pollev.com/cse333

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 Winter 2023

Instructor: Justin Hsia

Teaching Assistants:

Adina Tung
James Froelich
Noa Ferman
Saket Gollapudi
Timmy Yang
Zhuochun Liu
Danny Agustinus
Lahari Nidadavolu
Patrick Ho
Sara Deutscher
Wei Wu
Edward Zhang
Mitchell Levy
Paul Han
Tim Mandzyuk
Yiqing Wang

Relevant Course Information

- No Lecture on Monday (2/20 President's day)
- Exercise 9 is due Monday (2/20)
- Homework 3 is due next Thursday (2/23)
  - Debug using small custom test directories
  - Make use of the solution binaries to double-check your work
- Rest of the quarter: networking, concurrency, processes

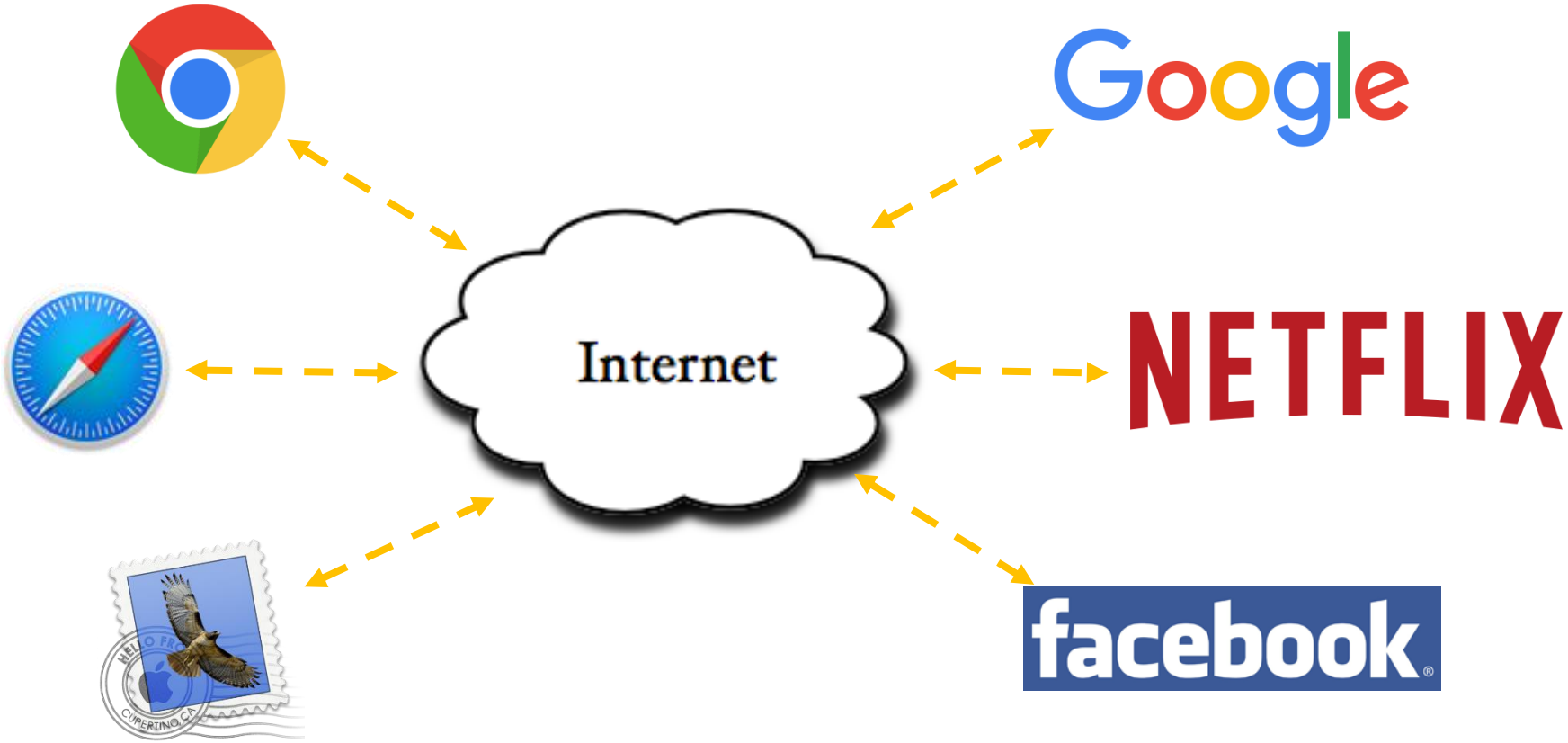
Lecture Outline

- **Introduction to Networks**
  - **Layers upon layers upon layers…**

Today's Goals

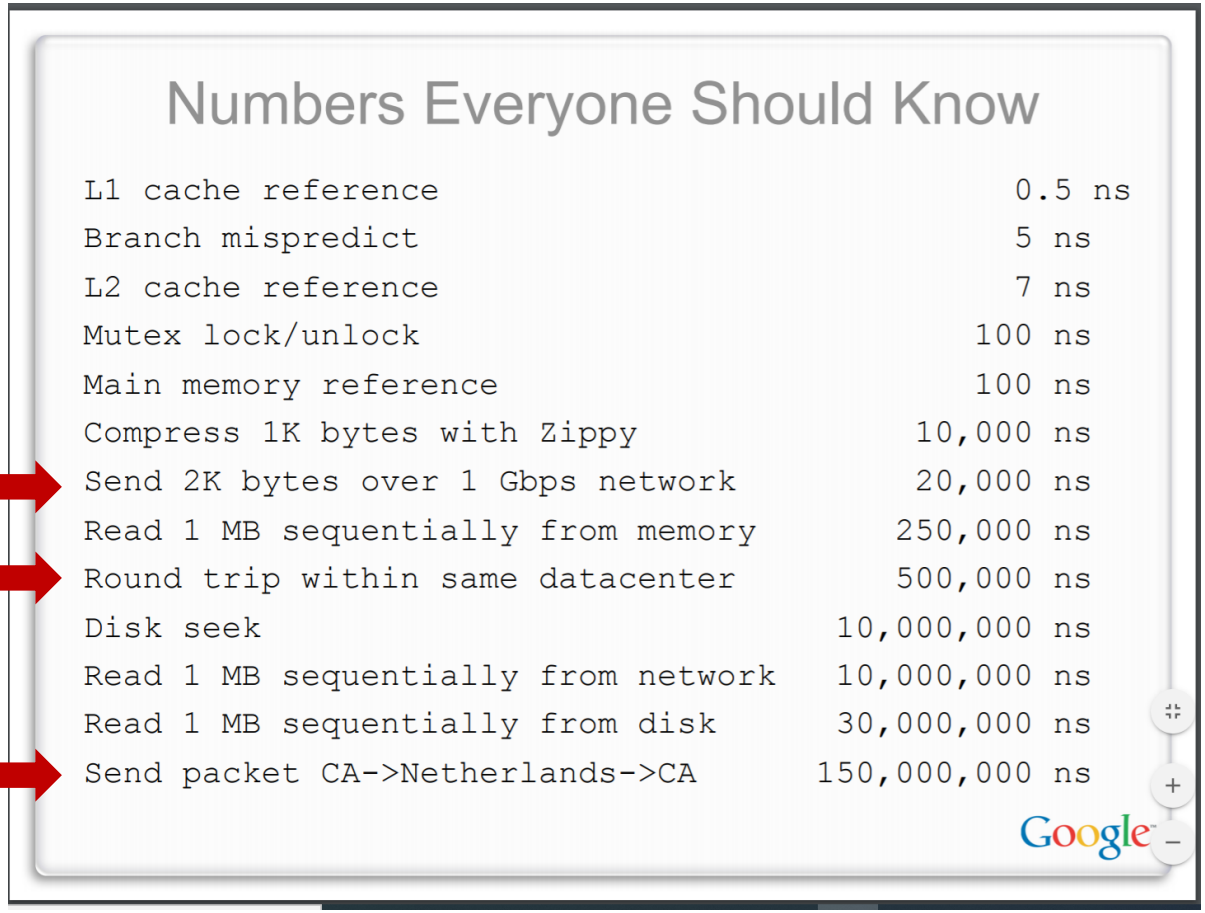
