Poll Everywhere

pollev.com/cse333justin

About where are you on Homework 3?

A. Haven't started yet
B. Working on Part A (WriteIndex)
C. Working on Part B (*Reader, QueryProcessor)
D. Working on Part C (filesearchshell)
E. Finished or about finished
F. Prefer not to say

Notes:

- ✓ Debug using small custom test directories
- ✓ Make use of solution binaries to double-check your work

Networks Introduction

CSE 333 Spring 2021

Instructor: Justin Hsia, Travis McGaha

Teaching Assistants:

Atharva Deodhar	Callum Walker	Cosmo Wang
Dylan Hartono	Elizabeth Haker	Eric Marnadi
Kyrie Dowling	Leo Liao	Markus Schiffer
Neha Nagvekar	Nonthakit Chaiwong	Ramya Challa

Administrivia

- Rest of the quarter:
  - Topics: Networking, Concurrency, Processes
  - Homework 3: file search shell
  - Homework 4: file search shell over the network
  - Final Exam: take-home reflection questions

- Exercise 9 is due Monday (5/17)
- Only 3 exercises after that:
  - TCP sender, TCP listener, concurrency

- Homework 3 is due next Thursday (5/20)

Lecture Outline

- **C++ Conversions**
- Introduction to Networks

Implicit Conversion

- The compiler tries to infer some kinds of conversions
  - When types are not equal and you don't specify an explicit cast, the compiler looks for an acceptable implicit conversion

```
void bar(std::string x);

void foo() {
  int x = 5.7;   // conversion, float -> int
  char c = x;    // conversion, int -> char
  bar("hi");     // conversion, (const char*) -> string
}
```

Sneaky Implicit Conversions

- (`const char*`) to `string` conversion?
  - If a class has a constructor with a single parameter, the compiler will exploit it to perform implicit conversions
  - At most, one user-defined implicit conversion will happen
    - Can do `int` → `Foo`, but not `int` → `Foo` → `Baz`

```
class Foo {
 public:
  Foo(int xi) : x(xi) { }
  int x;
};

int Bar(Foo f) {
  return f.x;
}

int main(int argc, char** argv) {
  return Bar(5);  // equivalent to return Bar(Foo(5));
}
```

Avoiding Sneaky Implicits

- Declare one-argument constructors as `explicit` if you want to disable them from being used as an implicit conversion path
  - Usually a good idea

```
class Foo {
 public:
  explicit Foo(int xi) : x(xi) { }
  int x;
};

int Bar(Foo f) {
  return f.x;
}

int main(int argc, char** argv) {
  return Bar(5);  // compiler error
}
```

