
University of Pittsburgh
ECE 1150: Computer Networks
Protocols, Layering, TCP/IP
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1

Previous Lectures

- Circuit switching
- Packet switching
- Delay components
- Throughput

Objectives of This Unit

- Describe what is meant by **layering**
- Explain why we need a **protocol**
- Describe **TCP/IP** protocol and **OSI** model
- Explain what ***encapsulation*** is and how it is used in communications networks
- Explain how the “Internet” is constructed in general terms

Processes

- **Software programs** run as **processes** on an operating system (OS)
  - In Unix like operating systems, terminal command *ps* lists the processes
  - In Windows, you can use the task manager to list processes

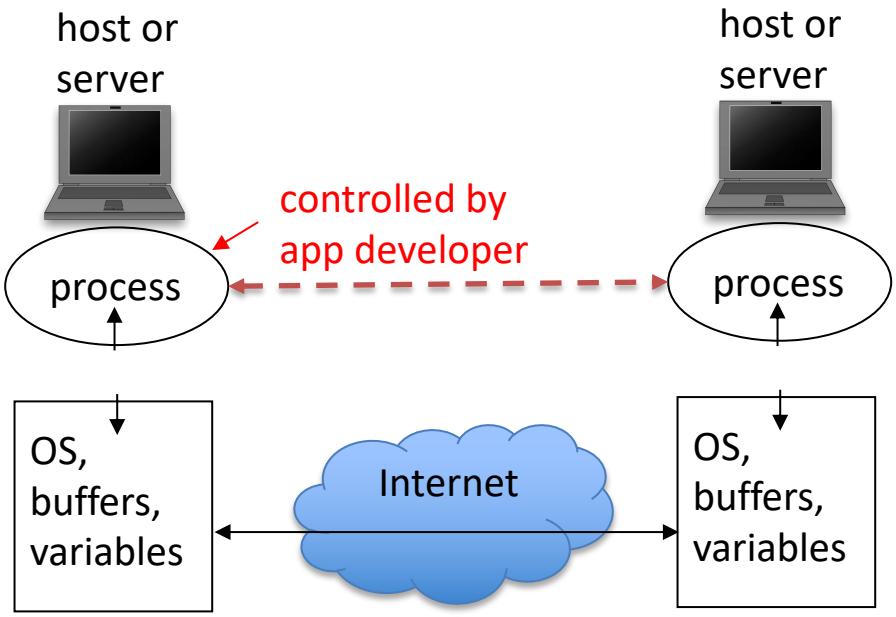


Figure modified from Kurose and Ross

Networked Applications

- Processes on computers can communicate

- If the processes are on the *same* end-host, they use **"inter-process communications"**
  - Rules are based on the **operating system**

- If the processes are on **different hosts**, they have to communicate over a **network**
  - Maybe different operating systems

Client and Server Processes

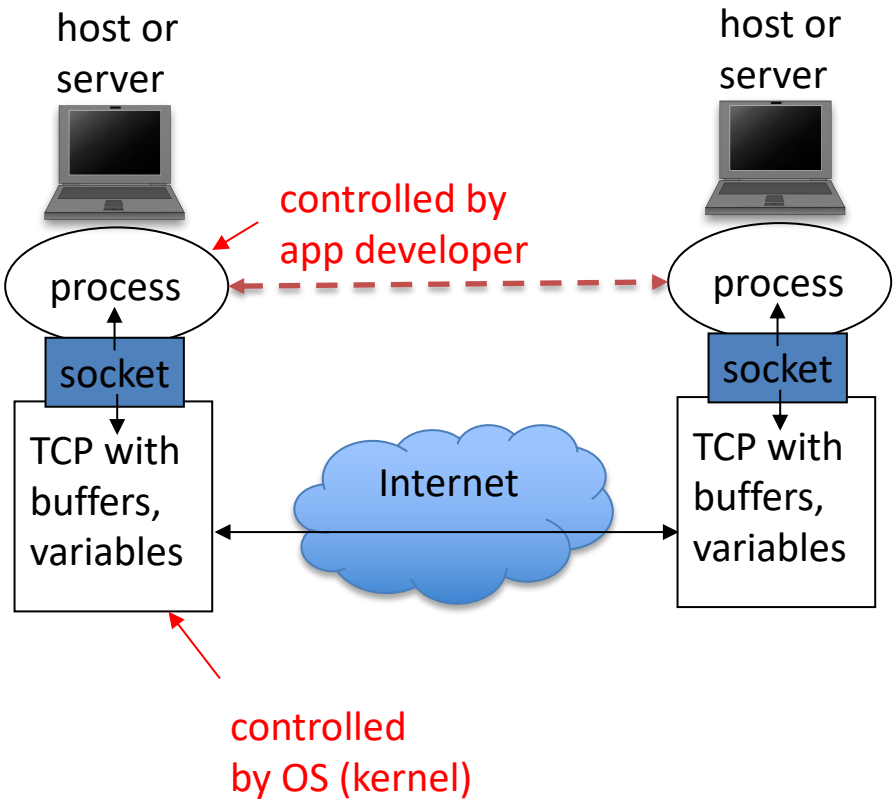
Example: Alice browsing amazon.com

- Alice's **browser** is a **client process** running on her computer

- A **server process** is running somewhere on some machine in **Amazon.com's network**

Sockets

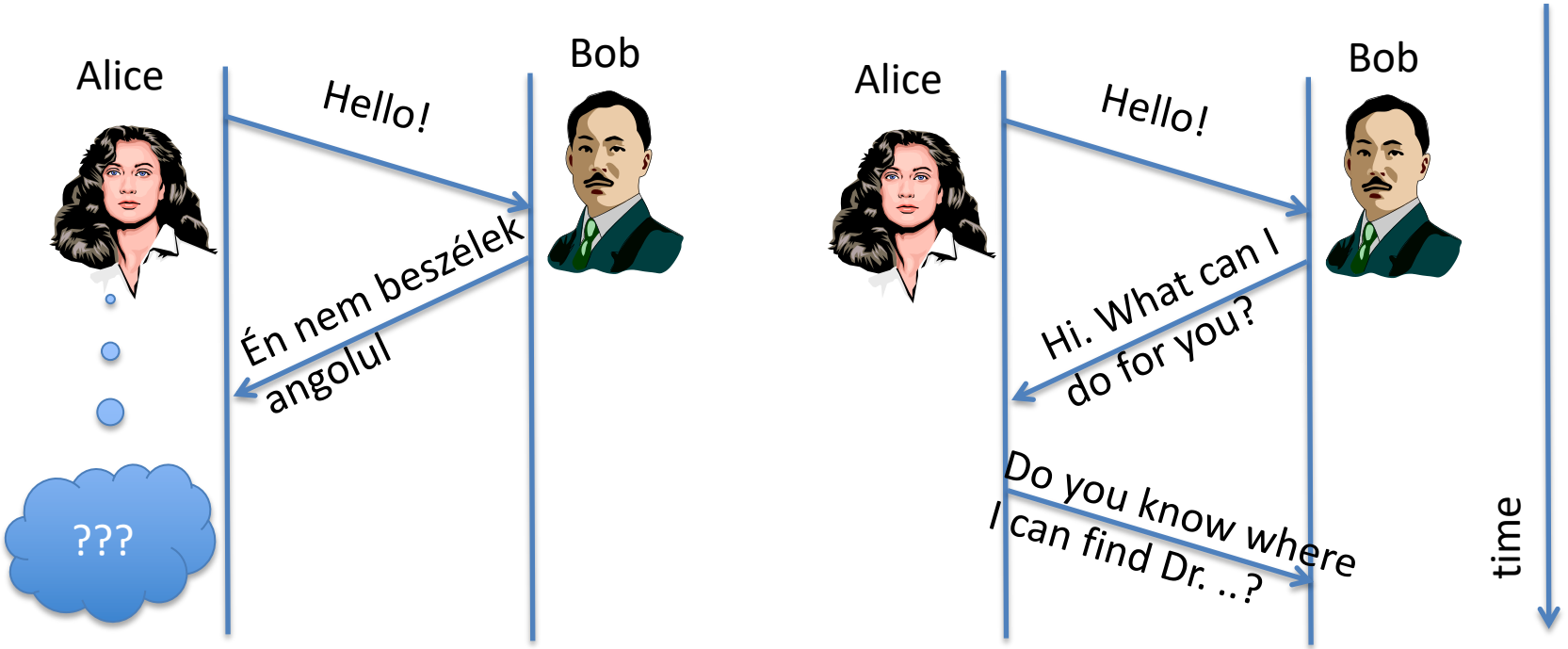
- **Programming interface used by a process to send and receive messages**
  - Sending/receiving process sends/receives the message to/from the **socket**
  - Like the door to a house
  - We will describe what is outside the door!
- **Application developer** only controls the process



Protocols

Protocol is: “**a set of rules governing the exchange or transmission of data between devices**”

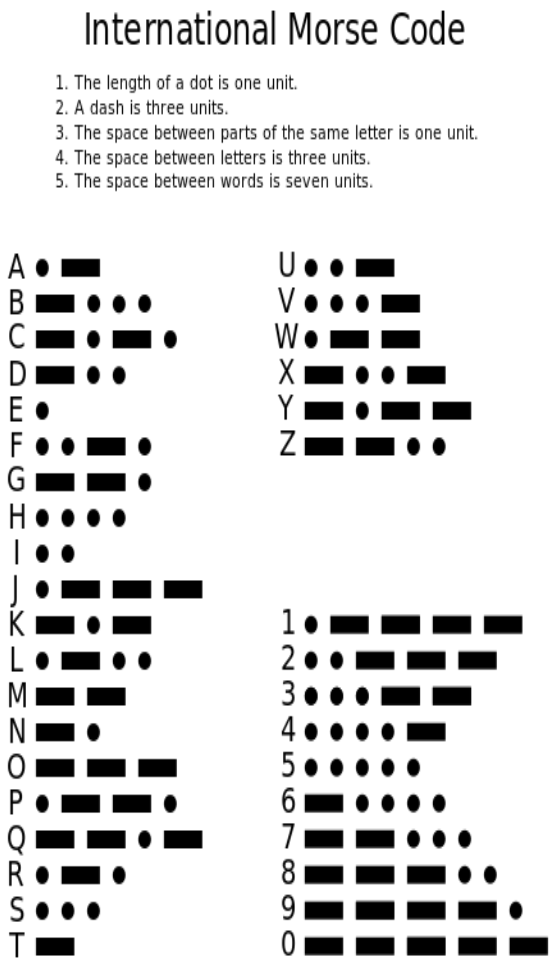
Example of Protocol



- The rules are there to make sure the communicating parties understand each other

Example of Protocol - Recall Telegraph

- Wire connects Transmitter and receiver
- Rule: agreed upon pattern known as Morse code