- Networking is a very common programming feature
  - You will likely have to create a program that will read/write over the network at some point in your career
- We want to give you a basic, high-level understanding of how networks work before you use them
  - Lecture will be more "story-like;" we 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



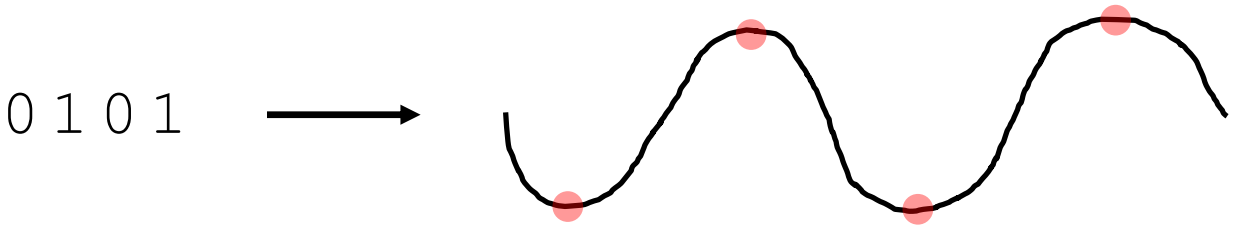
"Network" Latency is Highly Variable

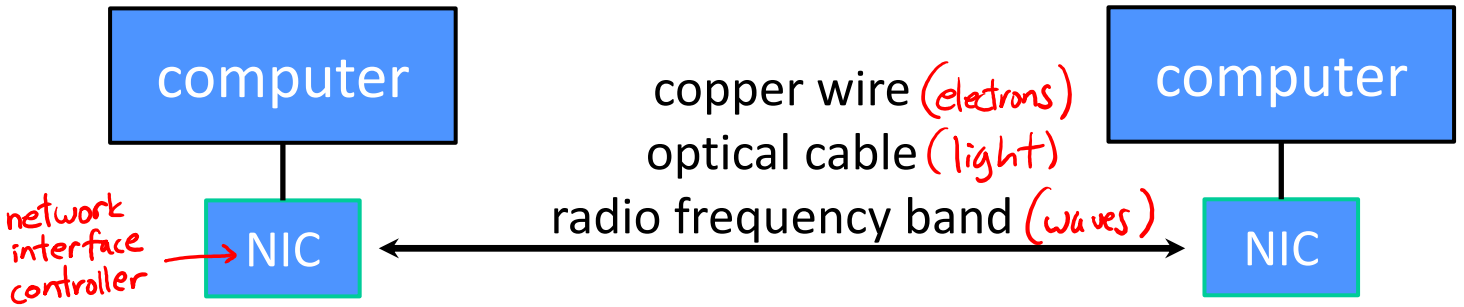
- Jeff Dean's "Numbers Everyone Should Know" (LADIS '09)



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

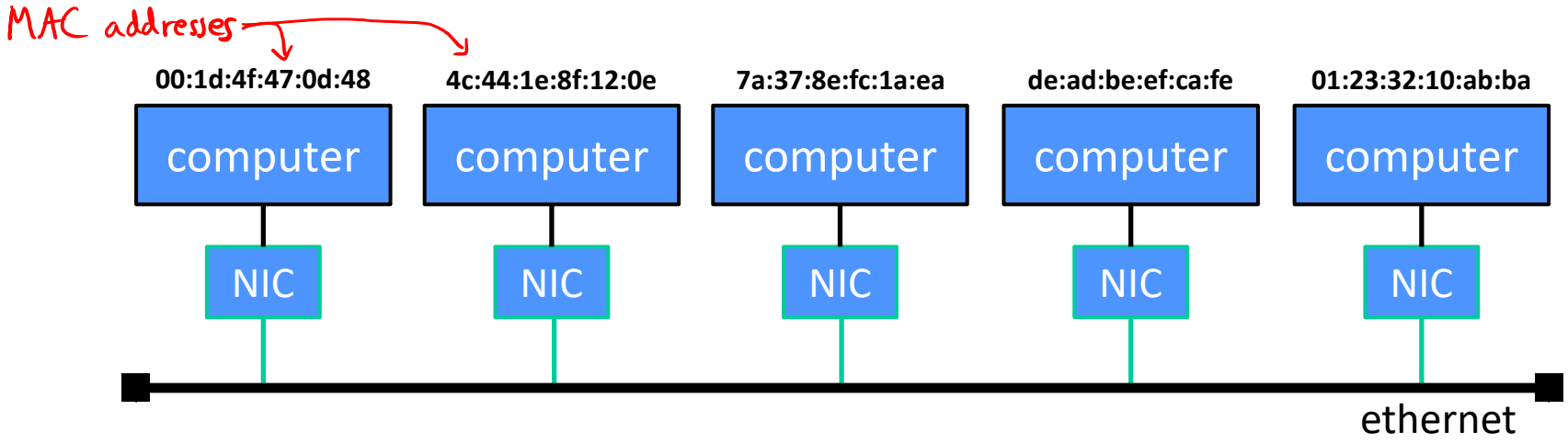
- Fiber optic cables are lower-latency and higher-bandwidth than traditional copper wiring
  - Much of the internet's "long haul" data is transmitted on these
  - (signal attenuation is much better too)

