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What would you value/prioritize if you were building a networking system?

- ❖ Open-ended word cloud!
- ❖ Networking system: a system to handle the transfer of information from one location to another

Networks Introduction

CSE 333 Summer 2023

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Relevant Course Information

- ❖ Exercise 9 is due Monday (7/31)
- ❖ Homework 3 is due next Thursday (8/03)
 - Debug using small custom test directories
 - Make use of the solution binaries to double-check your work
- ❖ Rest of the quarter: networking, concurrency, processes


Lecture Outline

- ❖ Introduction to Networks
 - Layers upon layers upon layers...

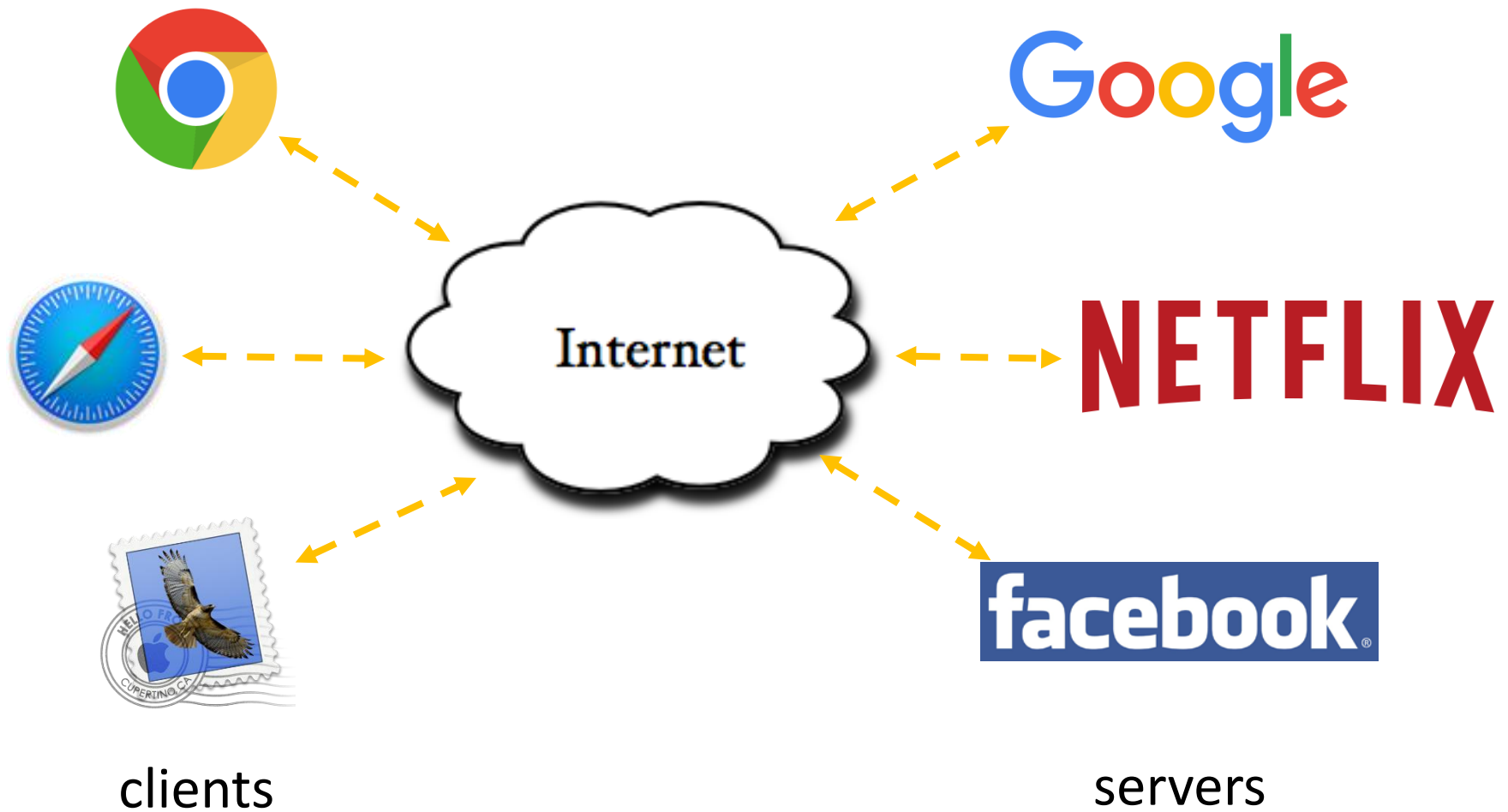


more awesome pictures at THEMETAPICTURE.COM

Today's Goals

- ❖ Networking is a very common programming feature
 - You will likely have to create a program that will read/write over the network at some point in your career
- ❖ We want to give you a basic, high-level understanding of how networks work before you use them
 - Lecture will be more “story-like;” we will purposefully skip over most of the details, but hopefully you will learn something new about the Internet today!
 - Take CSE 461 if you want to know more about the implementations of networks (the course is pretty cool 😊)
- ❖ Let's also examine “the network” as a *system* 
 - Inputs? Outputs? Robustness? Efficiency? Customers?

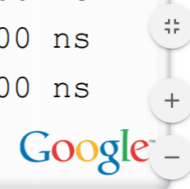
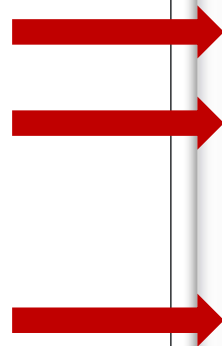
Networks From 10,000 ft



