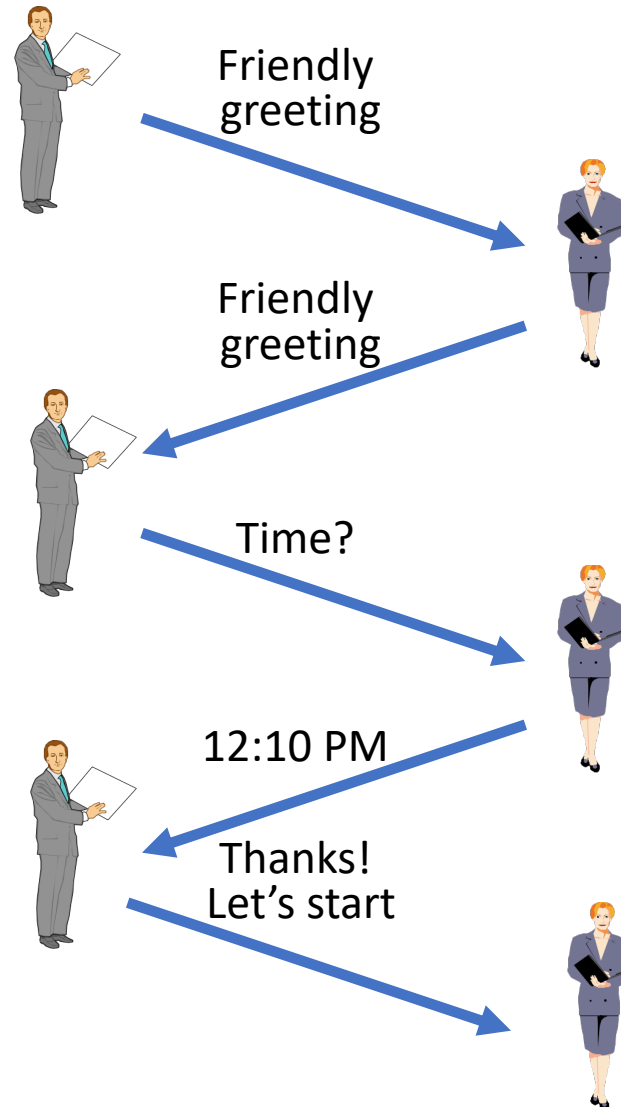
Friendly greeting

Friendly greeting

Time?

12:10 PM

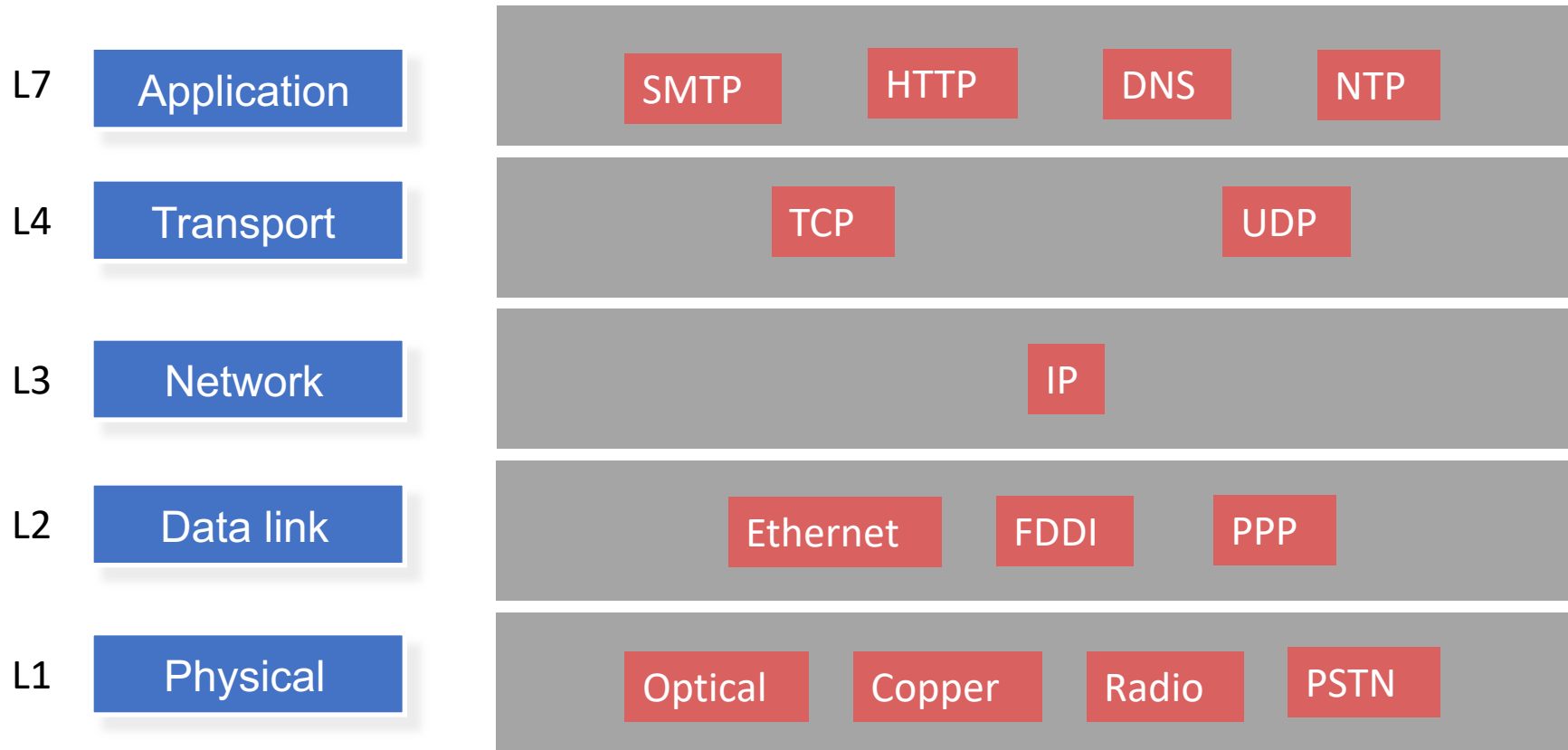Thanks! Let's start

What is a Protocol?