Network Protocols

- **Protocols** needed for network components to interact and **enable information flows**
- Protocols define **format, order of messages** sent and received among network entities, and **actions** taken on message transmission, receipt
- Circuit Switching
  - Signaling protocols to set up/tear down circuit (e.g., SS7)
- Packet Switching
  - Protocols to control flow of information (e.g., TCP)

Questions

- How does the browser know **what** and **where** amazon.com is? (**Addressing**)
- How does it “communicate” with amazon.com? (**Transport and Routing**)
- How does the browser know if it has received the elements of the html page correctly? (**Error control**)

There seems to be many functions needed!

tophat

Q_bigProject

A big project requires many functions to be completed. Which of the following practices is recommended

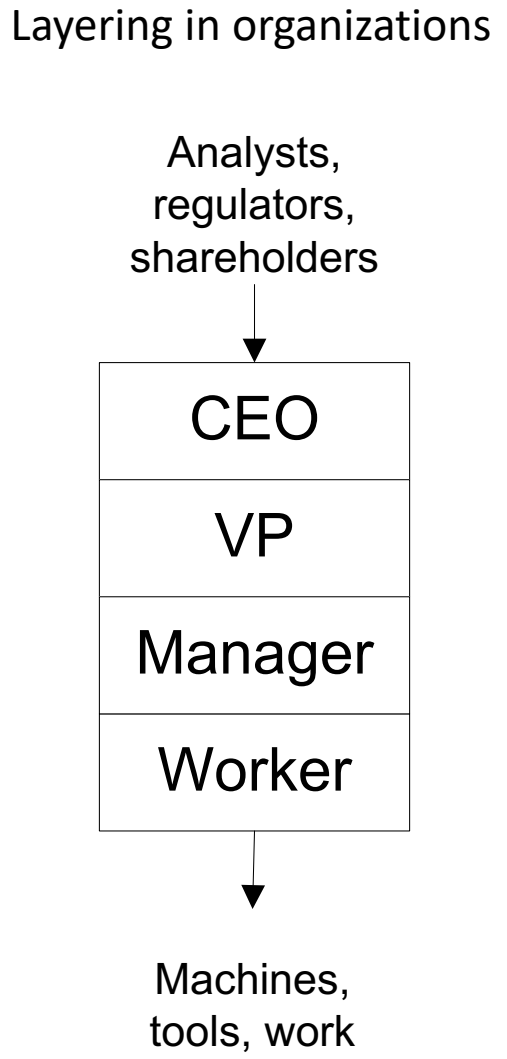
A	Write one big computer program that contains required steps of all functions in sequential order needed
B	Implement each of the functions separately, and integrate them so that each function can call the next

Layering in Network Protocols

- **Layering** is arranging functionality in a hierarchical manner
  - Lower layers provide functions and services that support the functions and services of higher layers
- Networks make extensive use of layering of technology and protocols
  - Protocols are most often placed in layers

Layering Example

- Lower layers support higher layers
- Example: corporate
  - CEO, VP, Managers, workers
- There are “protocol layers” in computer networks



Layering in Packet Switched Networks

- Simplified view of layering

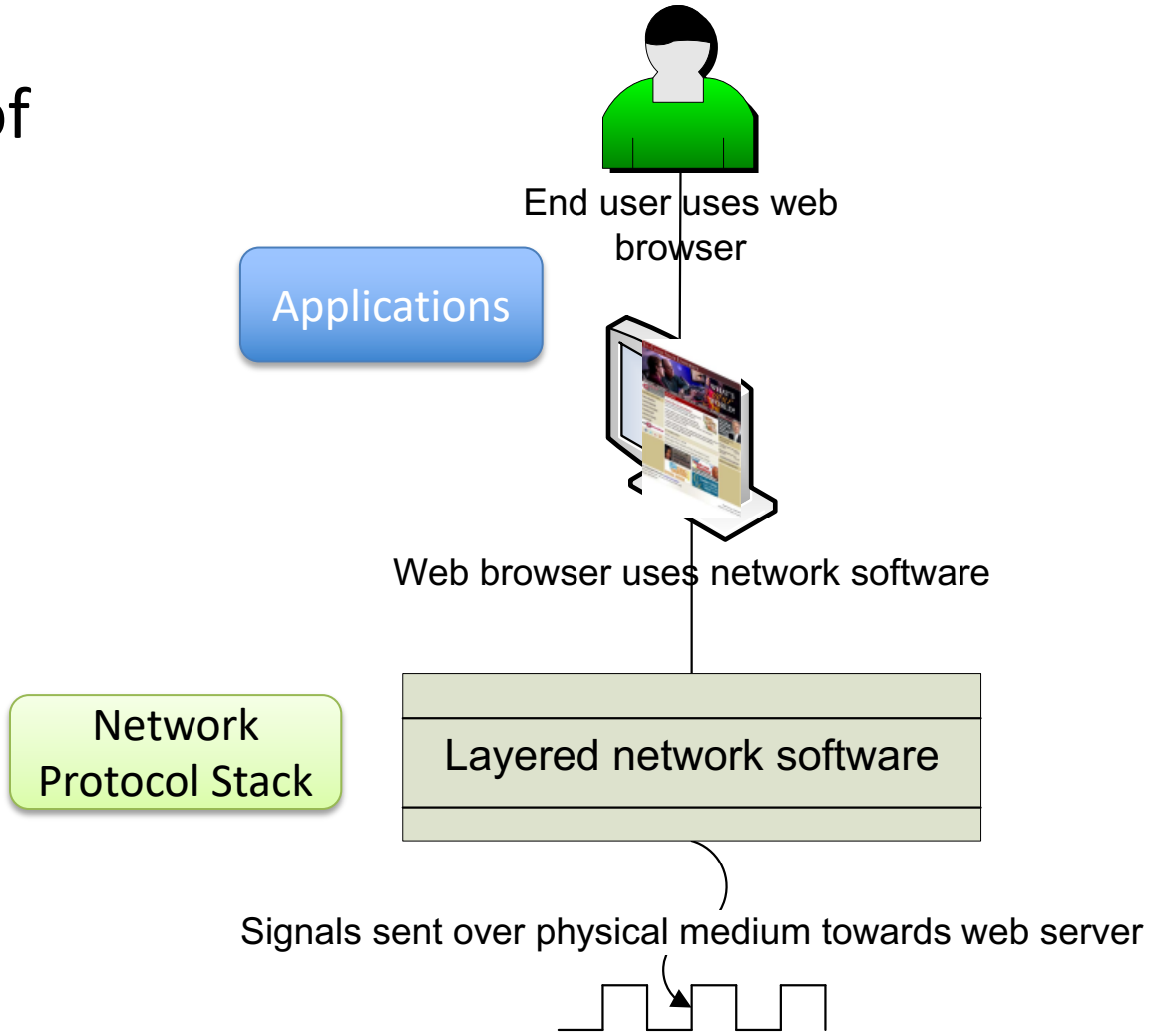
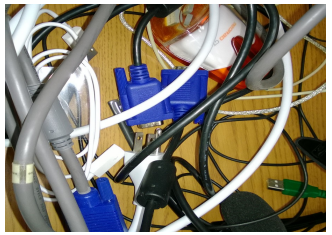


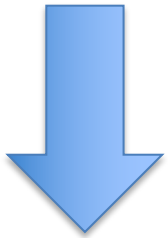
Figure from Agrawal

Slide modified from Agrawal

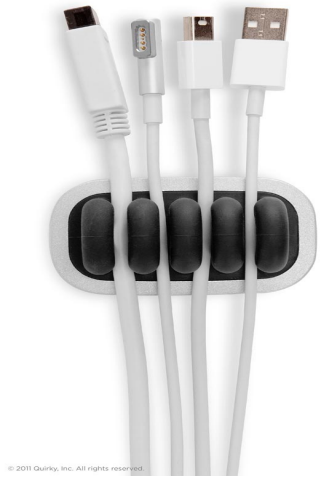
Advantages of Layering

- Why change from IPv4 to IPv6 does not require change in email clients or browsers?





- Why adding **wireless** network capability does not require change in web site addresses (**URLs**)



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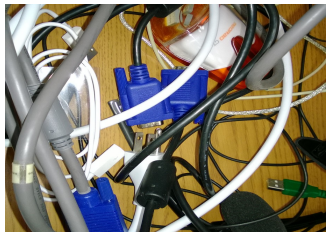
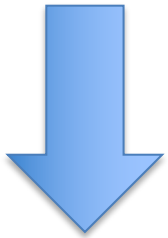
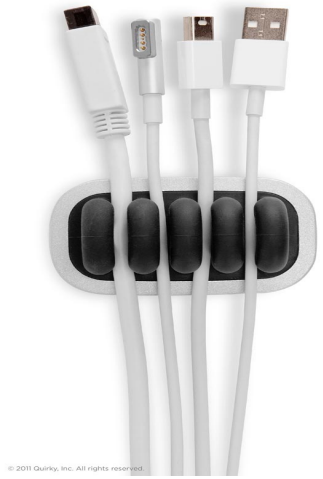
Advantages of Layering

- **Separation of functionality**
  - Simplification in upgrades
  - Simplification in adding new technology
- Specializes **technology development**
  - Well defined and specific
  - Modularity **reduces complexity of implementation**







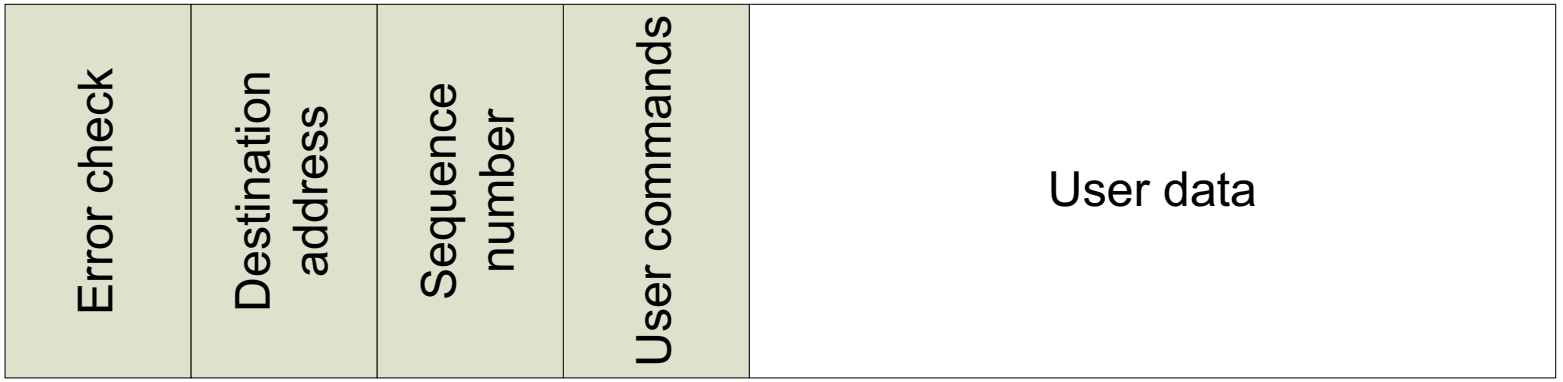
Slide modified from Agrawal

Header information

- Tasks are accomplished by adding additional required information to information packets
  - Packet header
    - Routers and end stations use this header information to handle packets appropriately

Typical Packet Structure

- A typical packet contains
  - Information sent from the layers above
  - Additional information (called headers) specific to the functions of each layer
- At a **high level (oversimplified),** looks like this:



What Functions Do We Need In Networking?