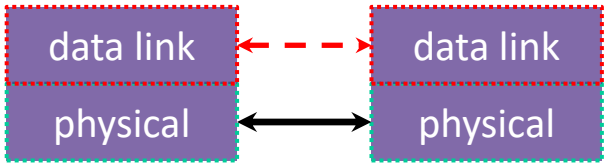
- Is it faster to send 1 person from UW to …
  - Downtown Seattle?
  - Ballard?

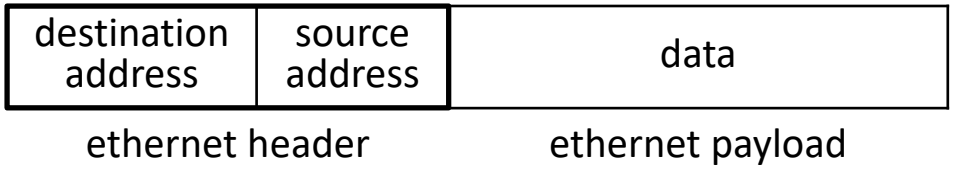
not just distance, but also speed limit & number of lanes
mode of transportation, route, traffic, etc.

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

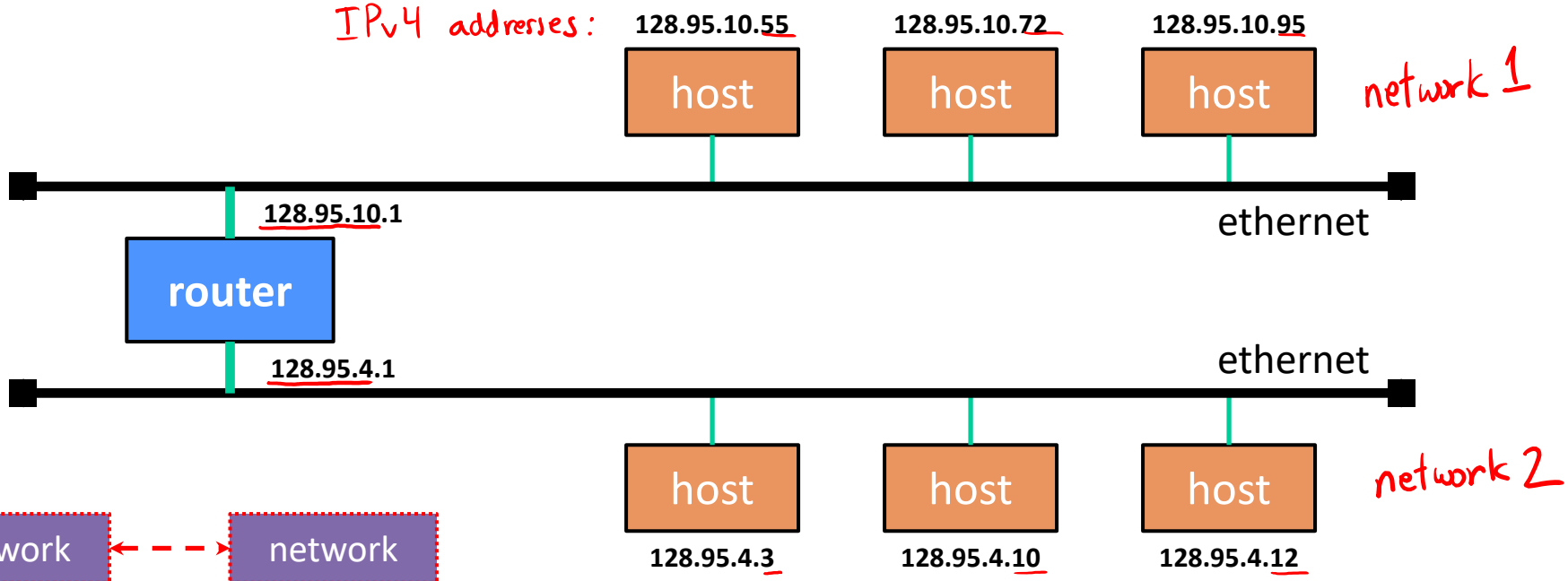


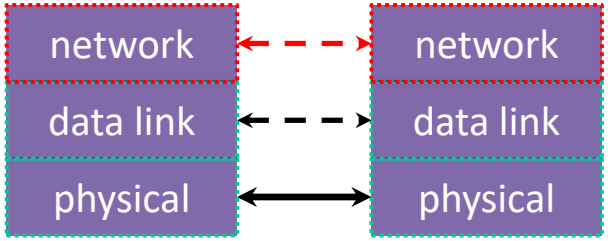




The Network Layer (IP)