- **An agreement between parties (in the same layer) 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"

Payload	Header

What is a Protocol?

- **An agreement between parties (in the same layer) 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**
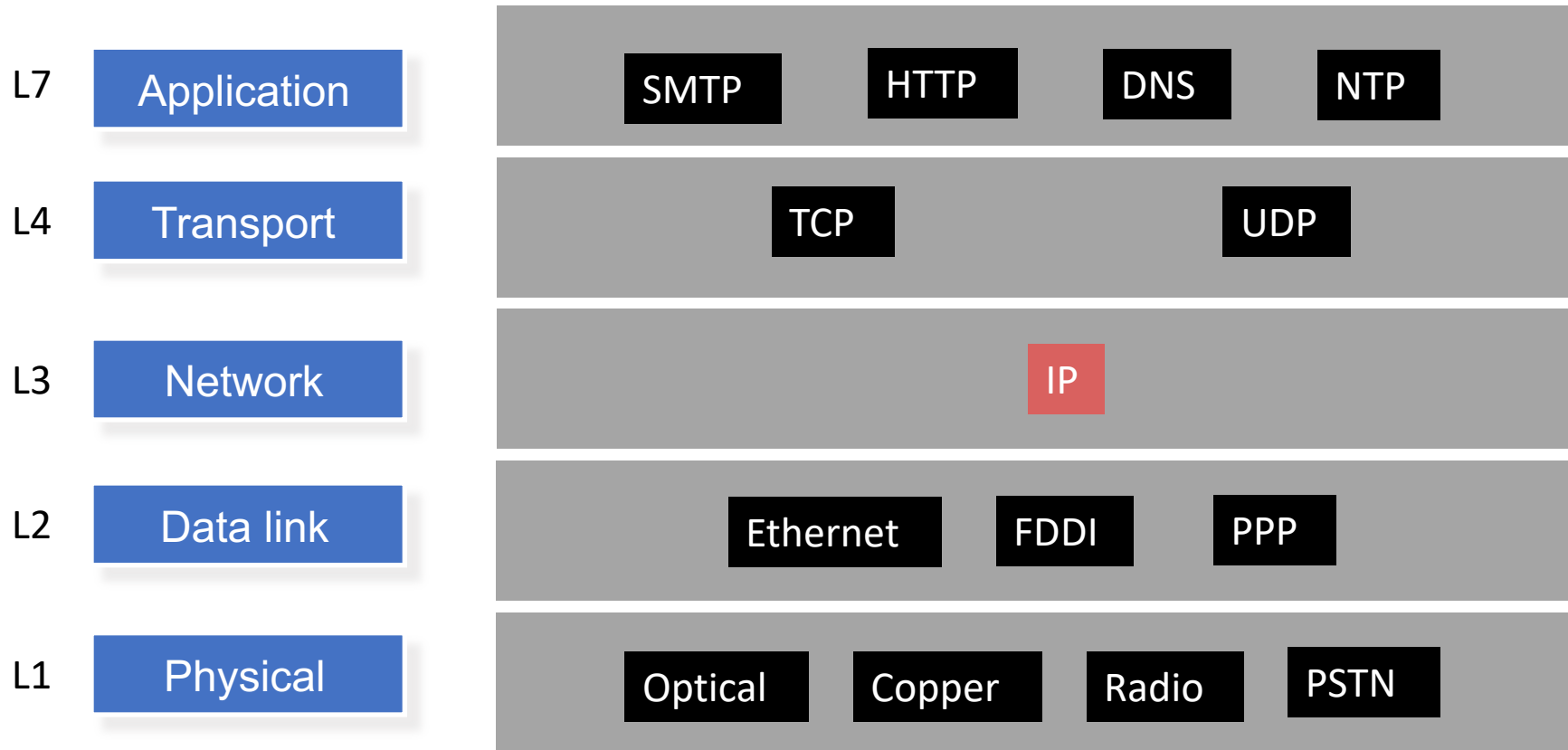 - ➢ Defined by standards bodies like IETF, IEEE, ITU

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

A Plethora of Protocol Acronyms

SNMP
WAP
SIP
IPX
PPP
MAC
LLDP
FTP
UDP
OSPF
RTP
ICMP
IMAP
IGMP
HIP
BGP
HTTP
ECN
PIM
RED
ARP
IP
TCP
RIP
MPLS
RTCP
SMTP
BFD
CIDR
RTSP
NNTP
TLS
NAT
SACK
STUN
DNS
SSH
DHCP
POP
VLAN
LISP
VTP
TFTP
LDP

ONE network layer protocol

| Layer		
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

What do students say about this course?