5-layered TCP/ IP stack

- Modern computer networks implement layering in **5 layers**
- Called the **TCP/ IP stack**
  - After the core set of technologies
    - TCP
    - IP

Slide modified from Agrawal

Internet Protocol stack

Five layer stack built around Internet Protocol (IP)

Protocol layer and function	Popular technologies
Application layer (what user wants)	E-mail (SMTP, IMAP, POP), web (HTTP)
Transport layer (ensure reliable data stream)	TCP, UDP
Network layer (routing)	IP
Data link layer (error-free transmission over hop)	Ethernet, Wi-fi, ATM
Physical layer (data sent as signals over media)	AM, FM, CDMA, Manchester encoding, SONET

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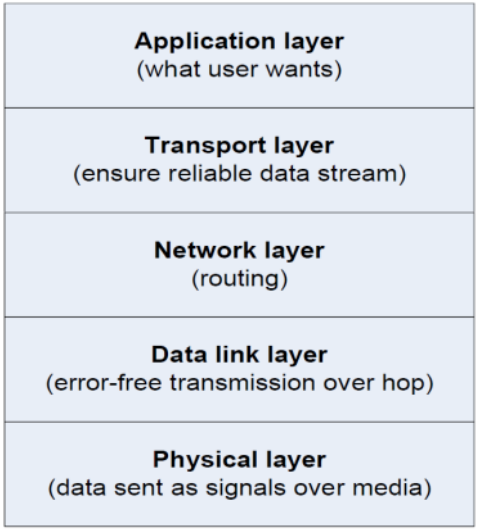
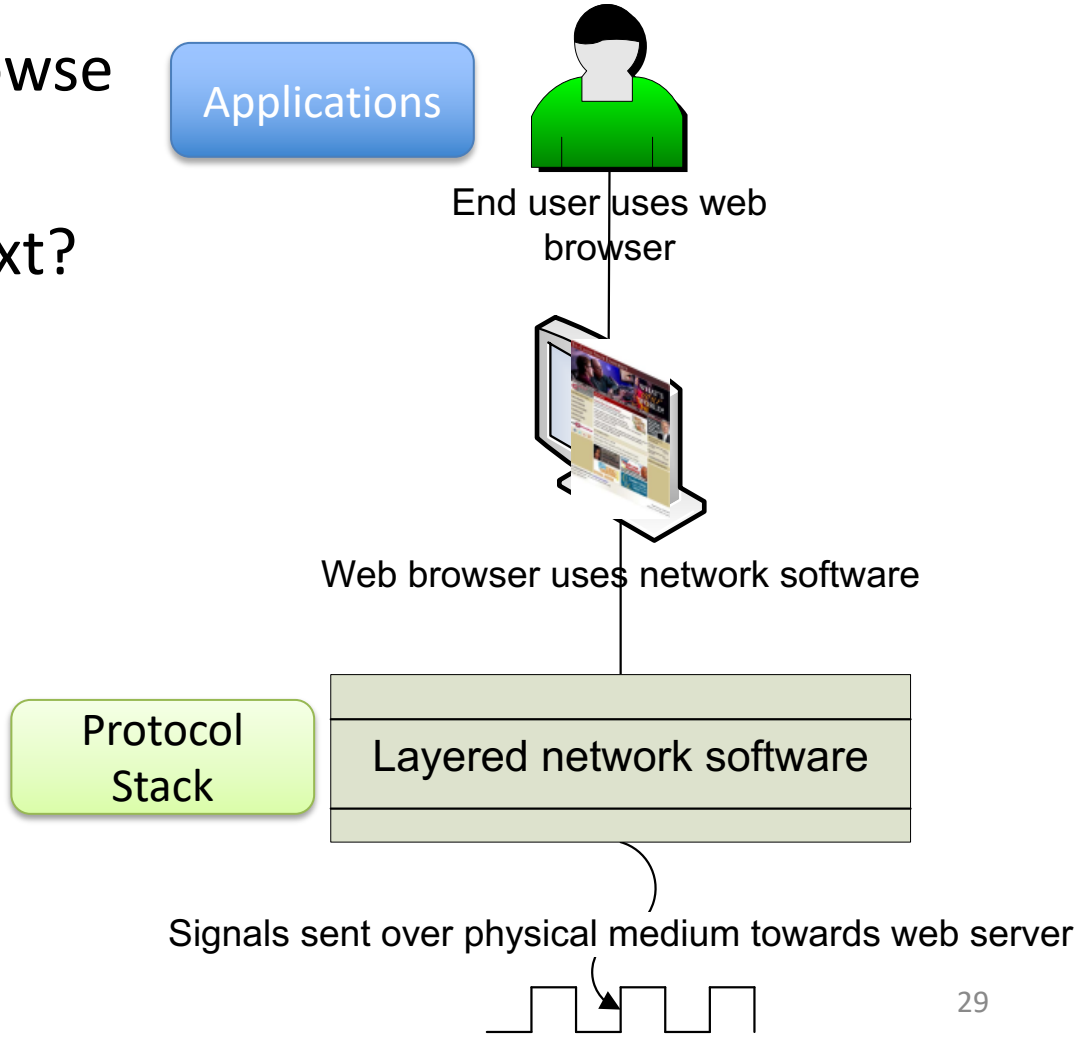
Layer Names and Tasks - Simplified

Layer number	Layer name	Networking task	Header information
5	**Application**	Specify user needs, creates “message”	User commands
4	**Transport**	Segmentation and reassembly of data “segments”, sometimes reliable transfer & speed matching	Sequence numbers
3	**Network**	Identifying and locating destination, best effort delivery of “datagrams”	Address
2	**Data-link**	Reliable delivery of “frames” over a link, Error control	Error check
1	**Physical**	Signaling, moving individual bits based on medium	Usually none, but in WiFi there is a header

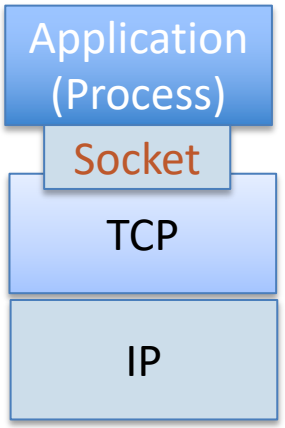
Browsing Example

- Alice wants to browse Amazon.com
- What happens next?

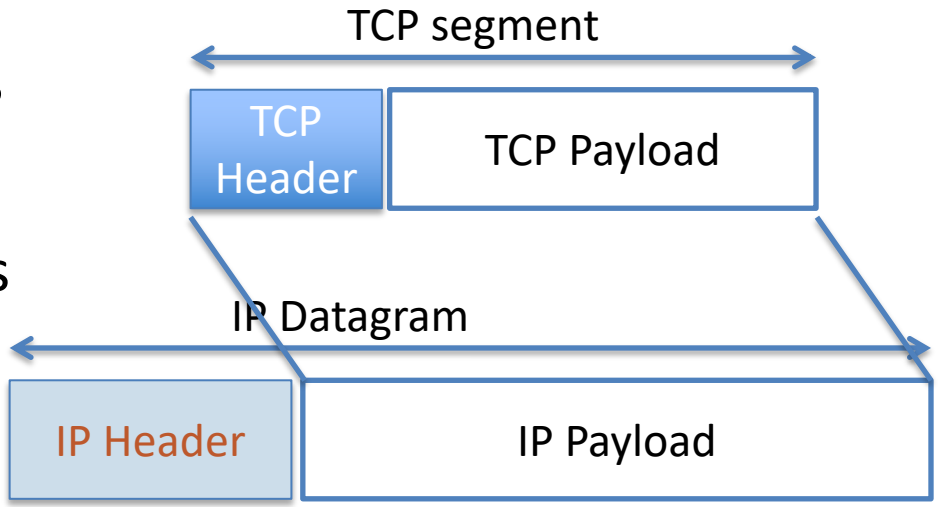




Simplified View of Browsing



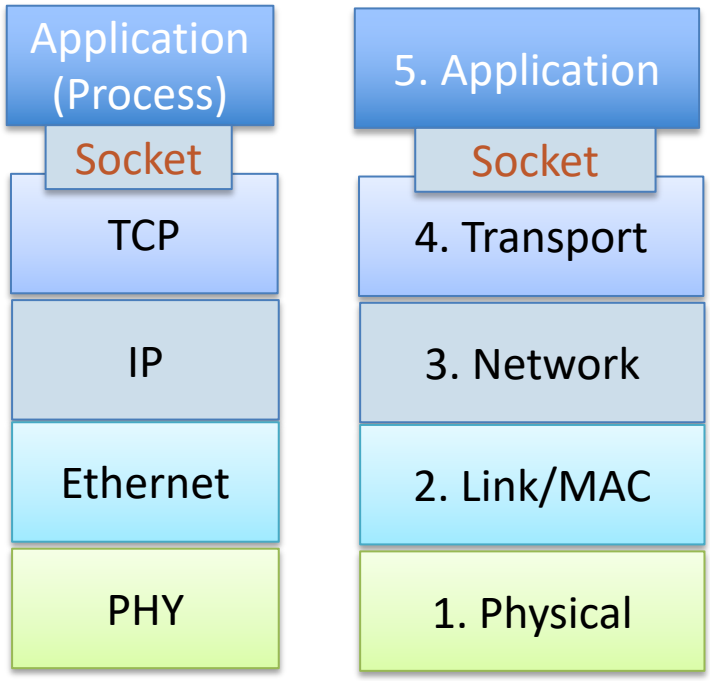
- A TCP "**segment**" is created which is passed on to the "network layer"
- Network layer creates **IP packet (datagram)**
  - TCP segment becomes the payload of an IP packet
- All of this happens in the operating system