“Network” Latency is Highly Variable

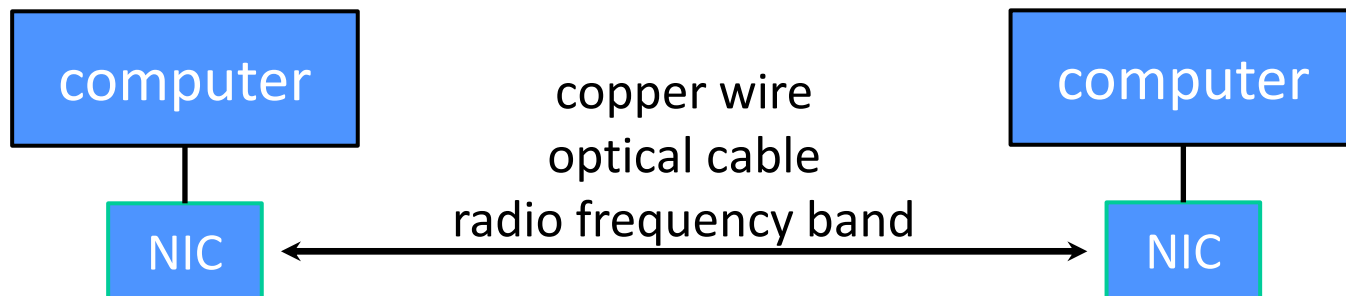
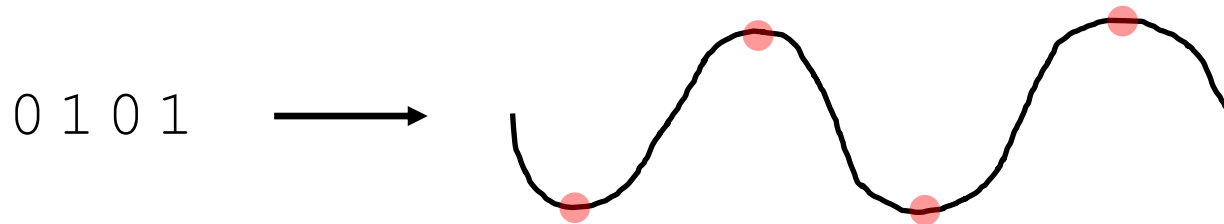
- ❖ Jeff Dean’s “Numbers Everyone Should Know” (LADIS ‘09)

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	100 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	10,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from network	10,000,000 ns
Read 1 MB sequentially from disk	30,000,000 ns
Send packet CA->Netherlands->CA	150,000,000 ns



The Physical Layer

- ❖ Individual bits are modulated onto a wire or transmitted over radio
 - Physical layer specifies how bits are encoded at a signal level
 - Many choices, *e.g.*, encode “1” as +1v, “0” as -0v; or “0”=+1v, “1”=-1v, ...



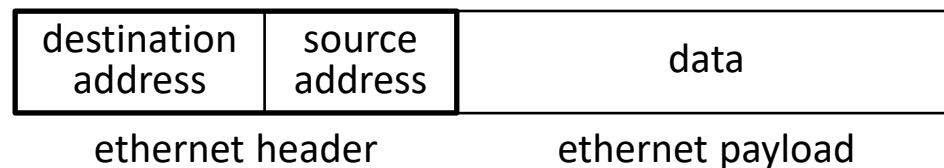
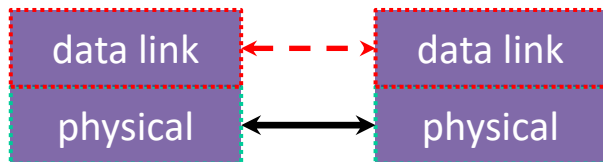
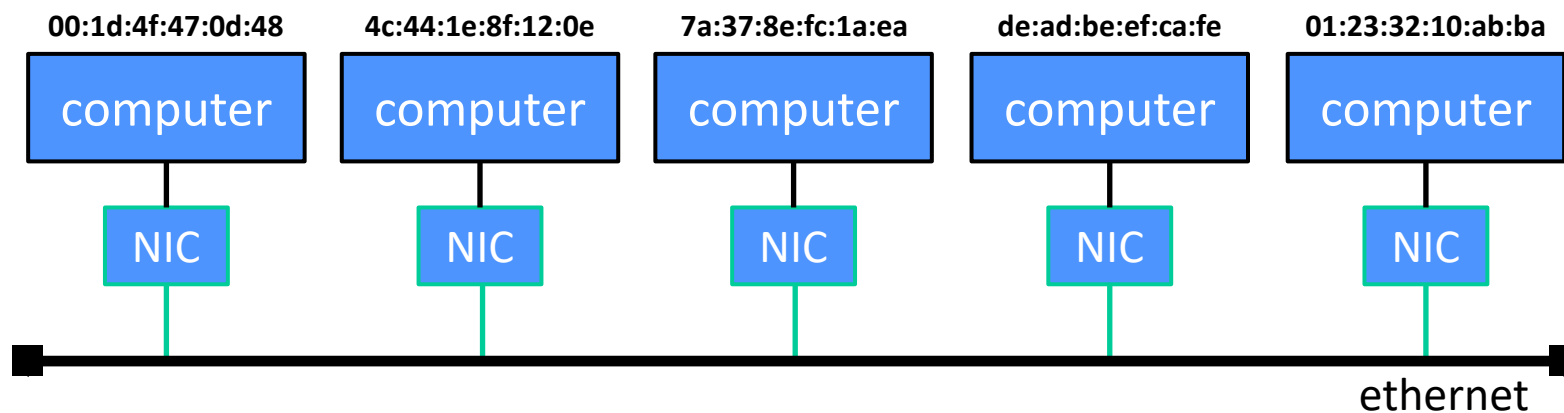


Materials Matter – Latency

- ❖ Fiber optic cables are lower-latency and higher-bandwidth than traditional copper wiring
 - Much of the internet's "long haul" data is transmitted on these
 - (signal attenuation is much better too)
- ❖ Is it faster to send 1 person from UW to ...
 - Downtown Seattle?
 - Ballard?