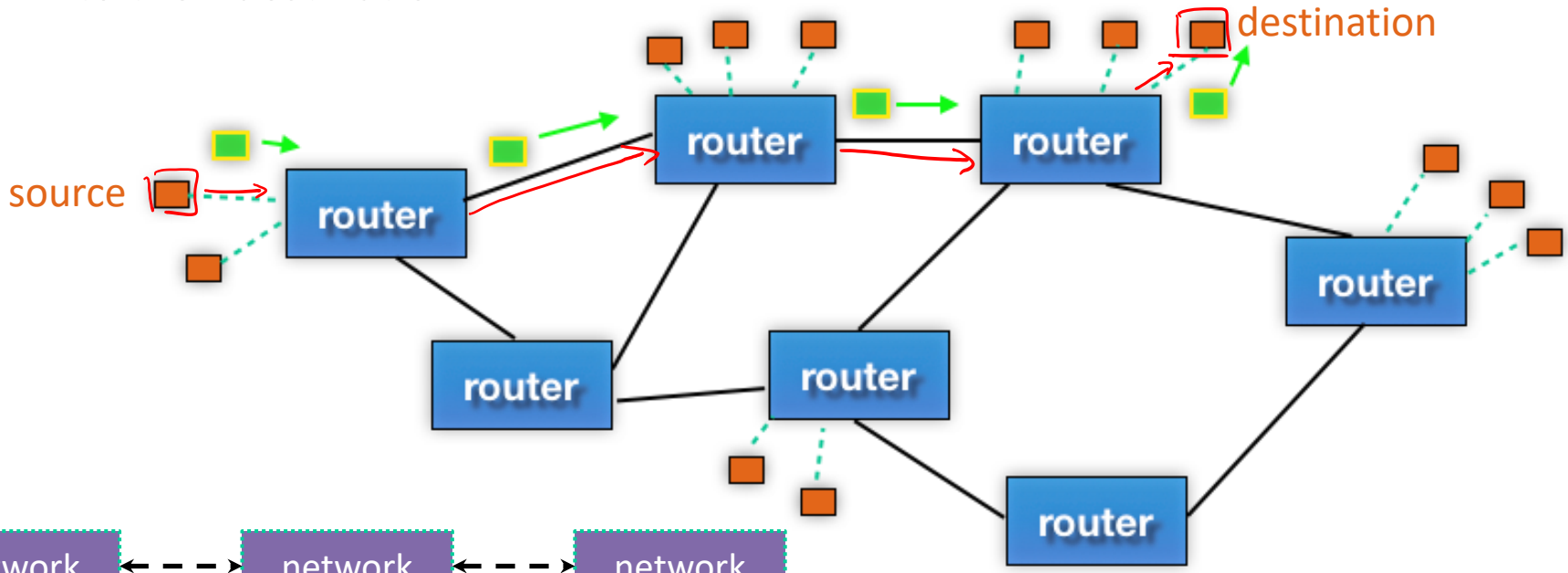
- Internet Protocol (IP) routes packets across multiple networks
  - Every computer has a unique IP address
  - Individual networks are connected by routers that span networks

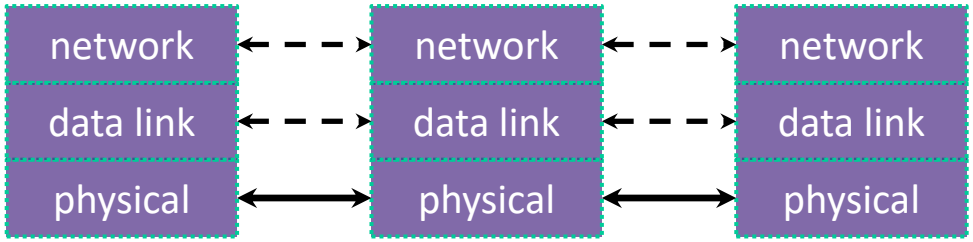




The Network Layer (IP)

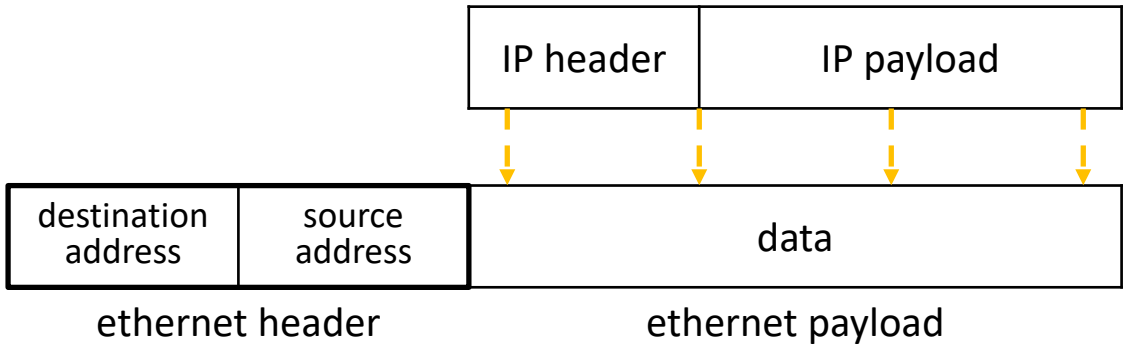
- There are protocols to:
  - Let a host map an IP to MAC address on the same network
  - Let a router learn about other routers to get IP packets one step closer to their destination

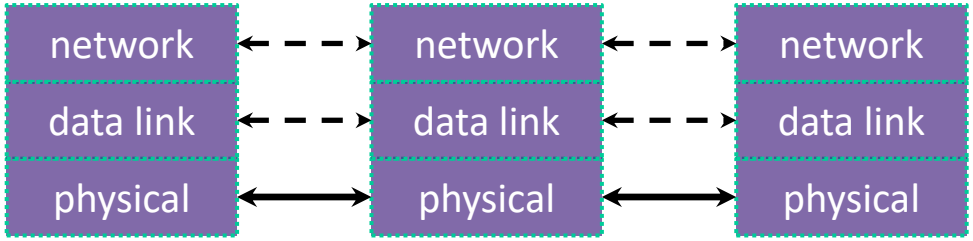




The Network Layer (IP)