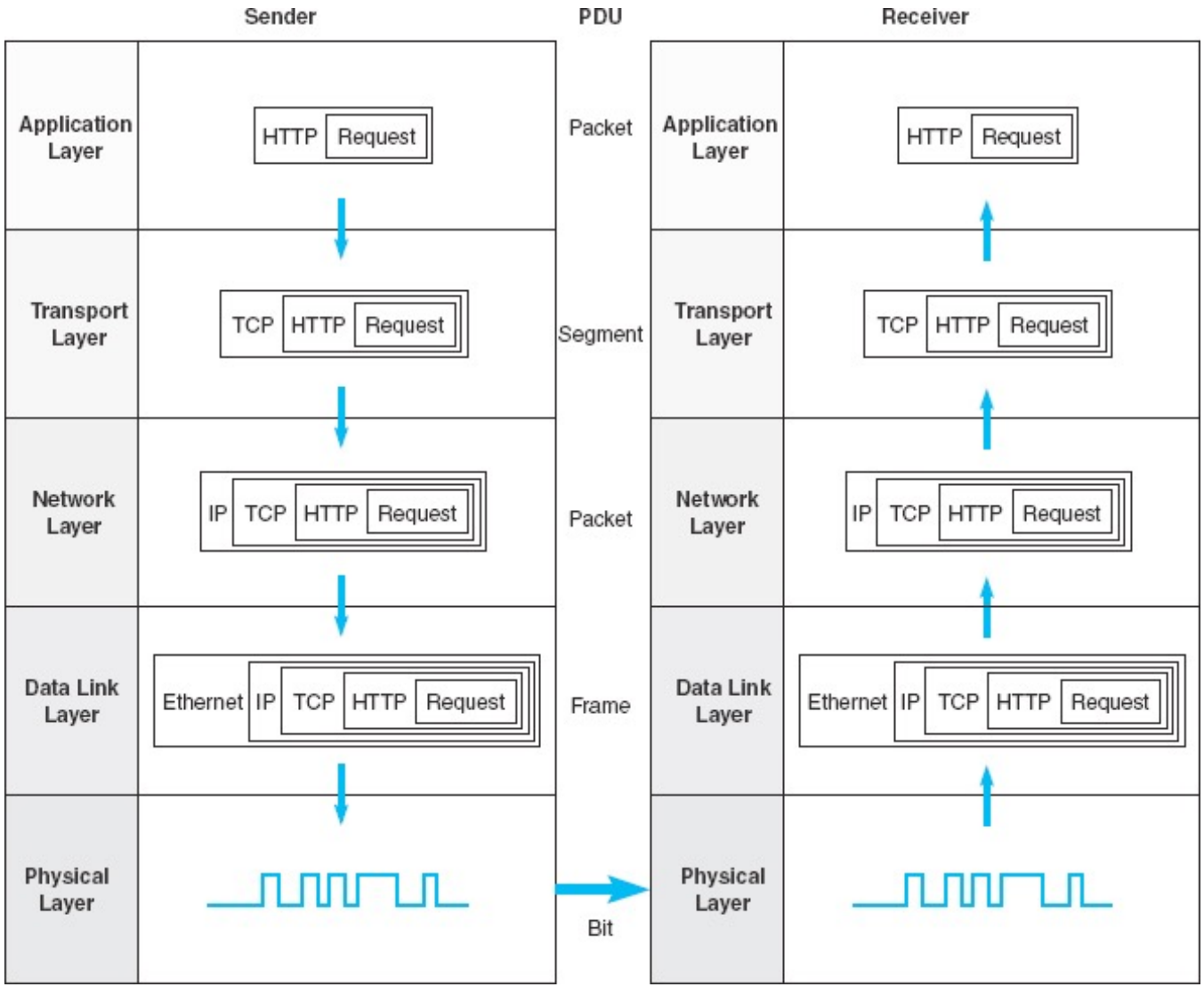
Note that the TCP segment and the IP datagram are simply groups of bits with some structure

Simplified View of Web Browsing

- IP datagram becomes the payload of the link/**MAC layer "frame"**
  - Say Ethernet frame
- PHY Layer
  - The Ethernet frame is converted into a set of electrical pulses (signal) that is placed on links, e.g. Ethernet cable

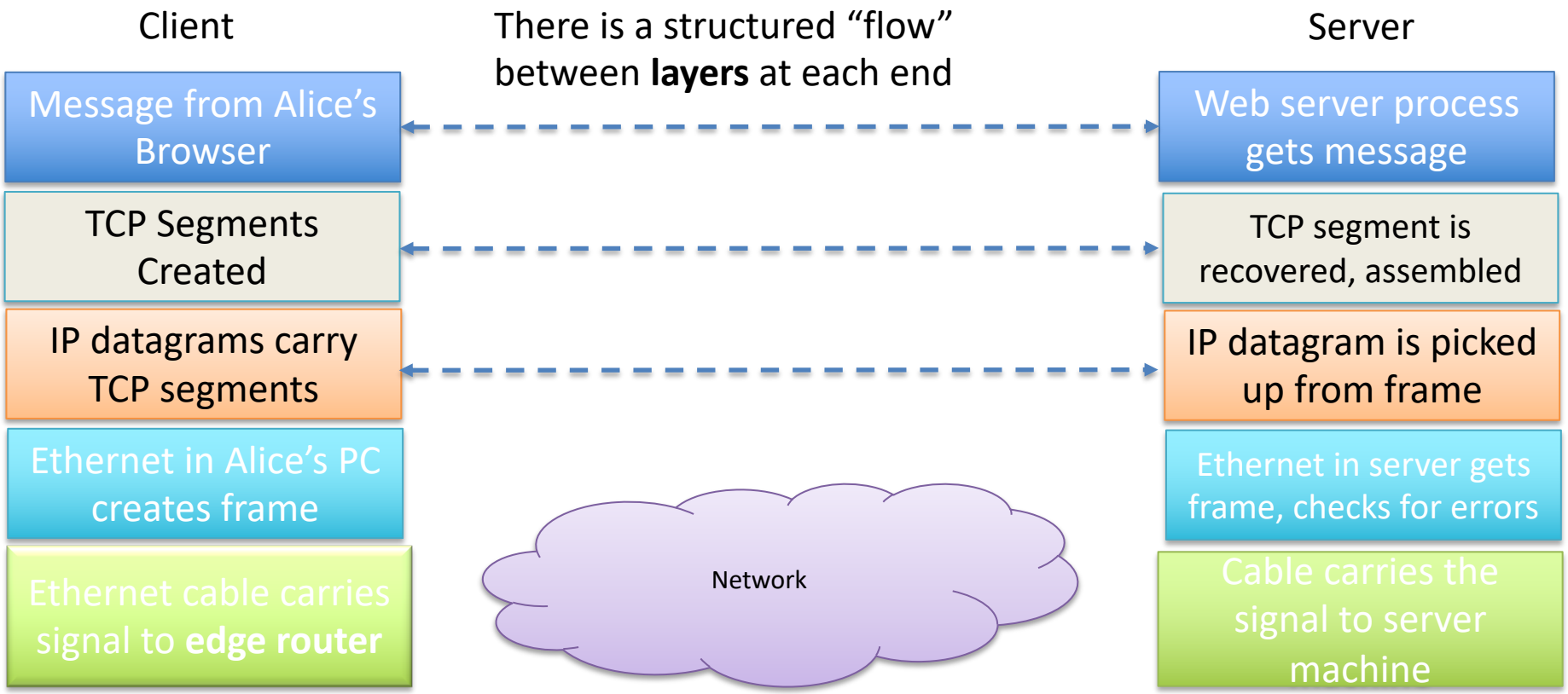


Encapsulation



Q_tcpProtocol

Simplified Web Browsing



There is a one-to-one correspondence between **layers** in the two end points

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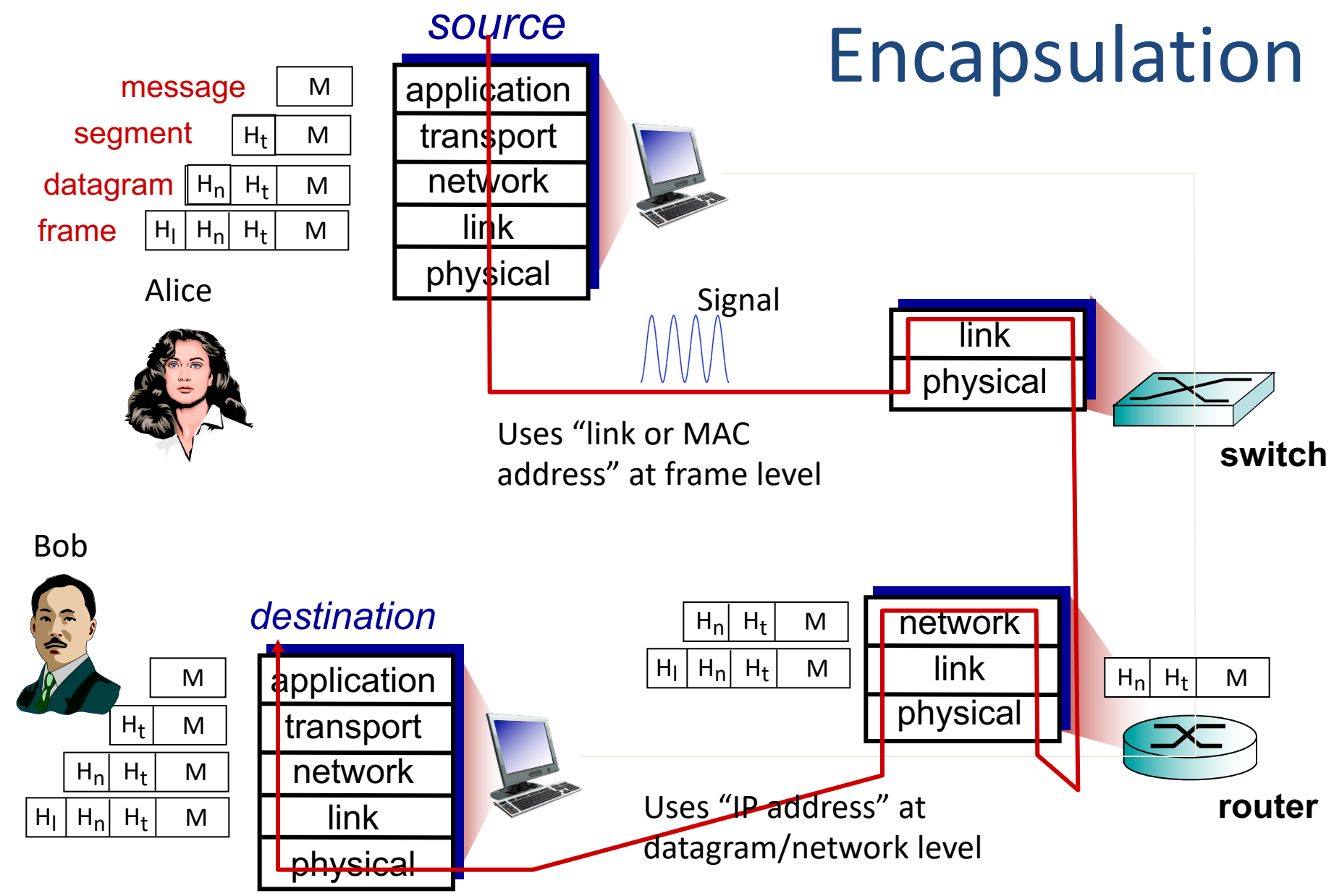
Encapsulation