- "In the computer networks class, I fell asleep at the start of the semester when the IP header was on the screen, and woke up at the end of the semester with the TCP header on the screen."

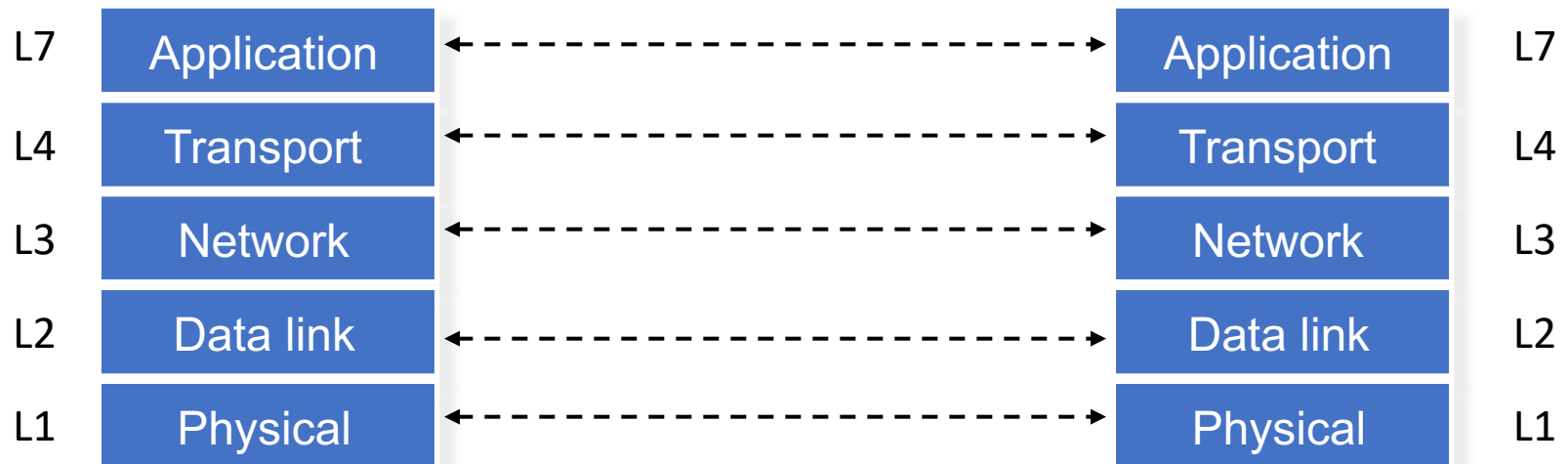- "Network class final: ARP, DHCP, ICMP, IGMP, IP, TCP, UDP."

Layer encapsulation: Protocol headers
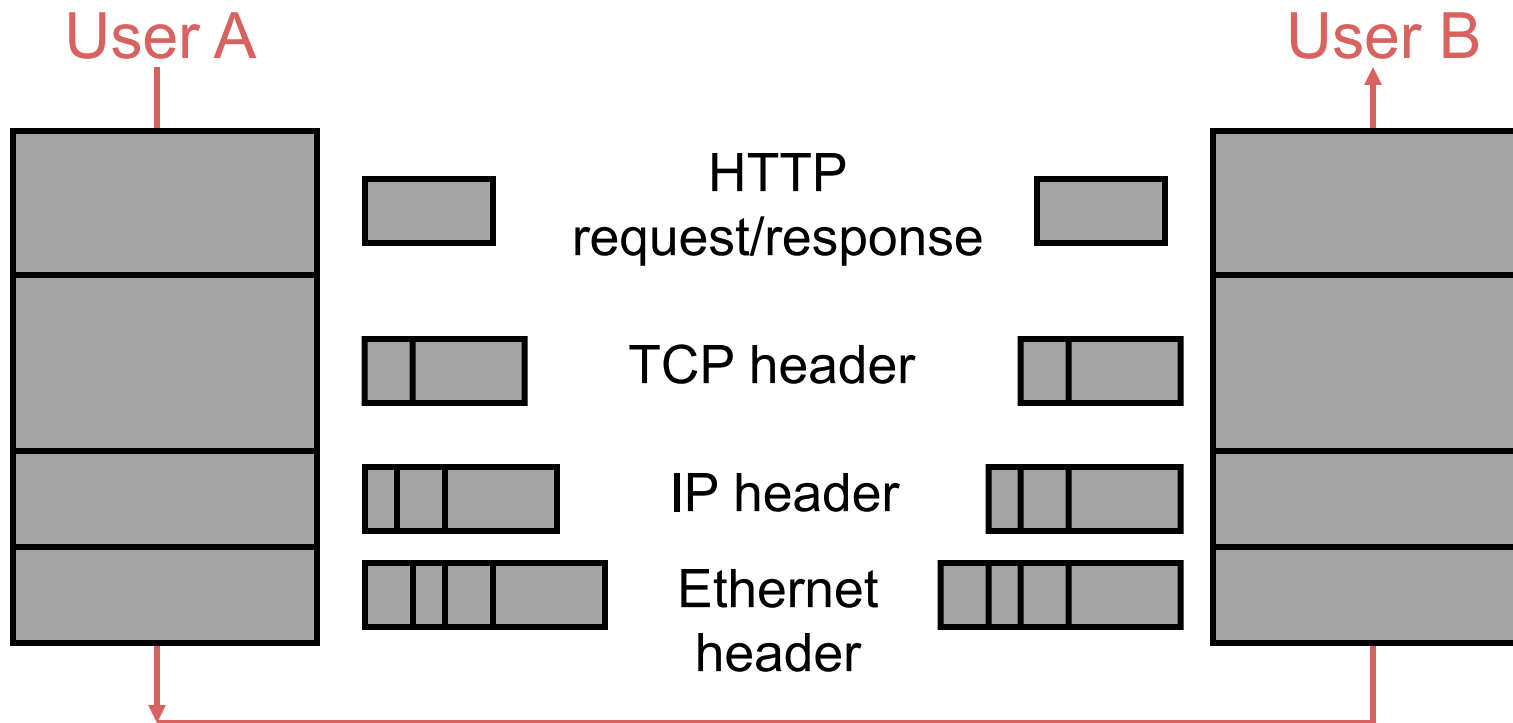
User A