- 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





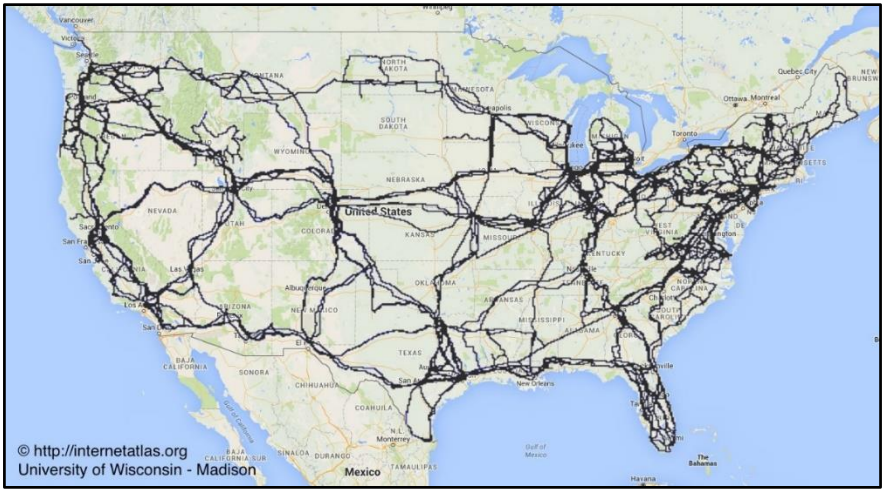
Distance Matters – Latency

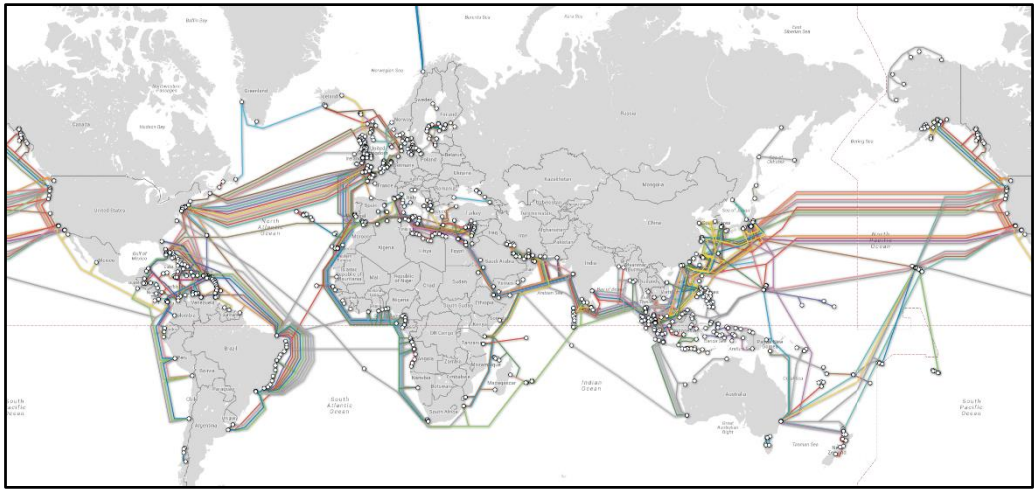
- Distances within a single datacenter are smaller than distances across continents
- Even within a datacenter, distances can sometimes matter

123Net Data Center, Wikimedia

Topology Matters – Latency, Reliability

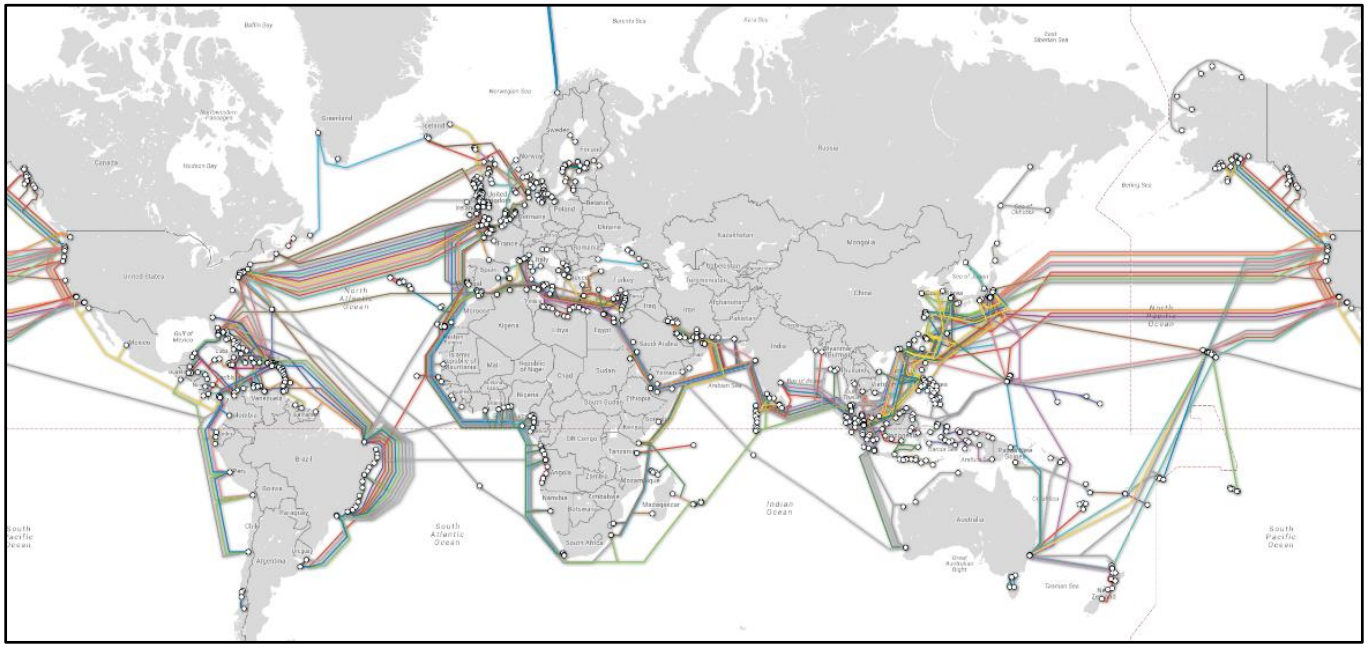
- Some places are surprisingly well- or poorly-connected to "backbone" infrastructure like fiber optic cables
- Unintuitive topology can create interesting failures
  - *e.g.*, 2006 7.0-magnitude Hengchun Earthquake disrupted communications to Singapore, Philippines, Thailand, China, etc. for a month