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OSI model

- OSI – Open Systems Interconnection

- Early packet switched networks involved multiple networking technologies that were not interoperable
  - SNA , DECnet, Appletalk
  - Created communication islands
  - Strong need to ensure **interoperability**

OSI model

- OSI model is a **logical** structure for communications networks, standardized by the **International Organization for Standardization (ISO**)
  - An effort by the ISO to standardize computer networks

Slide modified from Agrawal

OSI Model

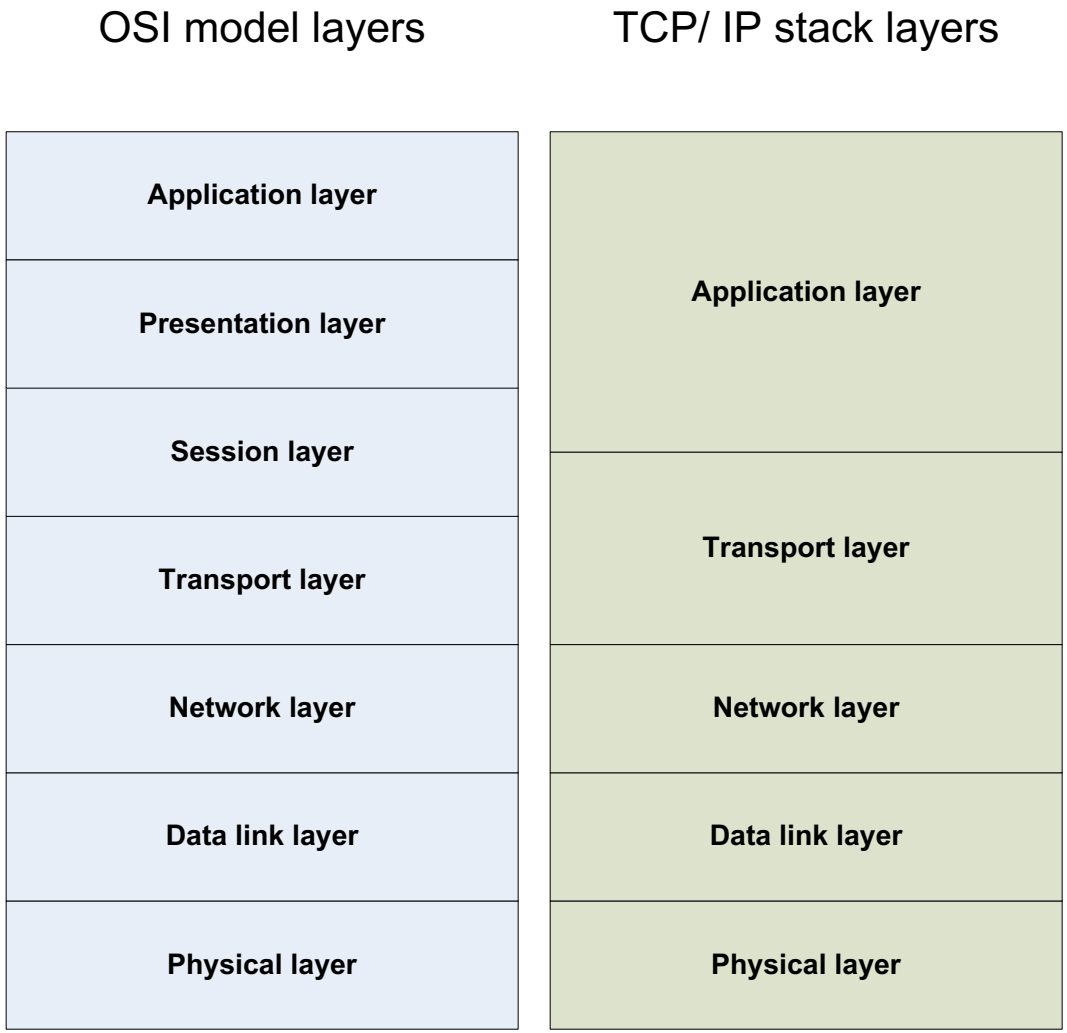
OSI model useful frame of reference

OSI model layer	Layer function
Application layer	**Request-reply mechanism for remote operations across a network**
Presentation layer	**Syntax conversion from host-specific syntax to syntax for network transfer**
Session layer	**Create and terminate connection; establish synchronization points for recovery in case of failure**
Transport layer	**Segmentation, reassembly of packets in one connection, multiplexing connections on one machine**
Network layer	**Routing and network addressing**
Data link layer	**Error-free data transmission over a single link**
Physical layer	**Convert data to signals for transmission over physical media**

Slide modified from Agrawal, Kurose & Ross

OSI and TCP/ IP

- *Presentation*
  - Allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *Session*
  - *S*ynchronization, checkpointing, recovery of data exchange
- Internet stack doesn't have these layers!
  - These services, *if needed,* must be implemented in application or transport layers



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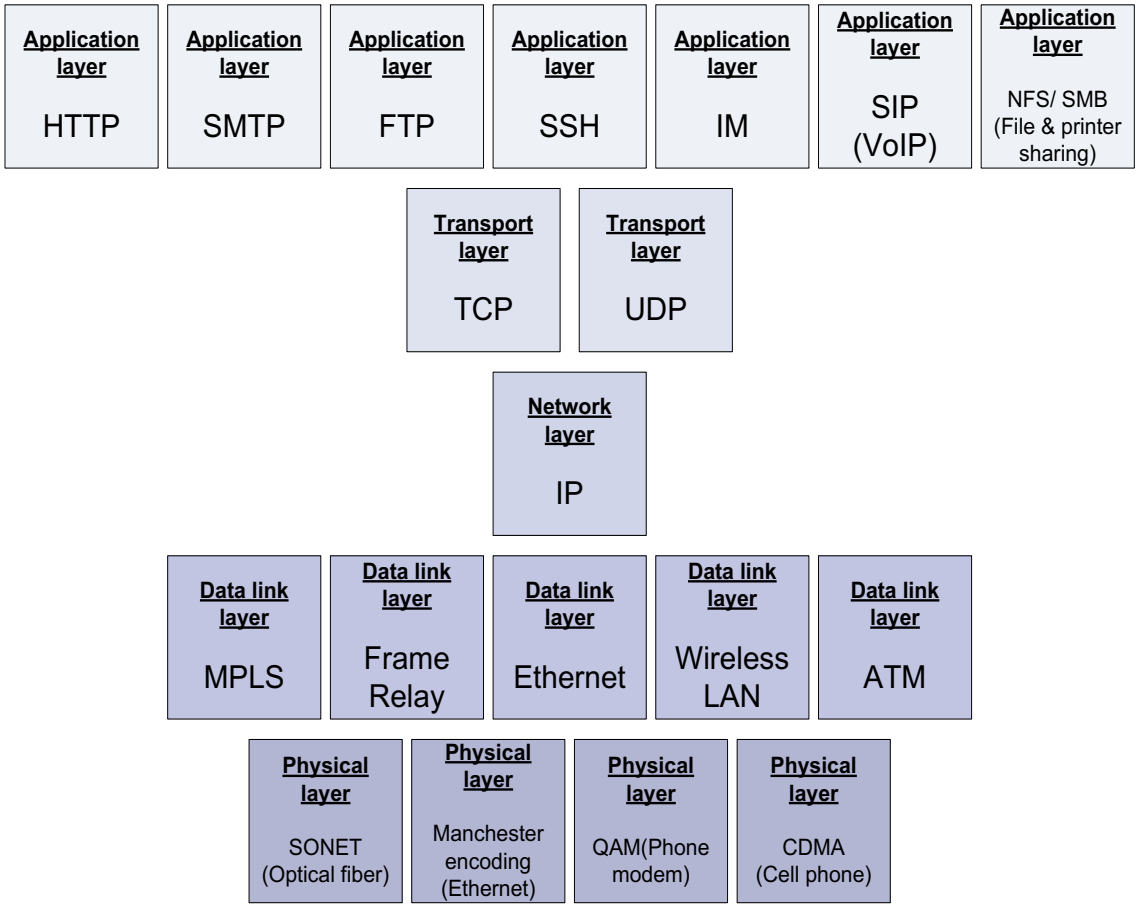
Internet Stack Technologies by Layer

- IP layer is the same – IP packets can be understood regardless of the technology
- This is not an exhaustive list, but shows some of the most popular technologies at each layer



Simplified Internet Structure

- The access network—the network that physically connects an end system to the first router

Reading: Chapter, Section 1.3.3, Kurose book, Computer Networking – A Top Down Approach, 6th edition