User B

HTTP request/response

TCP header

IP header

Ethernet header

Three steps

- Decompose the problem into tasks

- Organize these tasks

- Assign tasks to entities (who does what)

What get's implemented where?

|				
L7	Application	← - - - - - - - - - - - - - - →	Application	L7
L4	Transport	← - - - - - - - - - - - - - - →	Transport	L4
L3	Network	← - - - - - - - - - - - - - - →	Network	L3
L2	Data link	← - - - - - - - - - - - - - - →	Data link	L2
L1	Physical	← - - - - - - - - - - - - - - →	Physical	L1

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 → data link 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) at end systems supports

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Simple Diagram

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

| Application |
| Transport |
| Network |
| Data link |
| Physical |

End system **Switch** **End system**
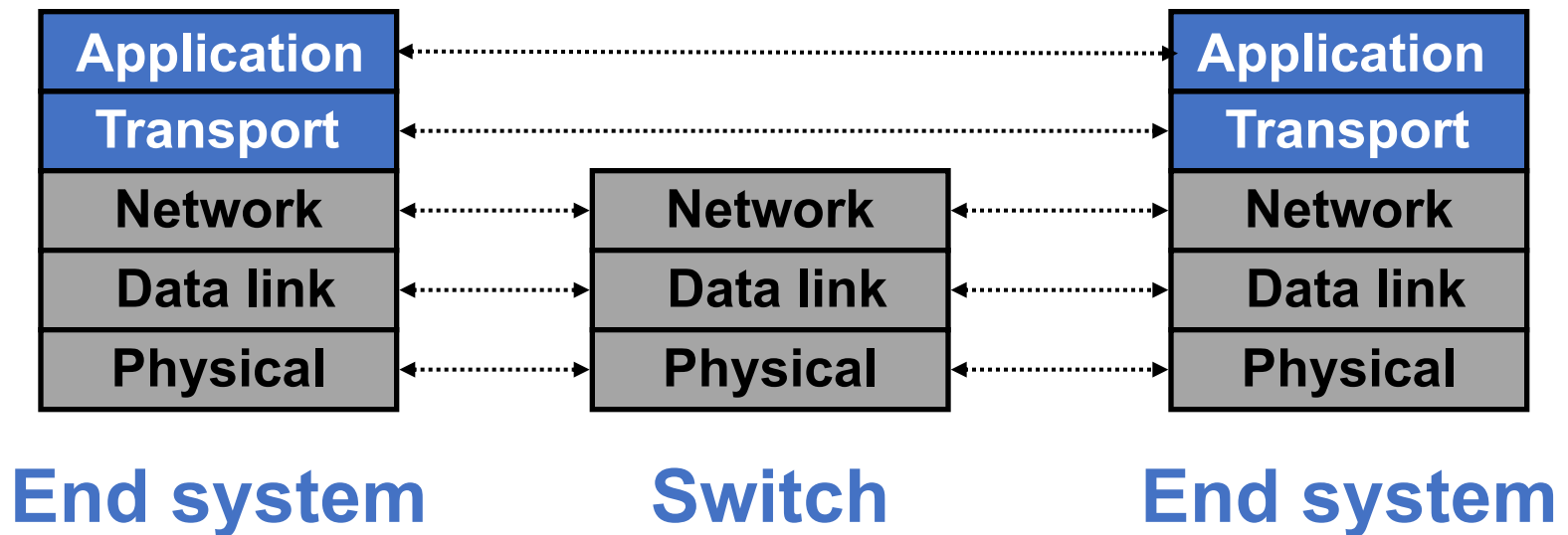
A closer look: End system

- **Application**
  - ➢Web server, browser, mail, game

- **Transport and network layer**
 - ➢typically part of the operating system

- **Data link 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 → data link 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