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/



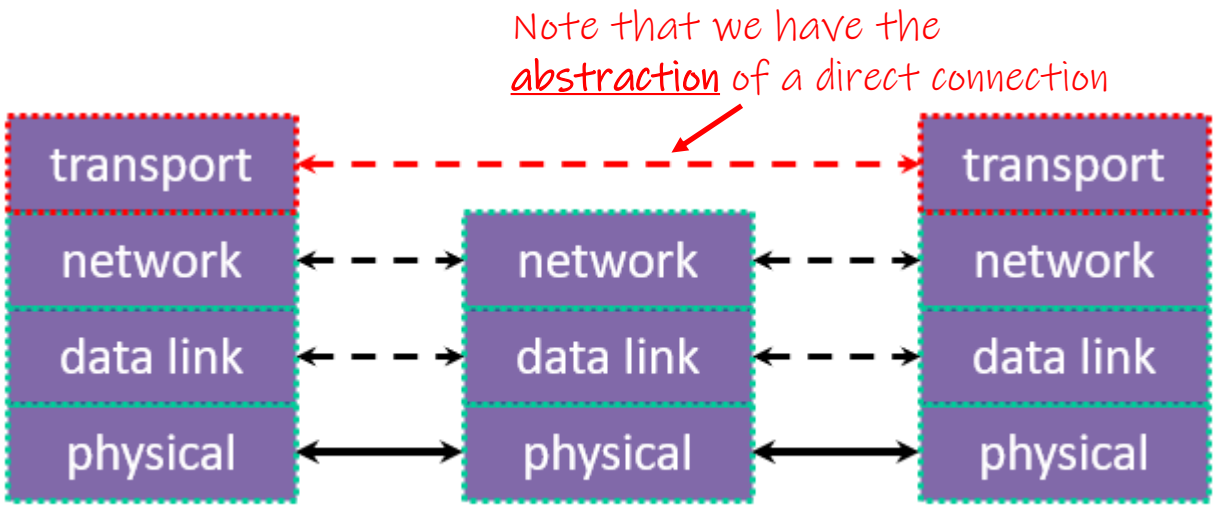
Submarine Cable Network Today

- ~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

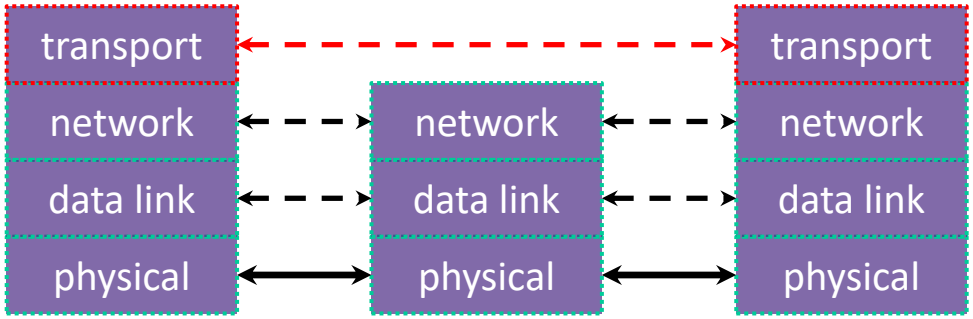
The Transport Layer

- 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…



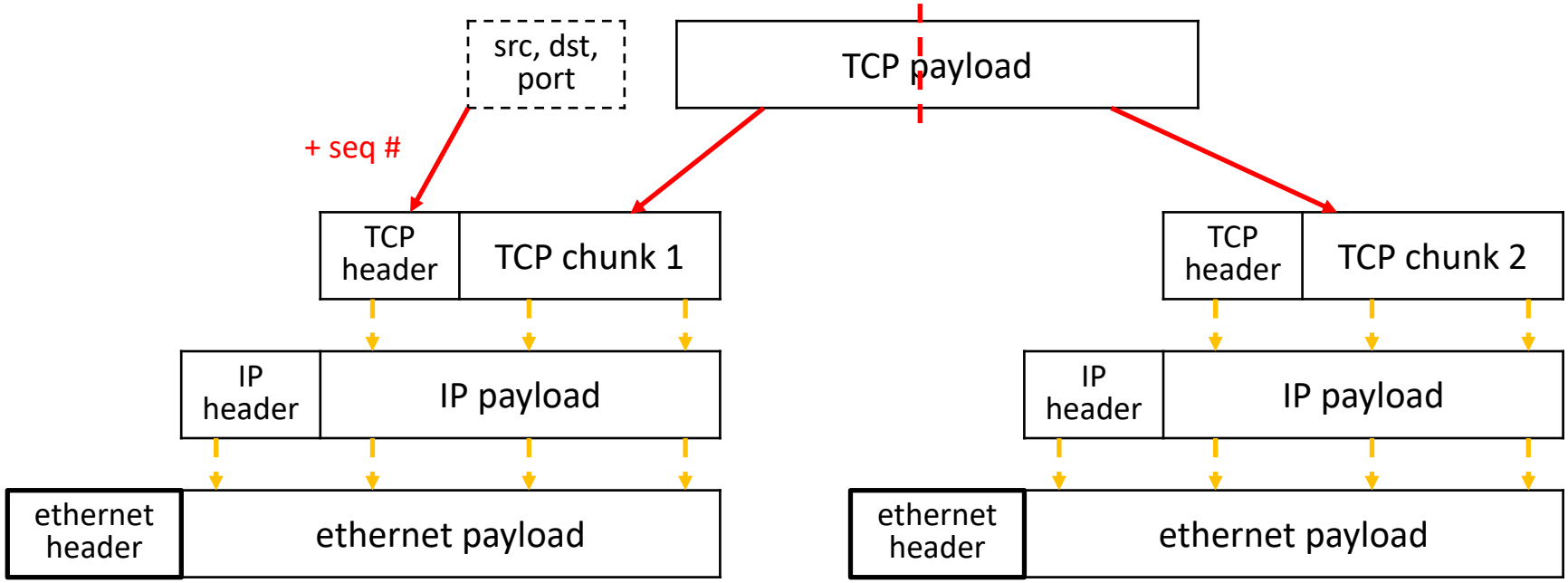
The Transport Layer (TCP)