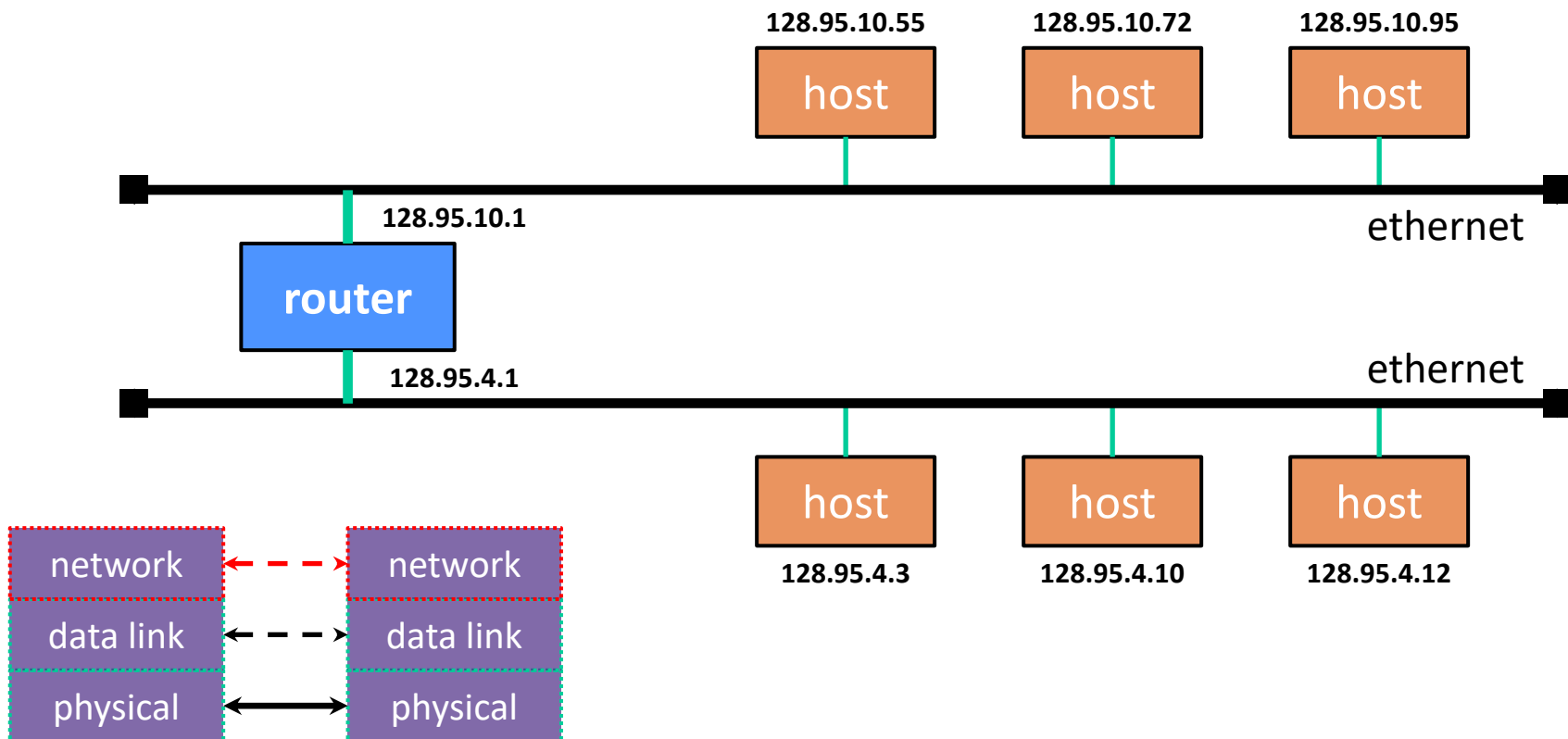
The Data Link Layer

- ❖ Multiple computers on a LAN contend for the network medium
 - Media access control (MAC) specifies how computers cooperate
 - Link layer also specifies how bits are “packetized” and network interface controllers (NICs) are addressed



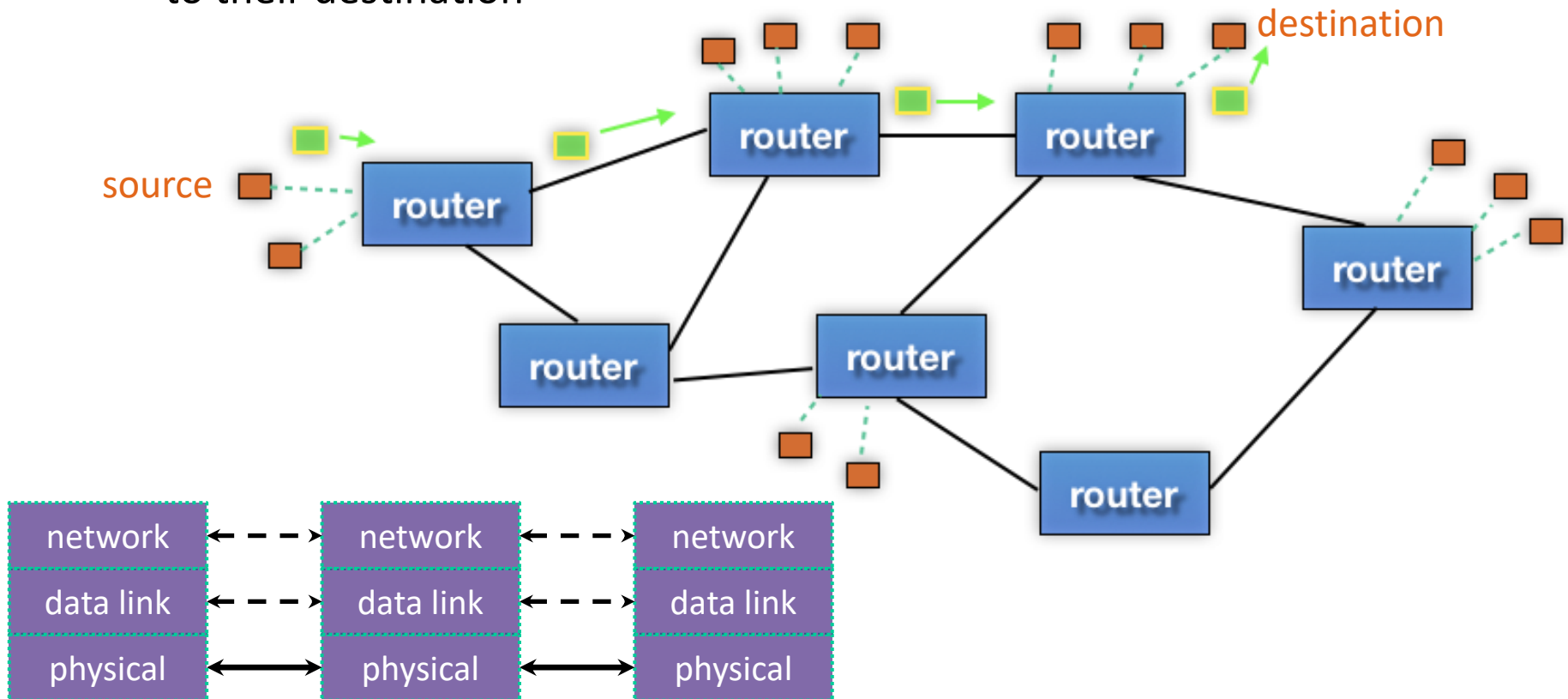
The Network Layer (IP)