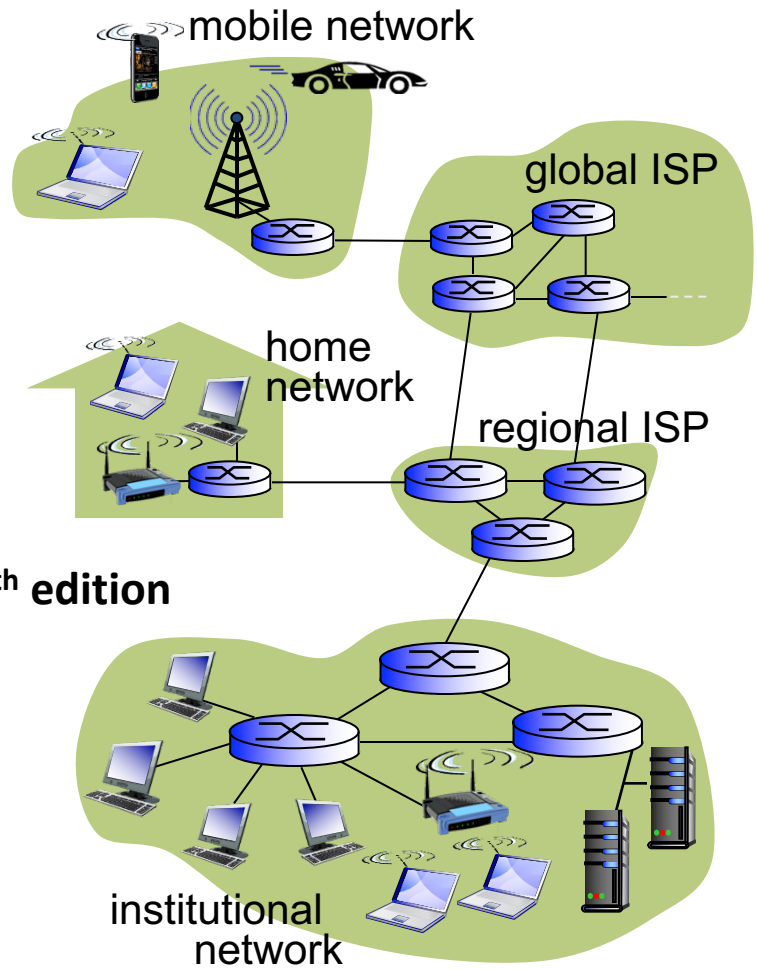
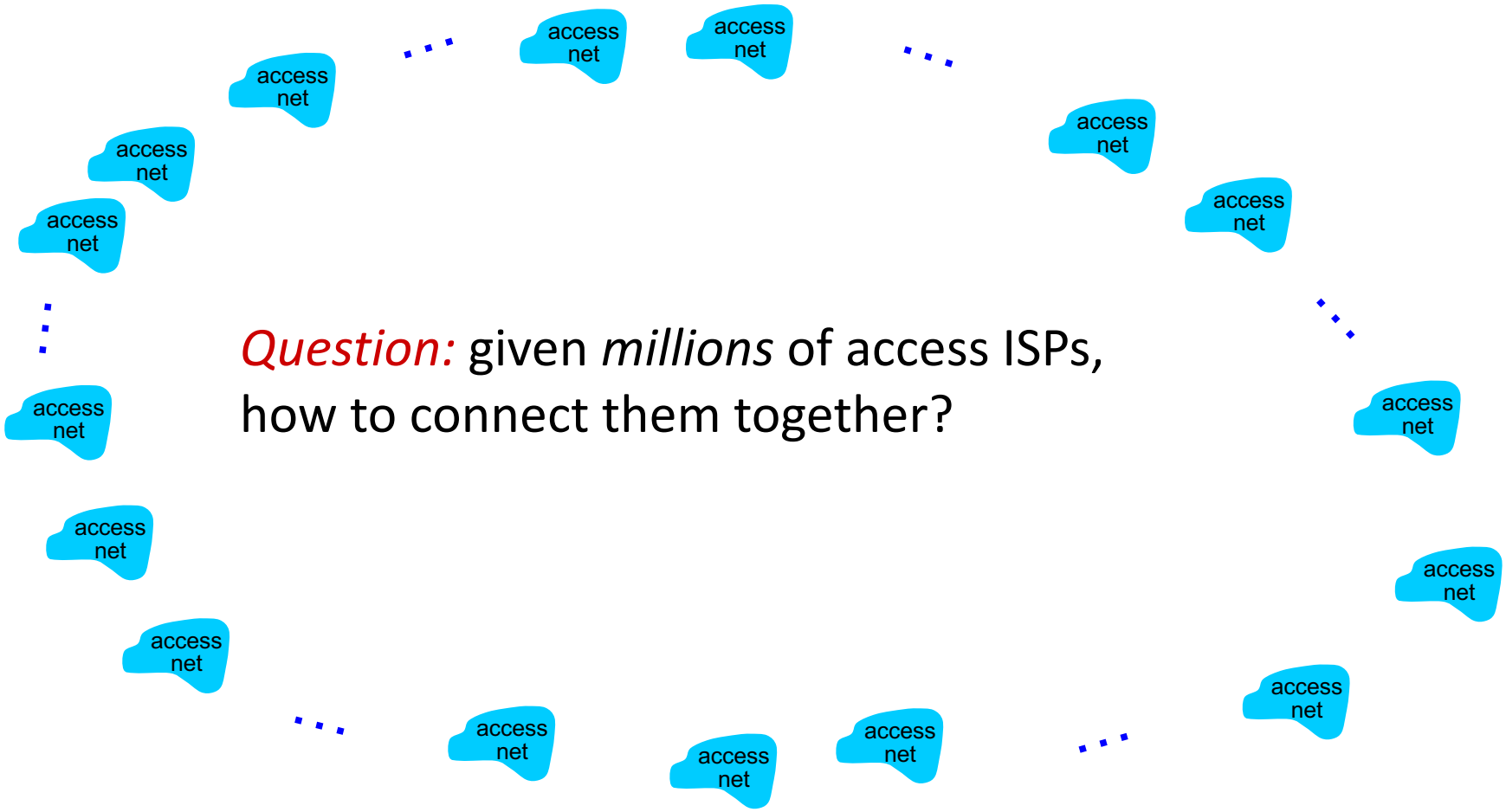


Figure from Kurose-Ross

Slide modified from Kurose & Ross

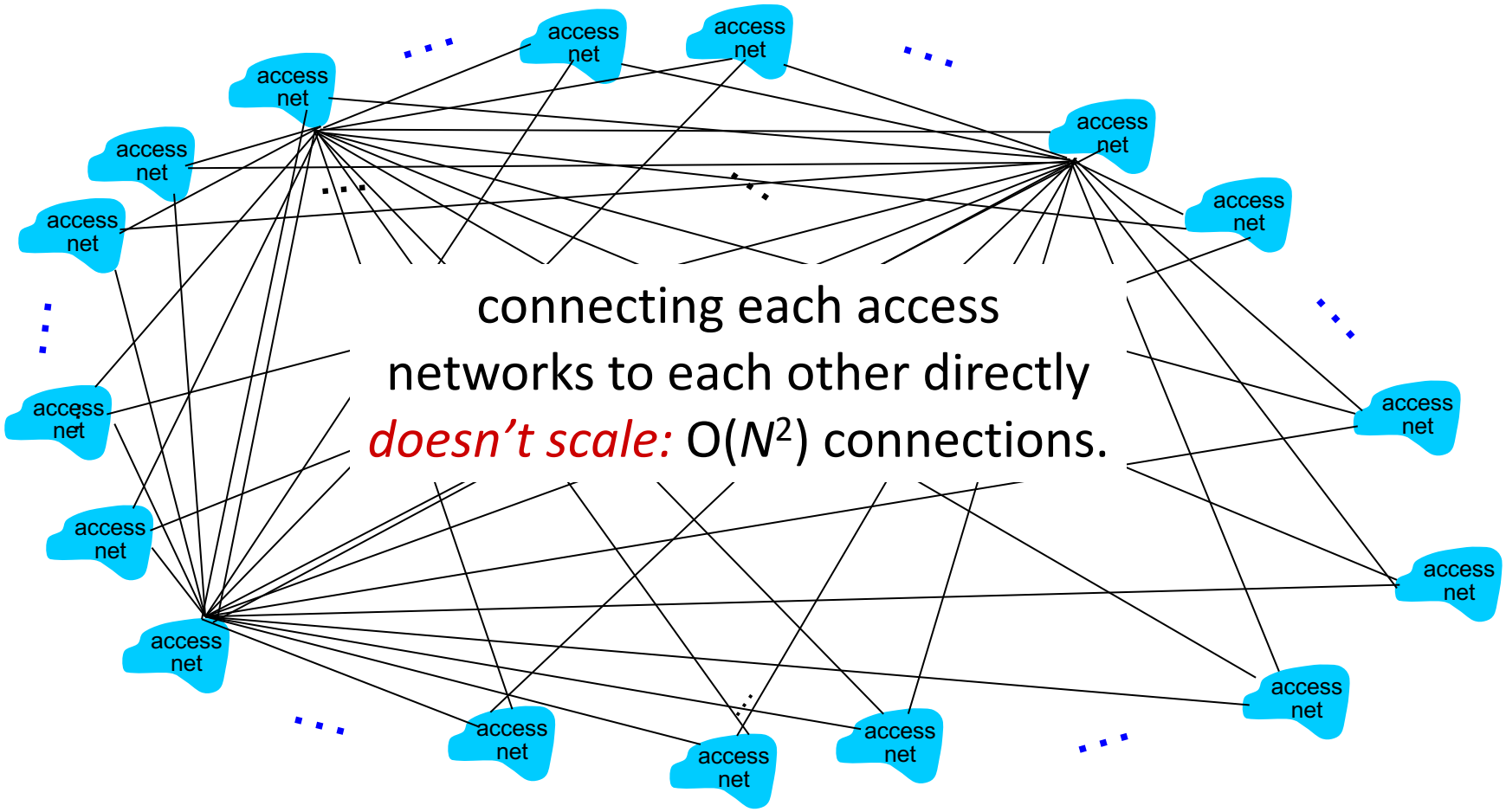
Internet Structure: Network of Networks



Question: given *millions* of access ISPs, how to connect them together?

Slide modified from Kurose & Ross

Option: connect each access network to every other access network?



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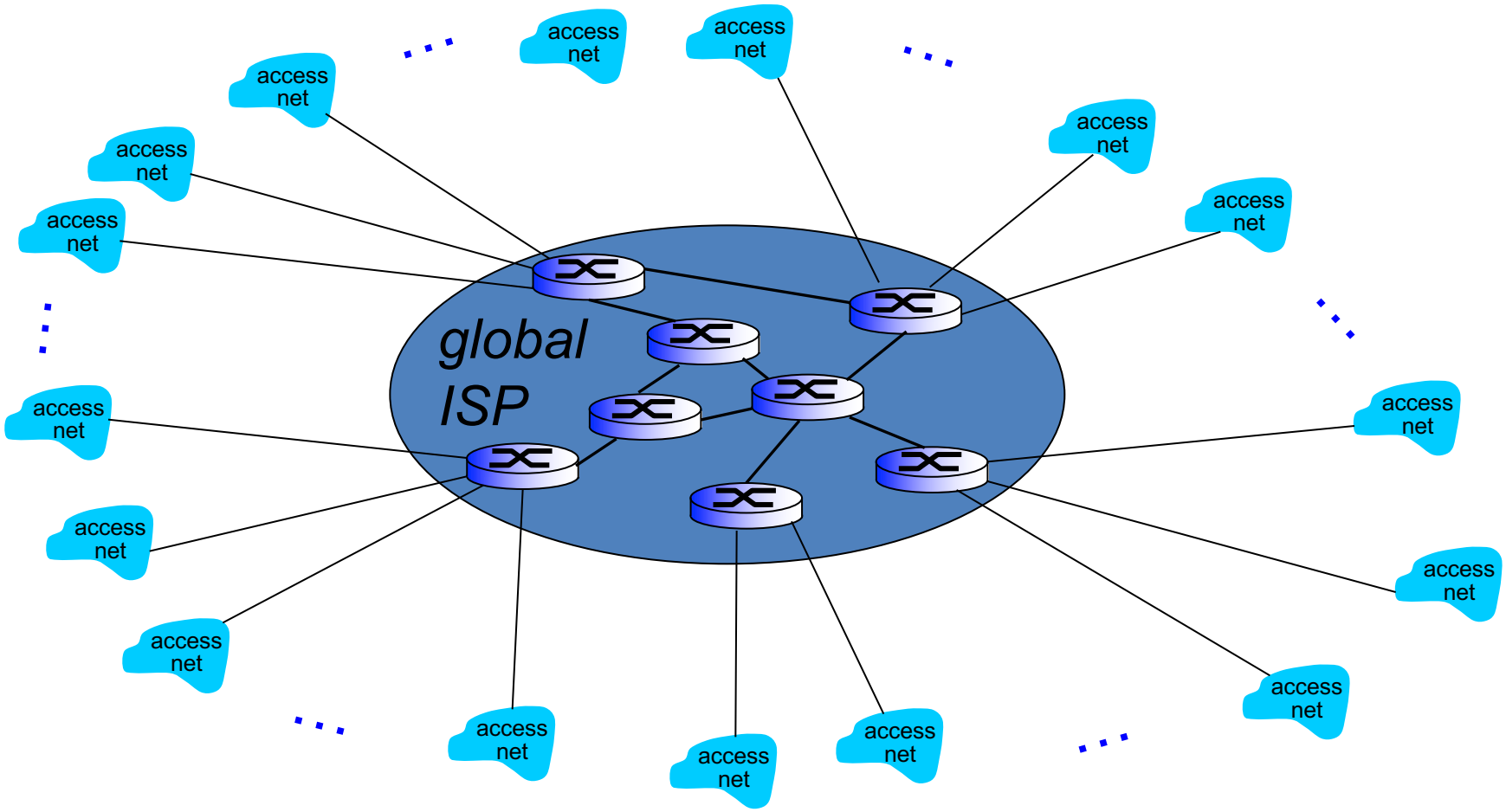
Option: connect each access ISP to a global transit ISP?