link

switch

switch

link

A closer look at the network
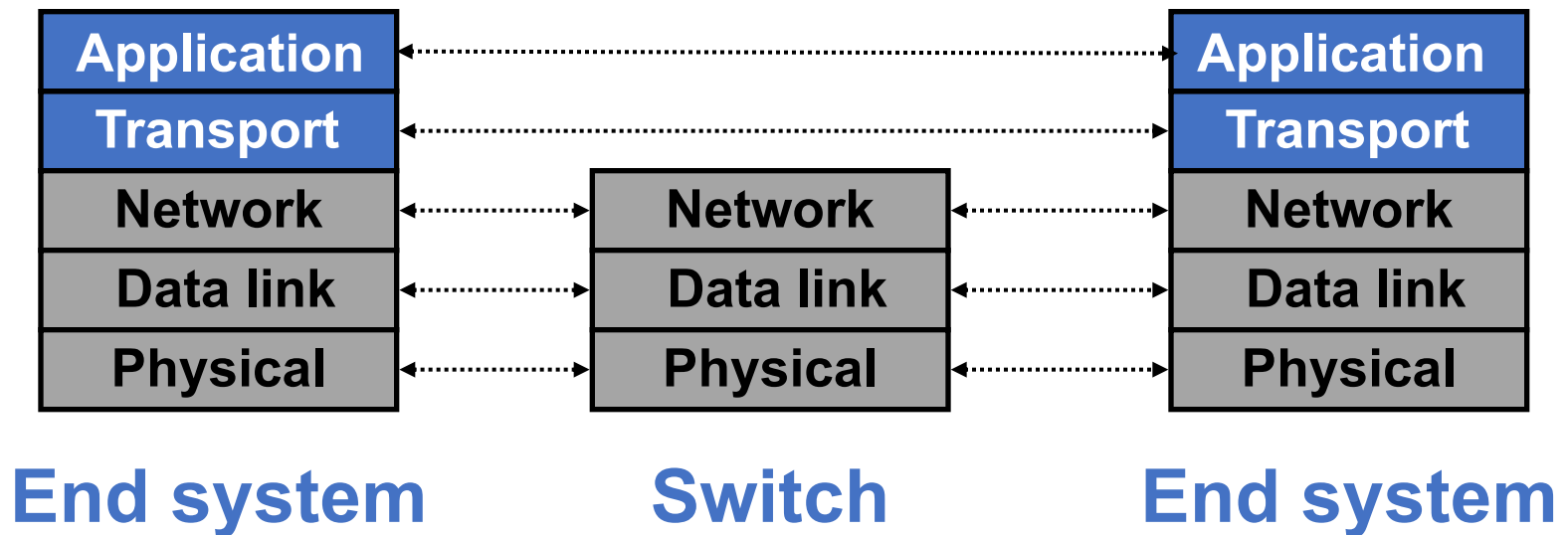
link
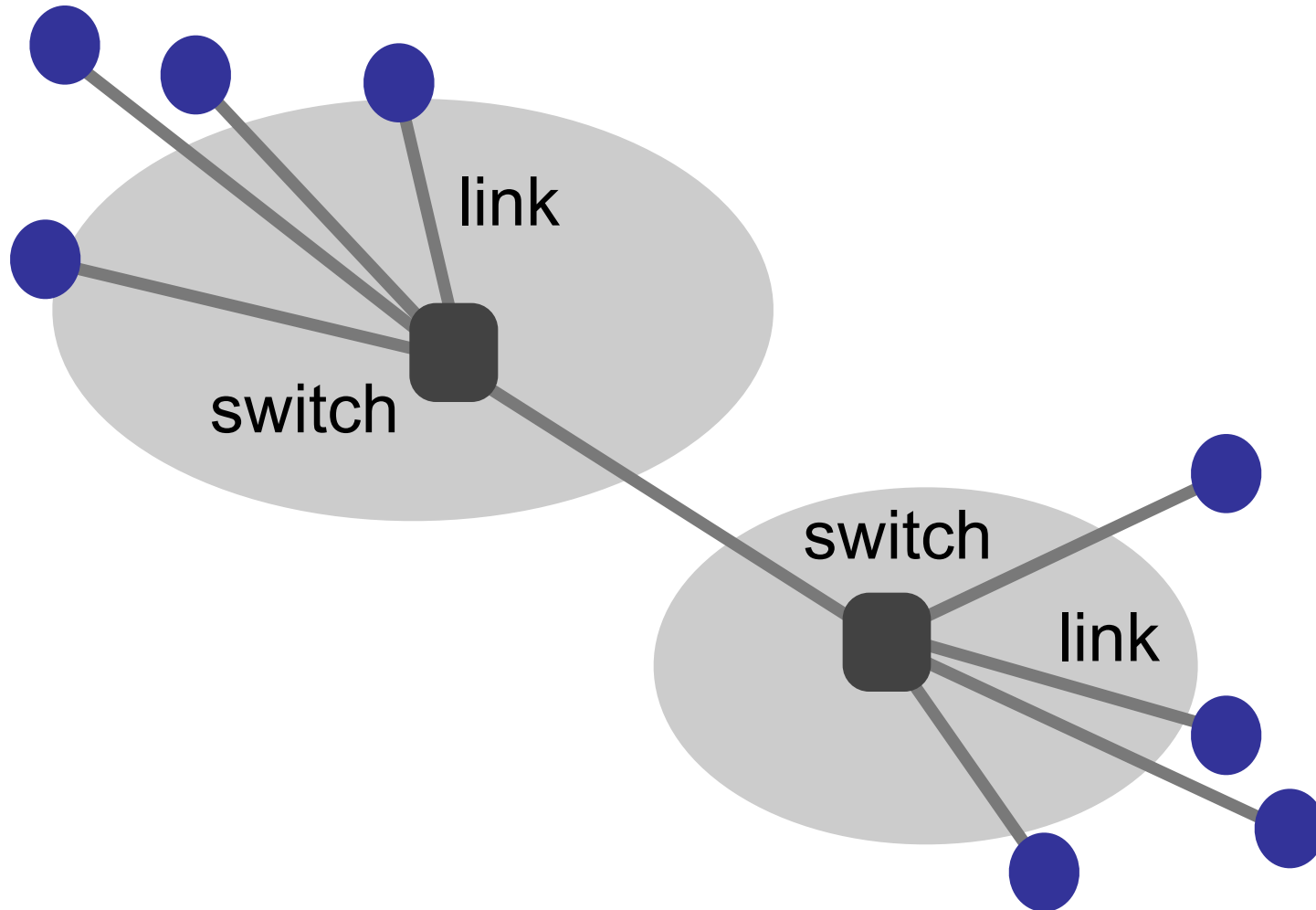
switch