- ❖ Internet Protocol (IP) routes packets across multiple networks
 - Every computer has a unique IP address
 - Individual networks are connected by routers that span networks



The Network Layer (IP)

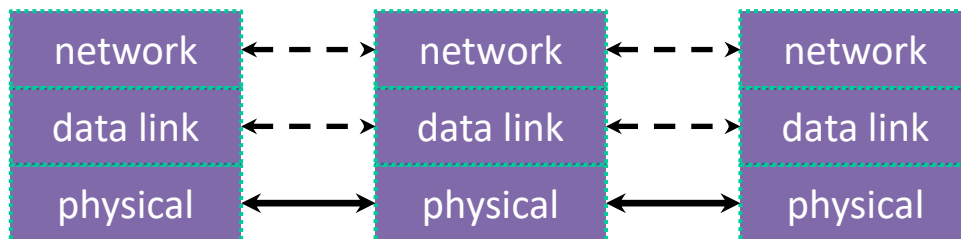
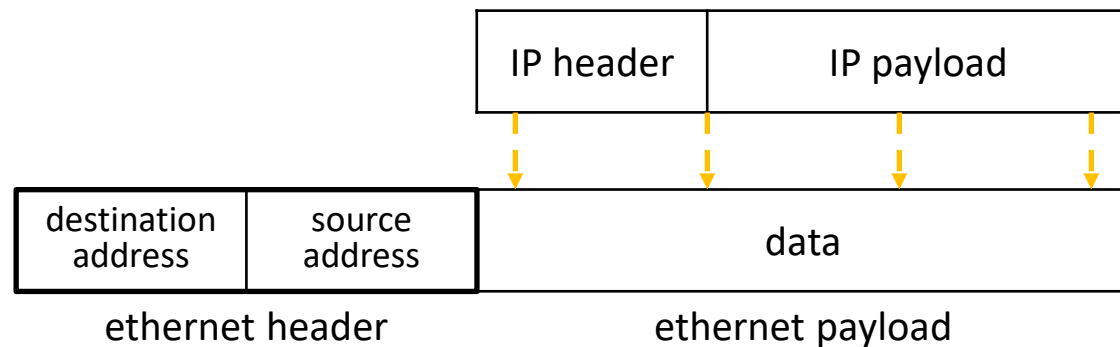
- ❖ There are protocols to:
 - Let a host map an IP to MAC address on the same network
 - Let a router learn about other routers to get IP packets one step closer to their destination



The Network Layer (IP)

❖ Packet encapsulation:

- An IP packet is encapsulated as the payload of an Ethernet frame
- As IP packets traverse networks, routers pull out the IP packet from an Ethernet frame and plunk it into a new one on the next network





Distance Matters – Latency

- ❖ Distances within a single datacenter are smaller than distances across continents
- ❖ Even within a datacenter, distances can sometimes matter