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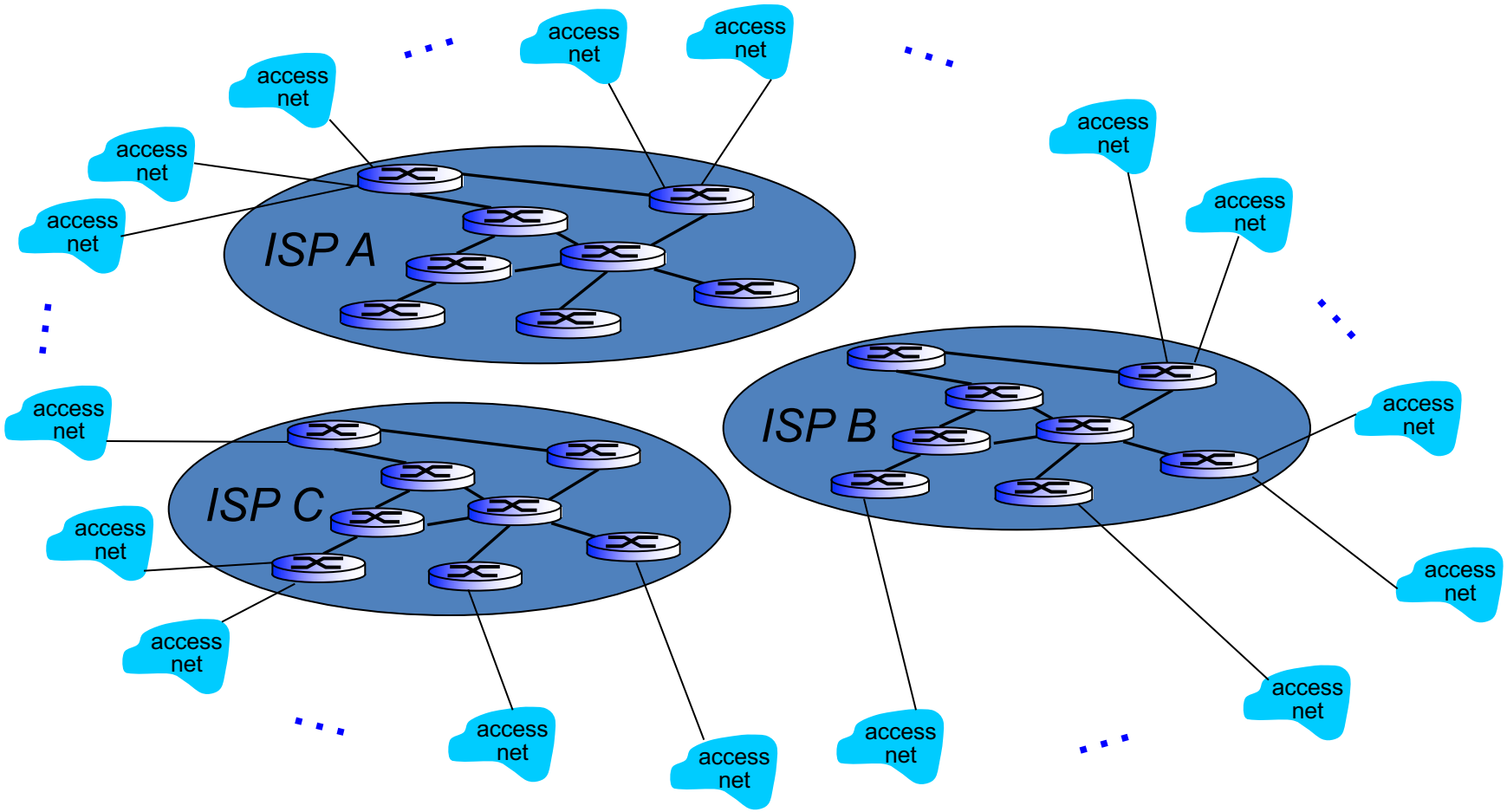
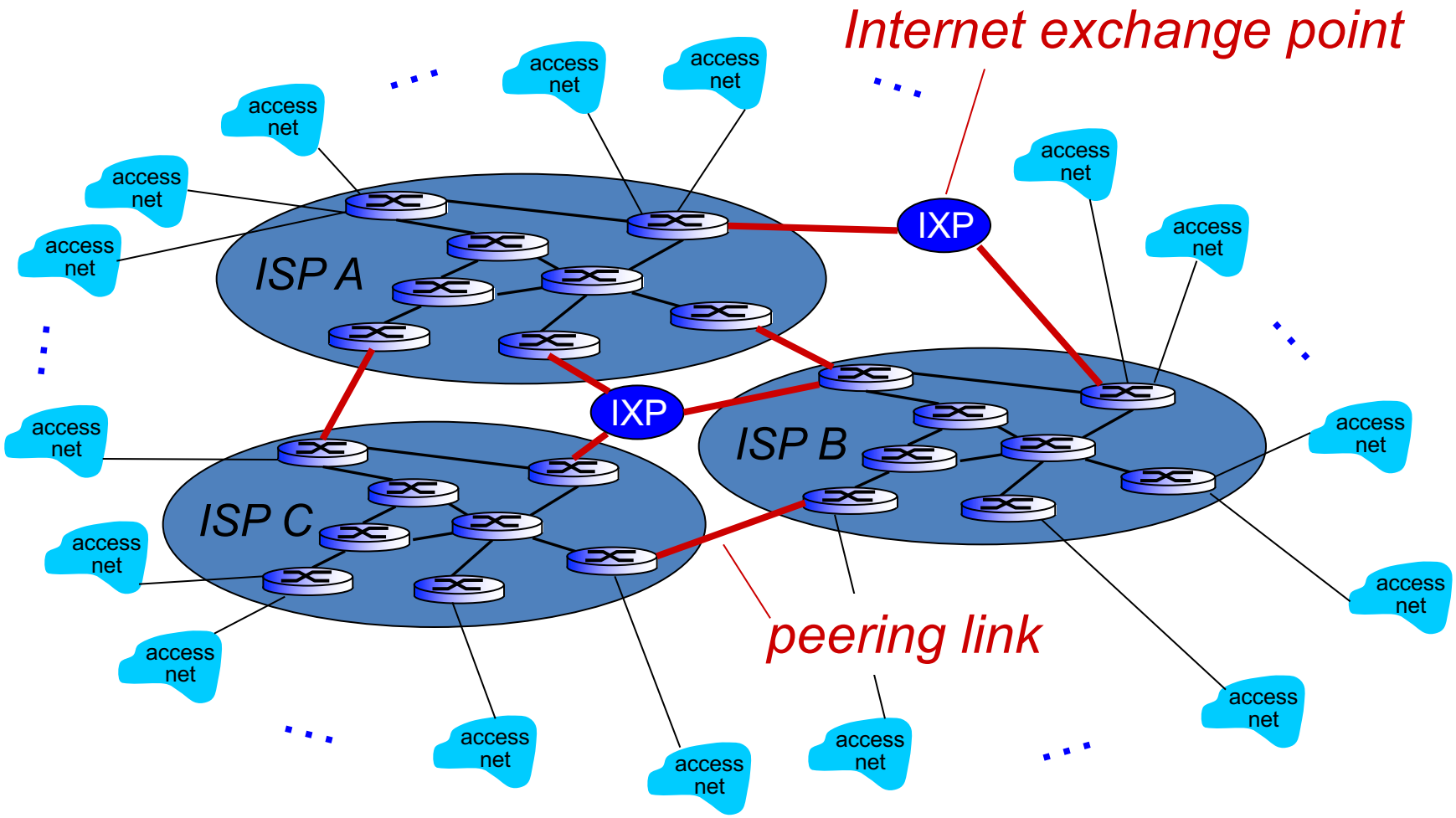
But if one global ISP is viable business, there will be competitors ….