routers

switch

link
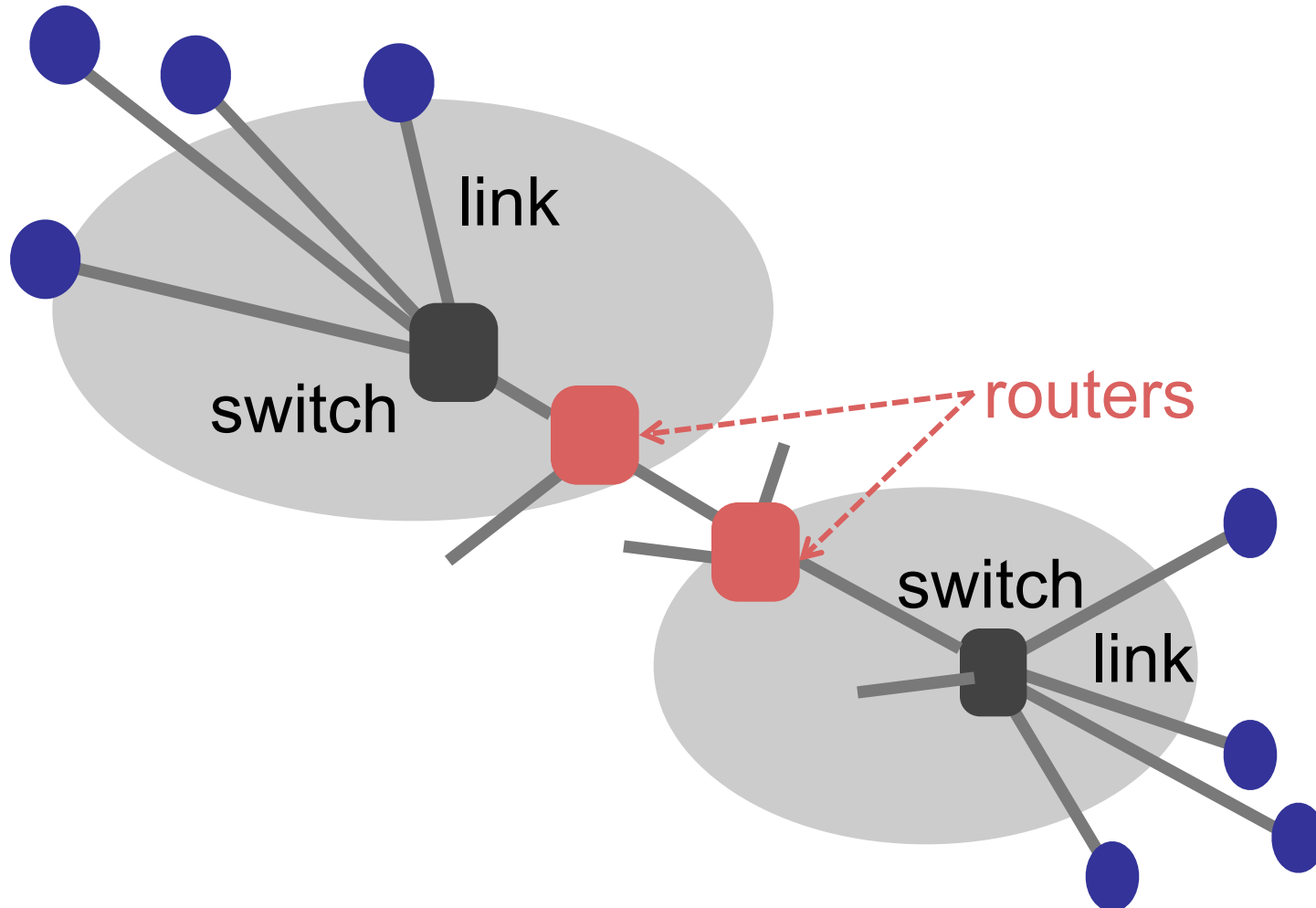
Switches vs. Routers

- **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**
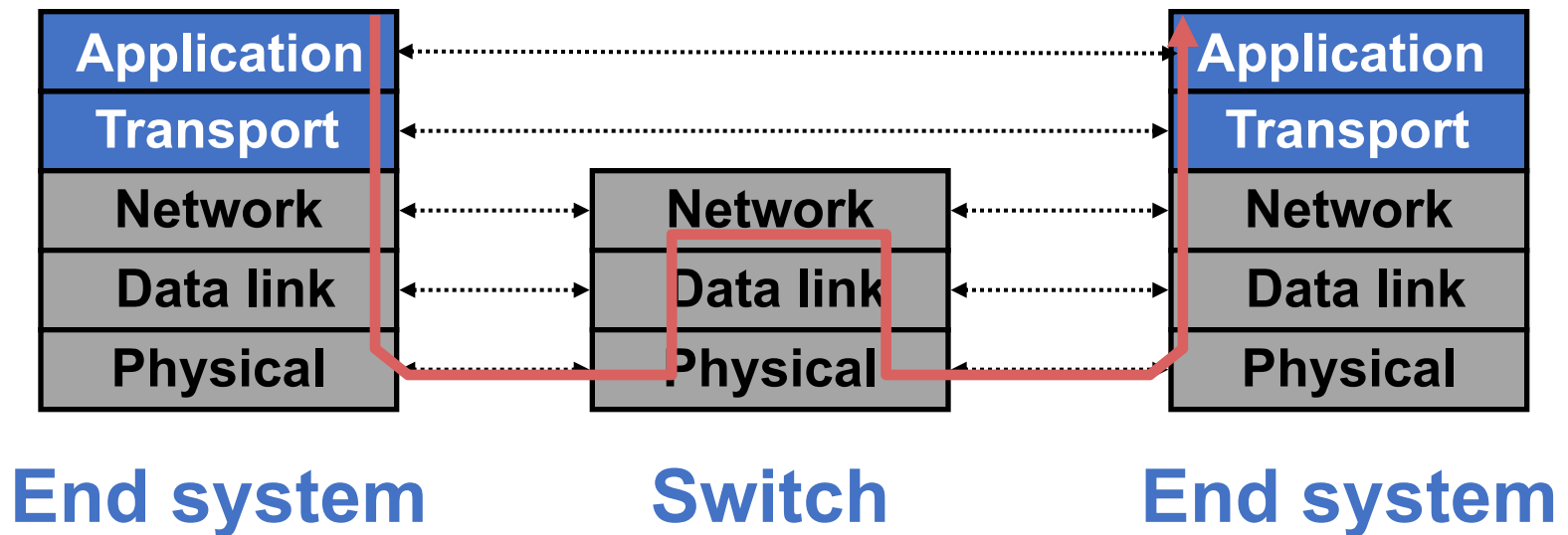 - ➢Almost all boxes support network layer these days

Logical communication
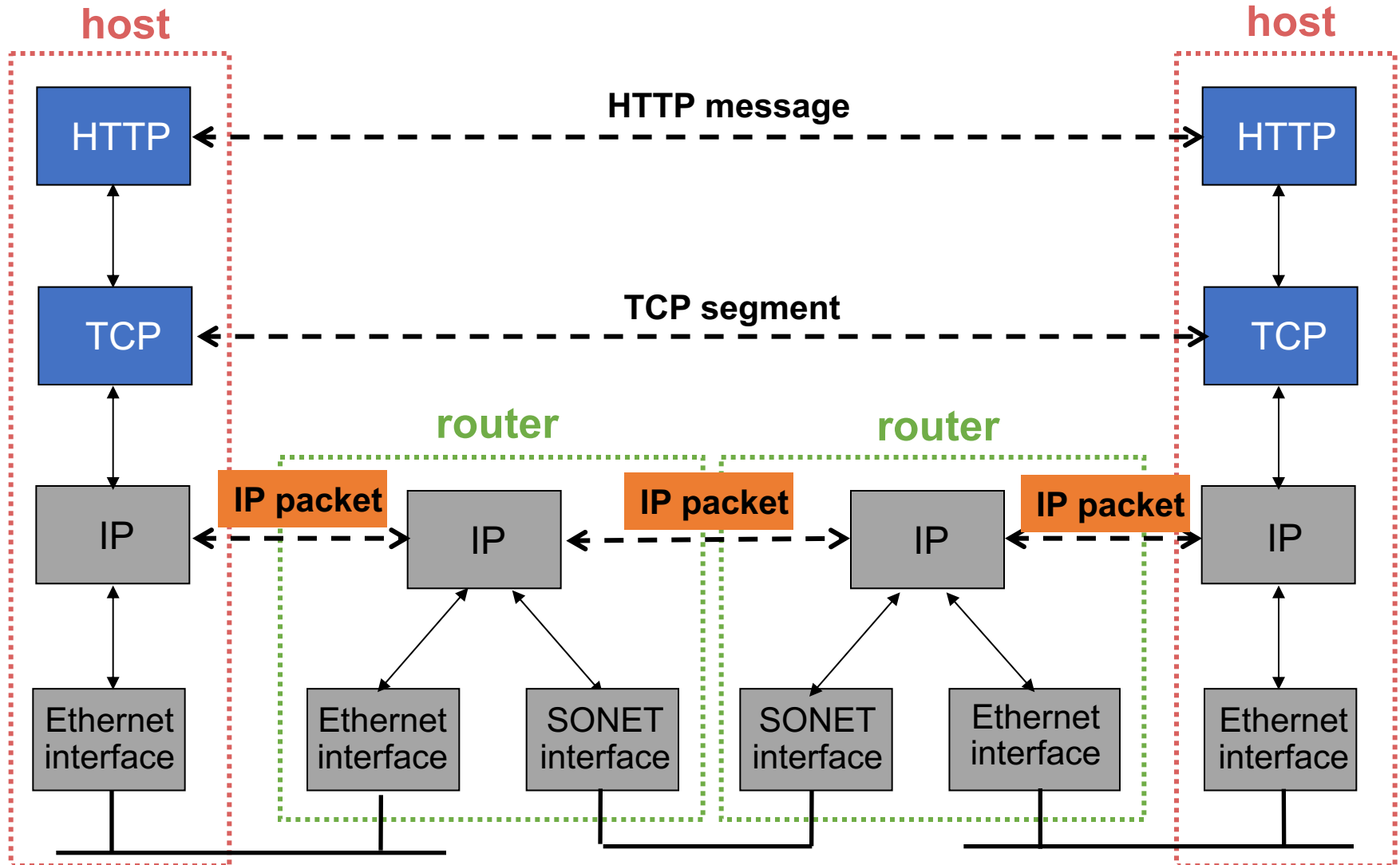
- **A layer interact with its peers corresponding layer**