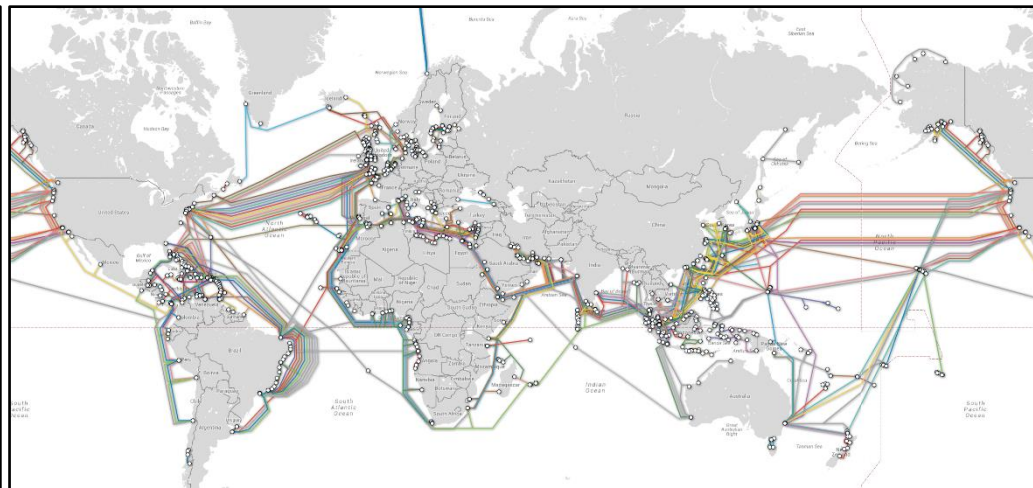


123Net Data Center, Wikimedia

Topology Matters – Latency, Reliability



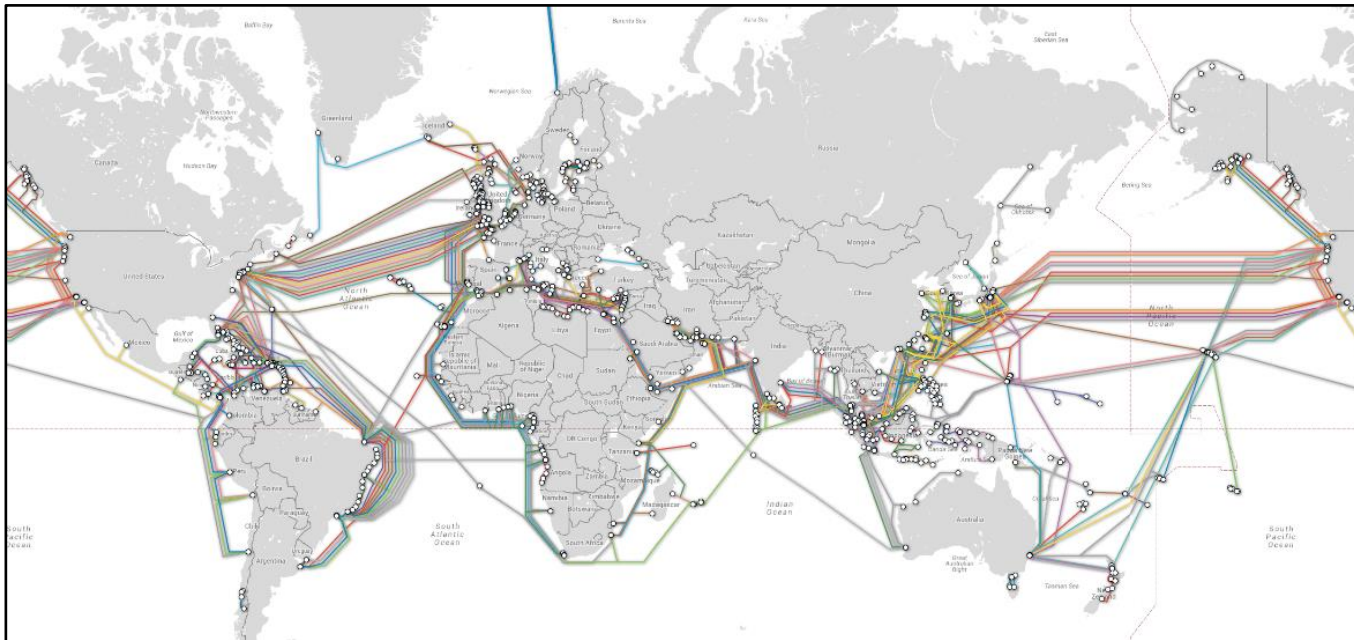
- ❖ Some places are surprisingly well- or poorly-connected to “backbone” infrastructure like fiber optic cables
- ❖ Unintuitive topology can create interesting failures
 - *e.g.*, 2006 7.0-magnitude Hengchun Earthquake disrupted communications to Singapore, Philippines, Thailand, China, etc. for a month





Reflect and Discuss

- ❖ Does this system of submarine cable connections seem ‘optimal’ to you?
- ❖ If not, who influences the decision-making process and what might their motivations be?
 - Explore the map here: <https://www.submarinecablemap.com/>



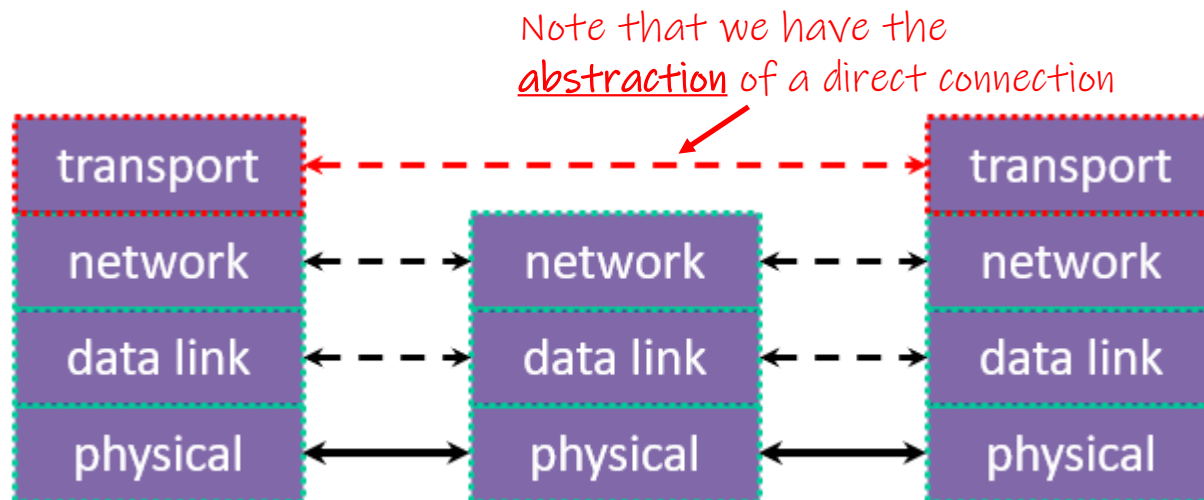


Submarine Cable Network Today

- ❖ ~436 fiber optic cables currently in use
 - Supports 99% of transoceanic communication
 - Primarily laid during early 2000's "fiber boom", but still occasional new cables and decommissioned cables
- ❖ Owners
 - Telecom carriers
 - Content providers
- ❖ Users
 - You and many others...
- ❖ Explore the network and its history:
<http://www.surfacing.in>

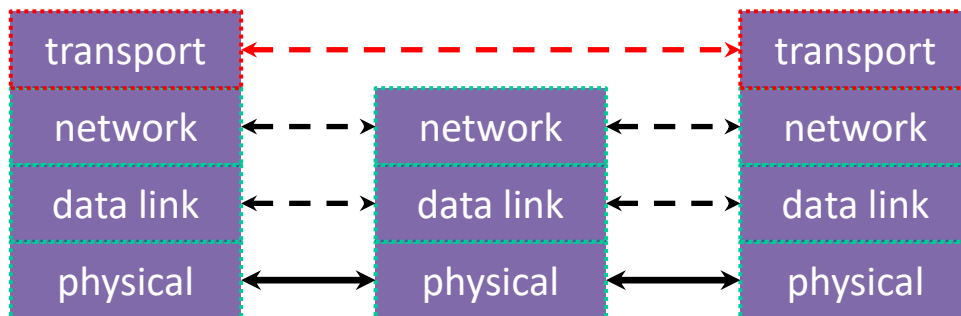
The Transport Layer

- ❖ Provides an interface to treat the network as a *data stream*
- ❖ Provides different protocols to interface between source and destination:
 - e.g., Transmission Control Protocol (TCP), User Datagram Protocol (UDP)
 - These protocols still work with packets, but manages their order, reliability, multiple applications using the network...