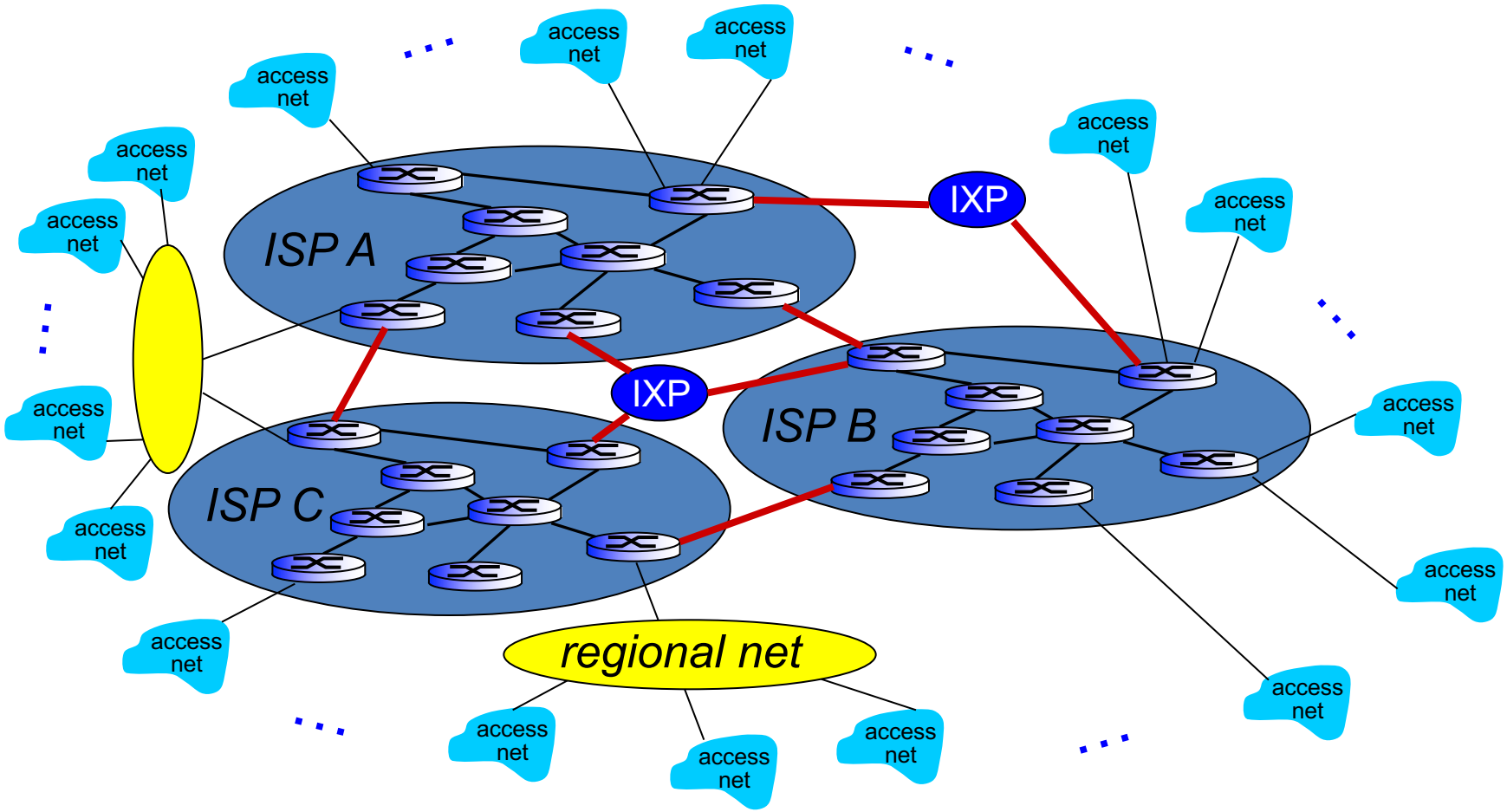


But if one global ISP is viable business, there will be competitors …. which must be interconnected

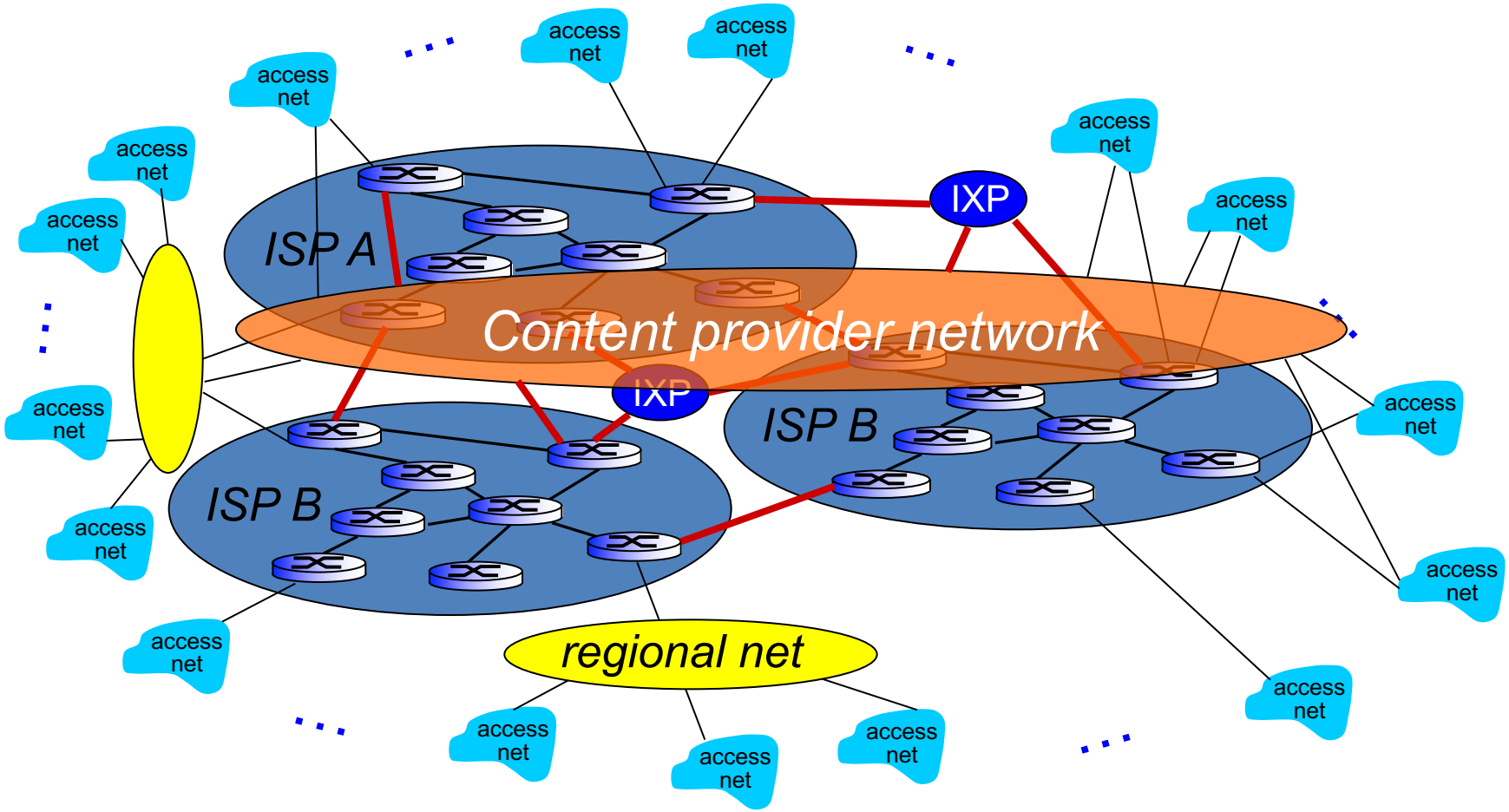


Slide modified from Kurose & Ross

Regional networks may arise to connect access nets to ISPS



Content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



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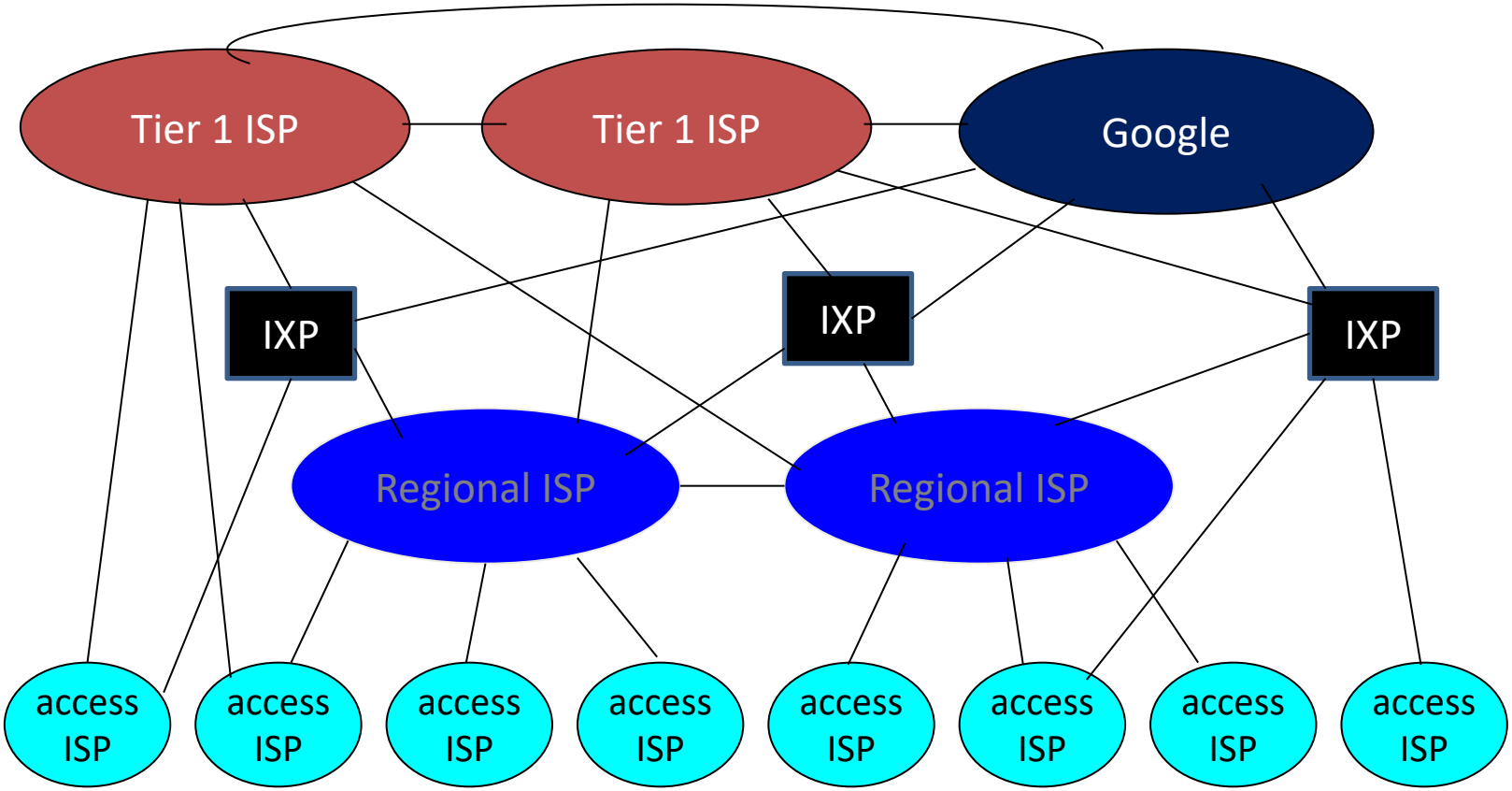

- Small number of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Telecom and Networking Industry is Regulated!

- Emphasis on standardization for interoperability
- International Telecommunications Union (ITU)
  - ITU is part of the United Nations
  - Worldwide coordination/ standardization (e.g., telephone numbers)
  - Allocation (e.g., satellite slots)
- Federal Communications Commission (FCC) in the US
  - Regulates wireless spectrum (bands, licenses, power levels, etc,)

Telecom and Networking Industry Standardization

- Standards bodies include
  - Internet Engineering Task Force (IETF)
    - Internet protocols and enhancements
  - Institute for Electrical and Electronic Engineers (IEEE)
    - Ethernet, 802.11 WiFi (layer 1 and 2)
  - European Telecommunications Standards Institute (ETSI)
    - GSM, DSL
  - 3rd Generation Partnership Project (3GPP)
    - UMTS, LTE, LTE-Advanced
  - National Institute of Standards and Technology (NIST)
  - Others: Zigbee Alliance, Thread group, …

Summary

- Layering
- TCP/IP
- OSI model
- Internet structure, regulation, standardizations