Application		Application
Transport		Transport
Network	Network	Network
Data link	Data link	Data link
Physical	Physical	Physical

End system　　　　**Switch**　　　　**End system**

Physical communication

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

Application		Application
Transport		Transport
Network	Network	Network
Data link	Data link	Data link
Physical	Physical	Physical

End system   **Switch**   **End system**

A protocol-centric diagram
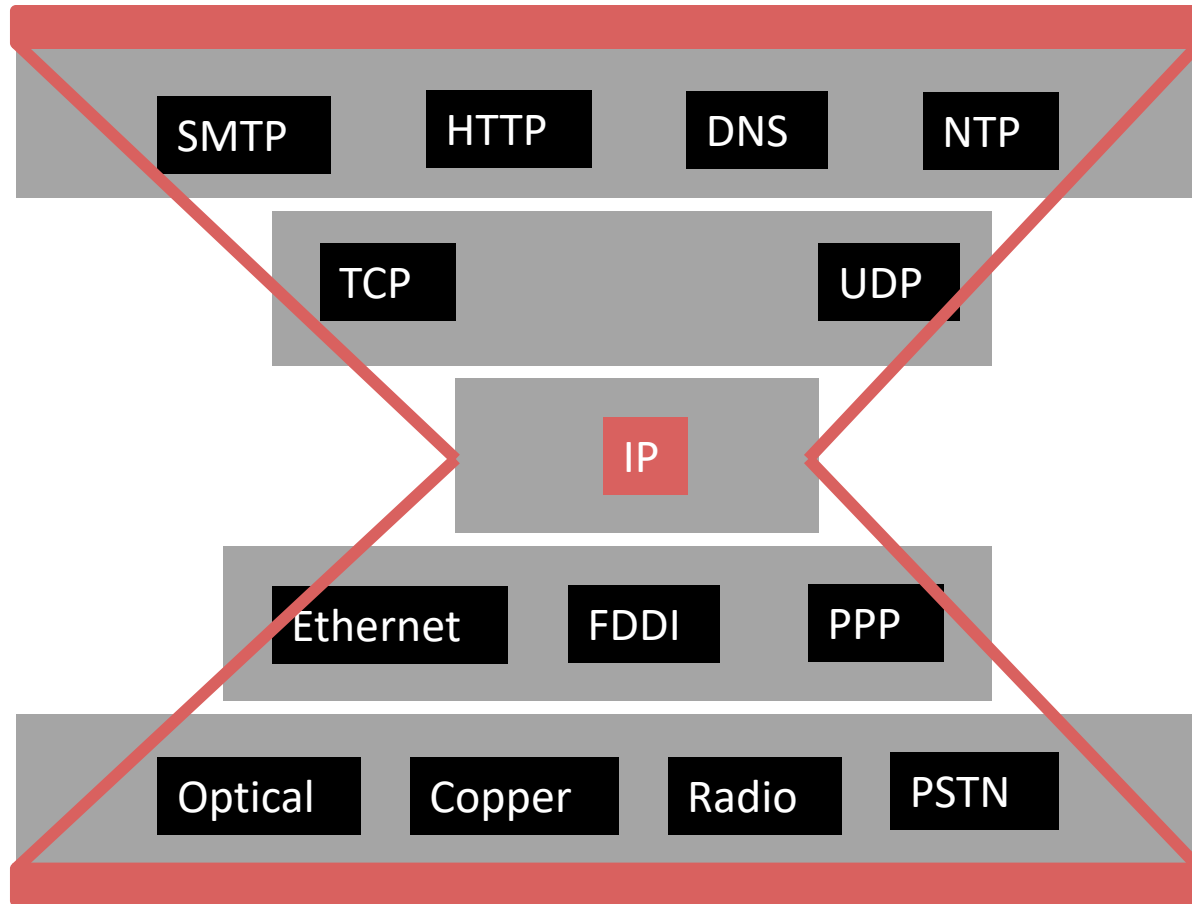
Pros and cons of layering

Why layers?

- Reduce complexity

- Improve flexibility

Why not?

- Higher overheads

- Cross-layer information 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

Assignment 1

- **Socket Programming**
  - ➢Socket: communication endpoint at the end hosts
  - ➢Provide an application interface to exchange data between processes.

- **Server side**
  - ➢socket() → bind() → listen() → accept() → recv() → close()

- **Client side**
  - ➢socket() → connect() → send() → close()

Group Discussion

- **Topic: protocol layering**
  - ➢What are the five layers?
  - ➢Pick a functionality. Should the functionality be implemented in the end systems or the network? Why?
    - • Example functionalities: compute forwarding path, handle packet loss, handle packet retransmission, packet packet corruption, handle packet reordering, etc.

- **Discuss in groups, and each group chooses a leader to summarize the discussion**
  - ➢In your group discussion, please do not dominate the discussion, and give everyone a chance to speak

Summary

- **Layering is a good way to organize networks**

- **Unified Internet layer decouples applications from networks**

- **E2E argument encourages us to keep IP simple**

- **Assignment 1 is out**

Thanks!
Q&A