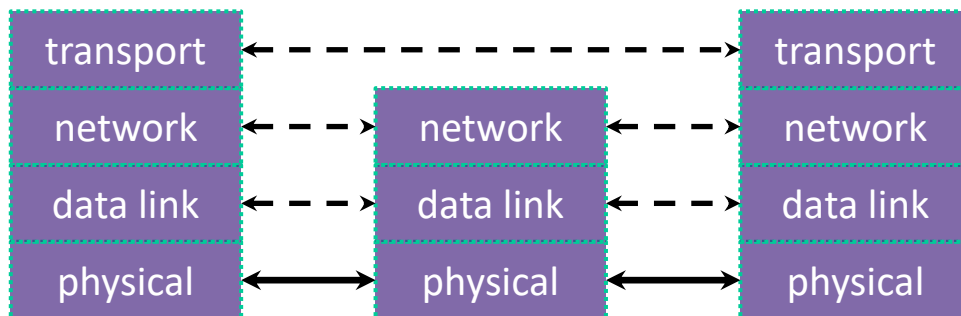
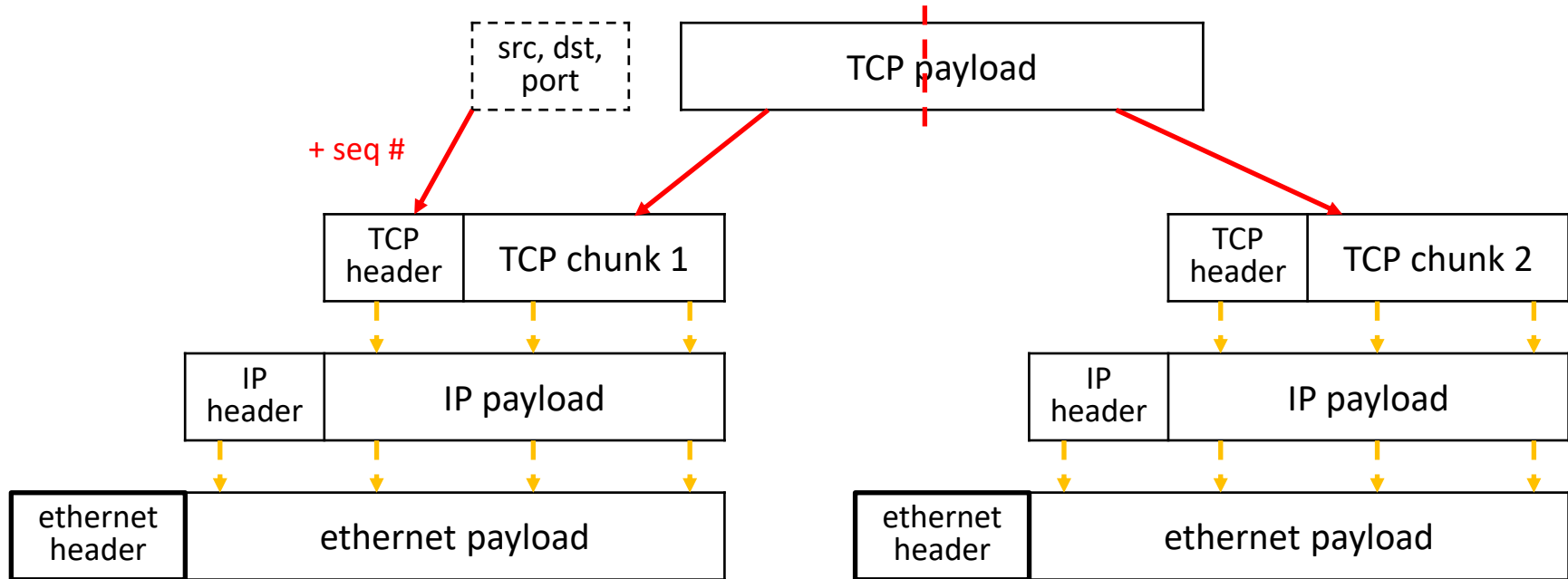
The Transport Layer (TCP)

- ❖ Transmission Control Protocol (TCP):
 - Provides applications with reliable, ordered, congestion-controlled byte streams
 - Sends stream data as multiple IP packets (differentiated by sequence numbers) and retransmits them as necessary
 - When receiving, puts packets back in order and detects missing packets
 - A single host (IP address) can have up to $2^{16} = 65,535$ “ports”
 - Kind of like an apartment number at a postal address (your applications are the residents who get mail sent to an apt. #)



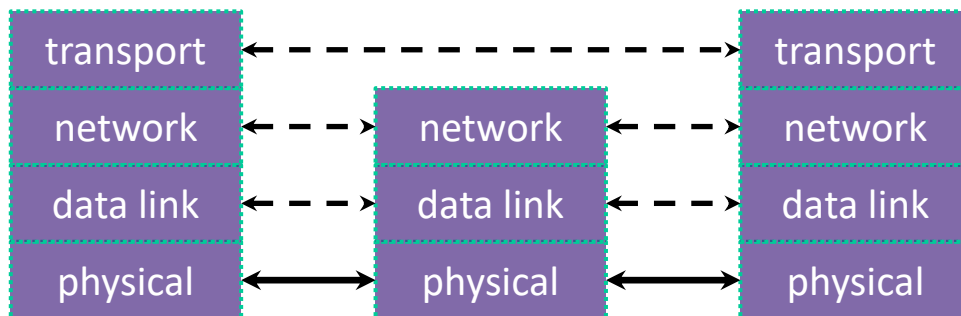
The Transport Layer (TCP)

- ❖ Packet encapsulation – one more nested layer!