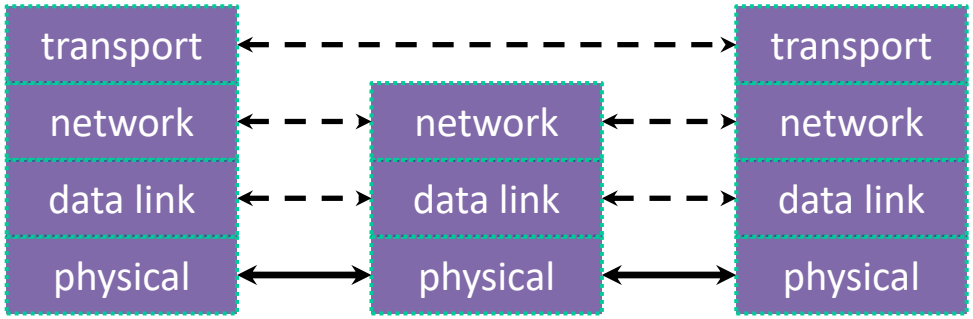
- Transmission Control Protocol (TCP):
  - Provides applications with reliable, ordered, congestion-controlled byte streams
    - Sends stream data as multiple IP packets (differentiated by sequence numbers) and retransmits them as necessary
    - When receiving, puts packets back in order and detects 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!

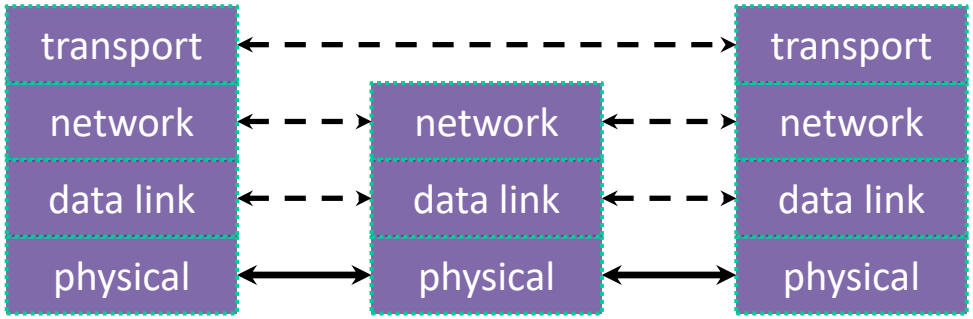




The Transport Layer (TCP)

- Applications use OS services to establish TCP streams:
  - The "Berkeley sockets" API
    - A set of OS system calls (part of POSIX for Linux)
  - 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

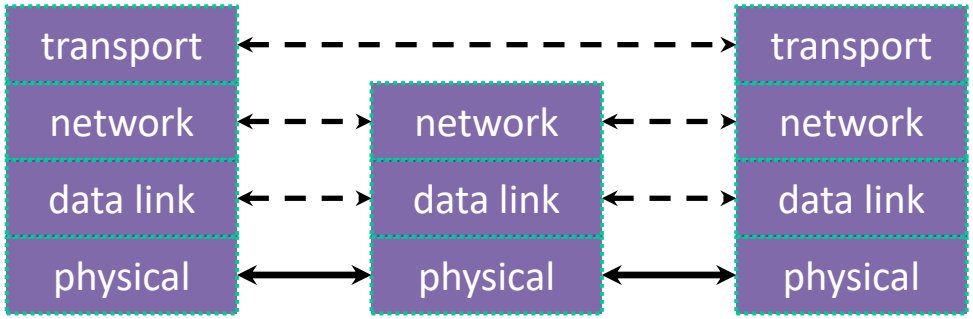
(same as for file I/O)



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

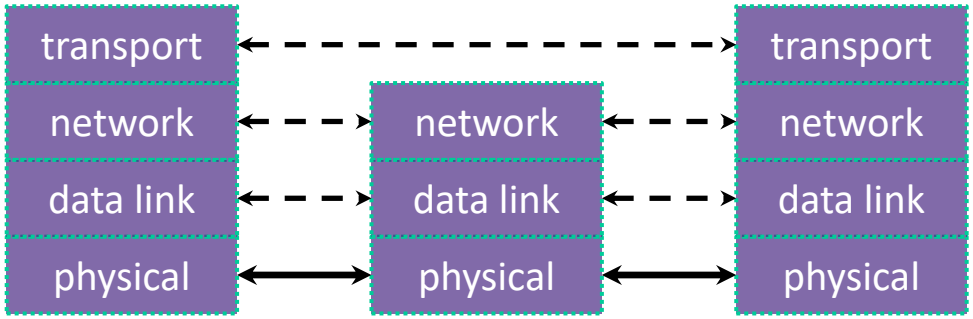
ok for things like video streaming



The Transport Layer

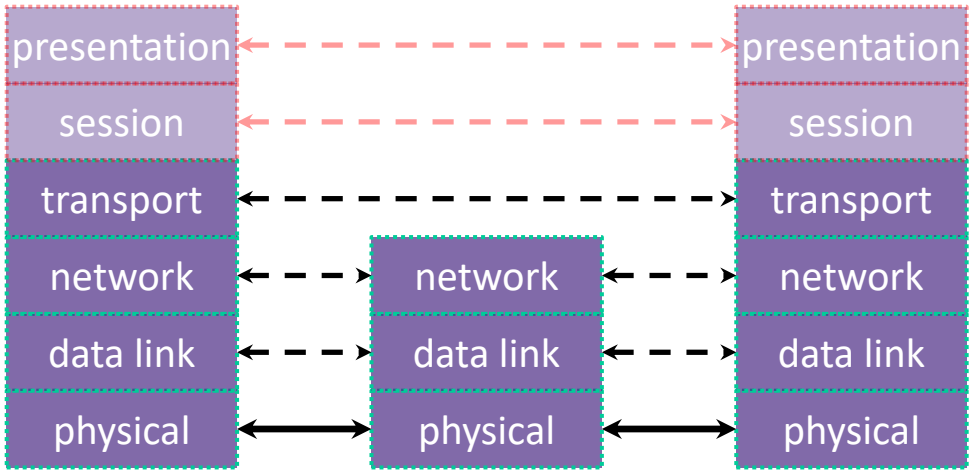
TCP:

UDP:



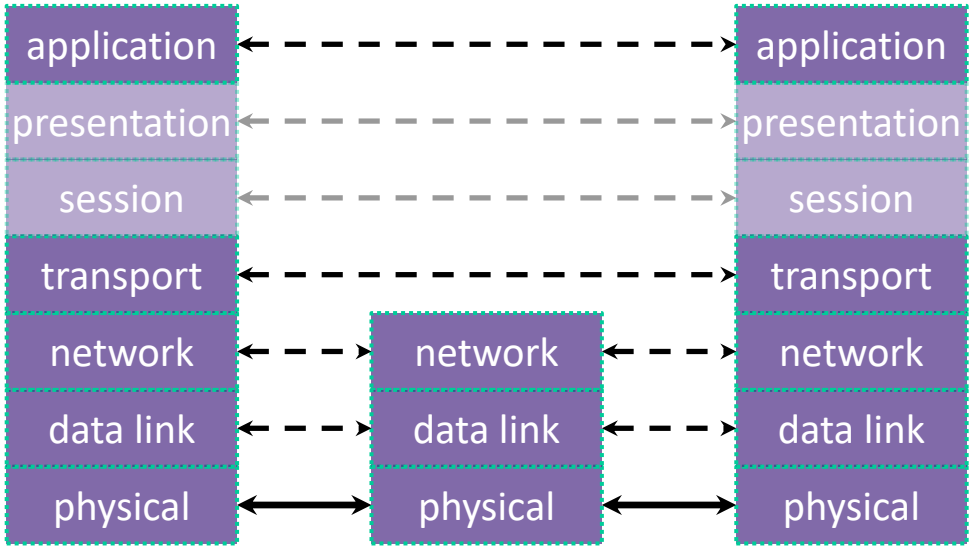
The (Mostly Missing) Layers 5 & 6

- 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



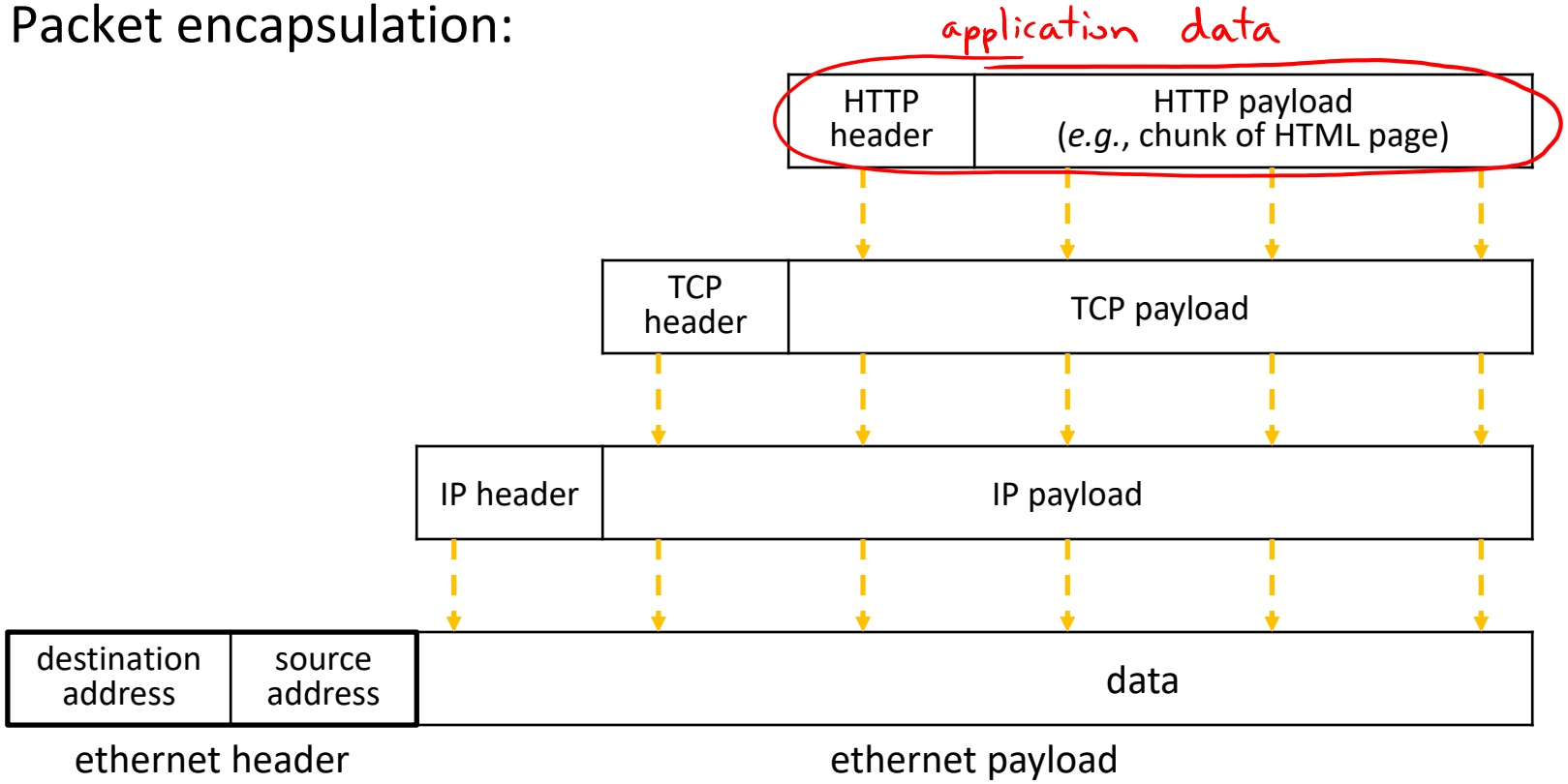
The Application Layer

- 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



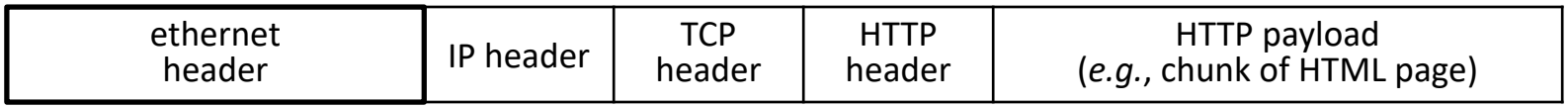
The Application Layer

- 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`