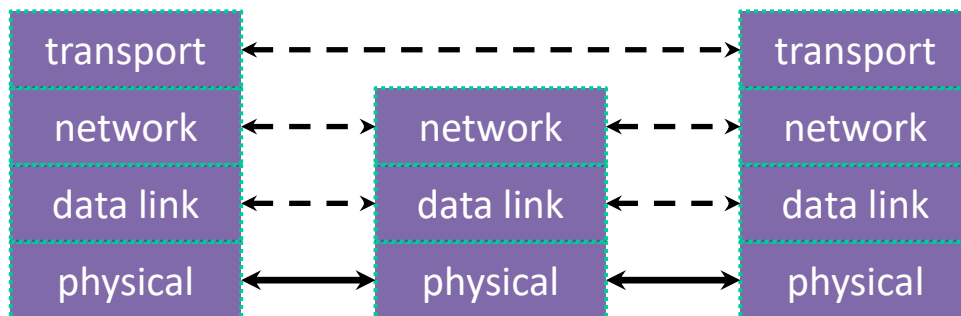
The Transport Layer (TCP)

- ❖ Applications use OS services to establish TCP streams:
 - The “Berkeley sockets” API
 - A set of OS system calls
 - Clients **connect** () to a server IP address + application port number
 - Servers **listen** () for and **accept** () client connections
 - Clients and servers **read** () and **write** () data to each other



The Transport Layer (UDP)

- ❖ User Datagram Protocol (UDP):
 - Provides applications with *unreliable* packet delivery
 - UDP is a really thin, simple layer on top of IP
 - Datagrams still are fragmented into multiple IP packets

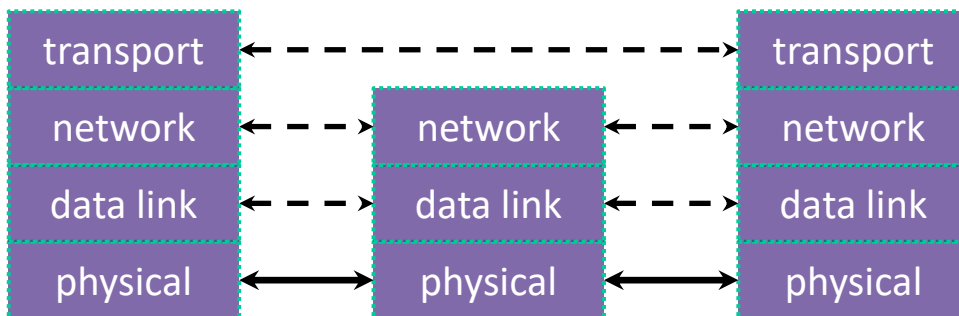


The Transport Layer

TCP:

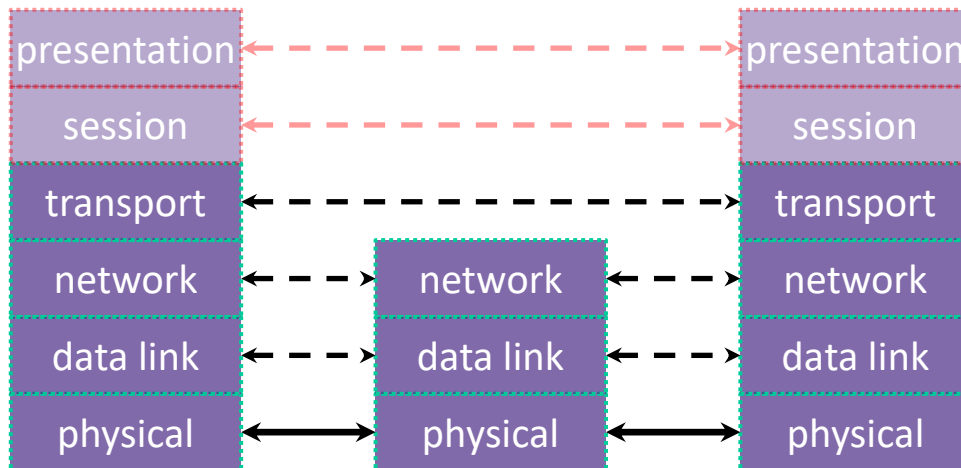


UDP:



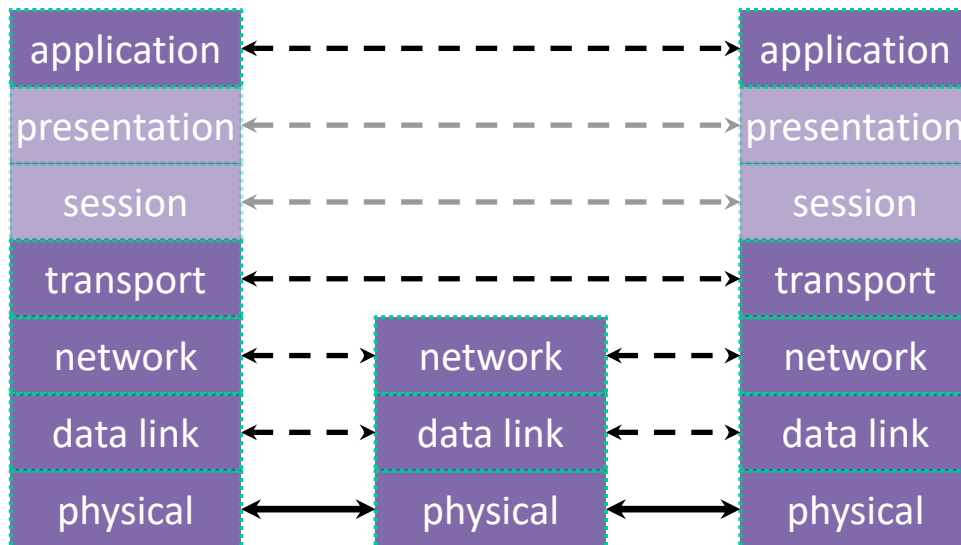
The (Mostly Missing) Layers 5 & 6

- ❖ Layer 5: Session Layer
 - Supposedly handles establishing and terminating application sessions
 - Remote Procedure Call (RPC) kind of fits in here
- ❖ Layer 6: Presentation Layer
 - Supposedly maps application-specific data units into a more network-neutral representation
 - Encryption (SSL) kind of fits in here



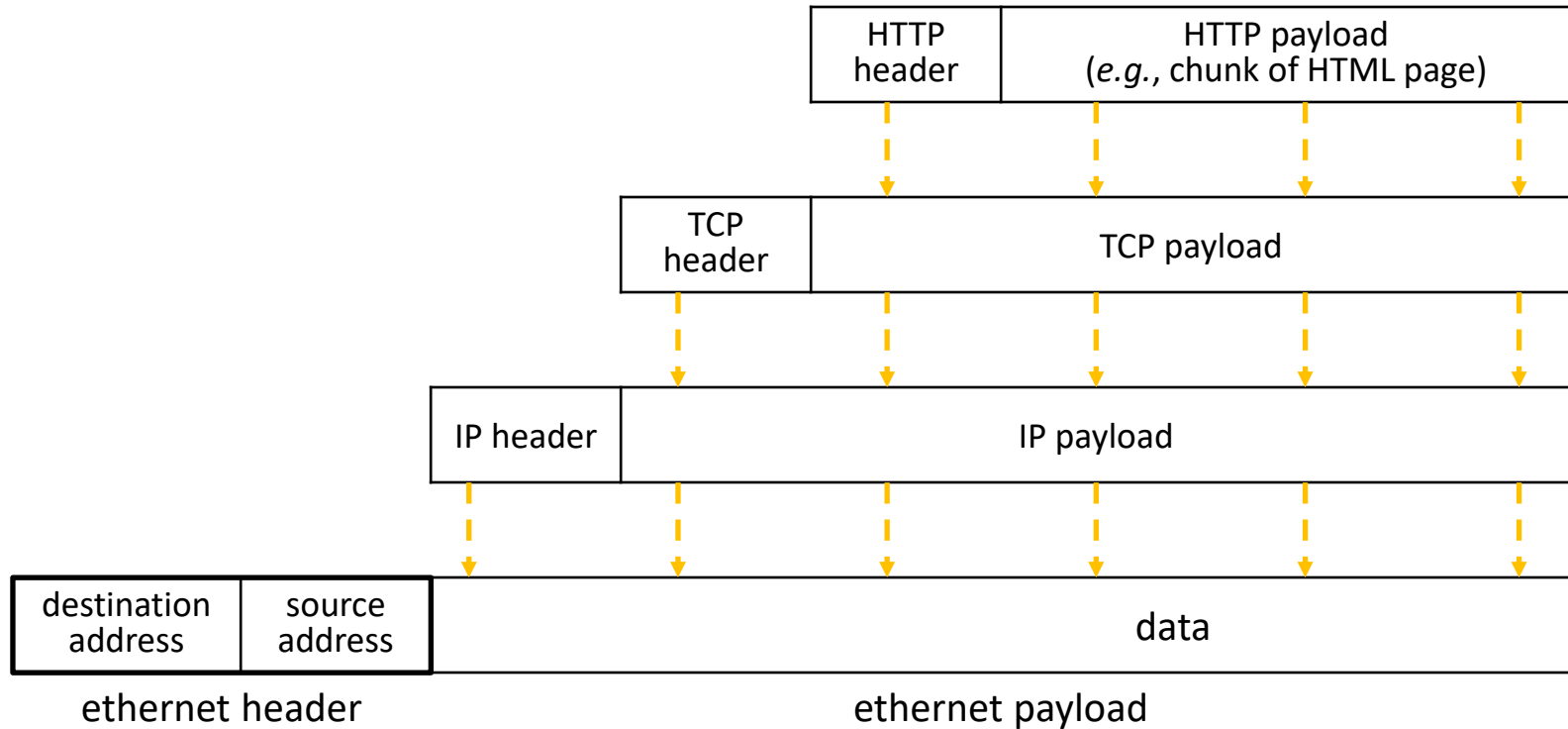
The Application Layer

- ❖ Application protocols
 - The format and meaning of messages between application entities
 - *e.g.*, HTTP is an application-level protocol that dictates how web browsers and web servers communicate
 - HTTP is implemented *on top of* TCP streams



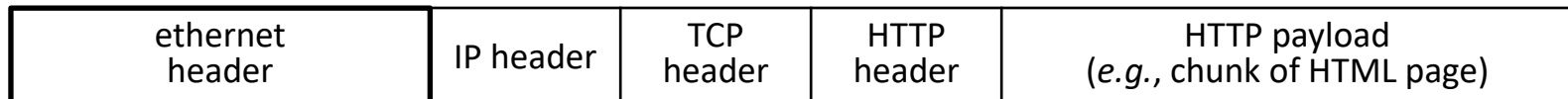
The Application Layer

❖ Packet encapsulation:



The Application Layer

- ❖ Packet encapsulation:



The Application Layer

- ❖ Popular application-level protocols:
 - **DNS:** translates a domain name (*e.g.*, www.google.com) into one or more IP addresses (*e.g.*, 74.125.197.106)
 - Domain Name System
 - An hierarchy of DNS servers cooperate to do this
 - **HTTP:** web protocols
 - Hypertext Transfer Protocol
 - **SMTP, IMAP, POP:** mail delivery and access protocols
 - Secure Mail Transfer Protocol, Internet Message Access Protocol, Post Office Protocol
 - **SSH:** secure remote login protocol
 - Secure Shell
 - **bittorrent:** peer-to-peer, swarming file sharing protocol

netcat demo (if time)

- ❖ netcat (`nc`) is “a computer networking utility for reading from and writing to network connections using TCP or UDP”
 - <https://en.wikipedia.org/wiki/Netcat>
 - Listen on port: `nc -l <port>`
 - Connect: `nc <IPaddr> <port>`
 - Local host: `127.0.0.1`