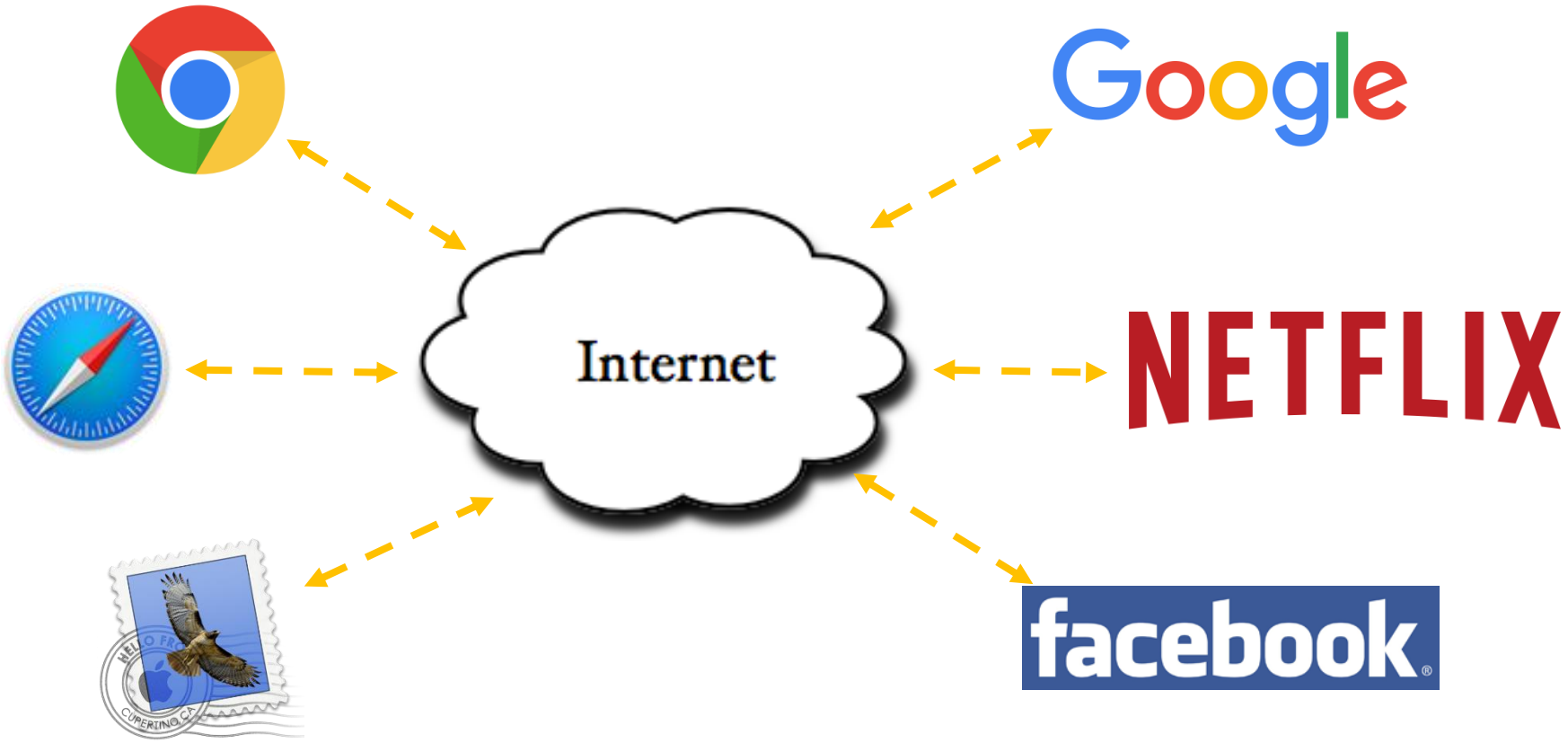
Lecture Outline

- C++ Conversions
- **Introduction to Networks**
  - **Layers upon layers upon layers…**

Today's Goals

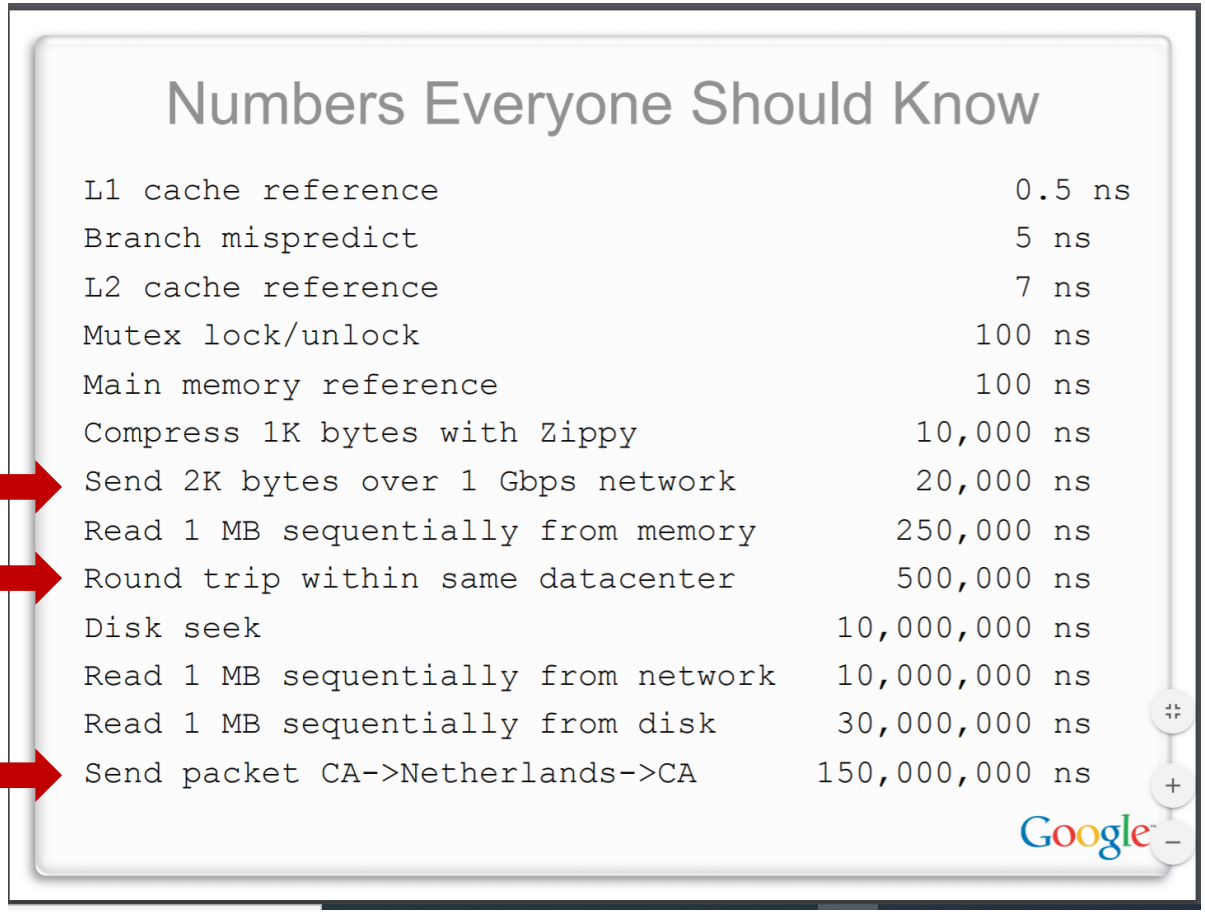
- Networking is a very common programming feature
  - You will likely have to create a program that will read/write over the network at some point in your career
- We want to give you a basic, high-level understanding of how networks work before you use them
  - Lecture will be more "story-like;" we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



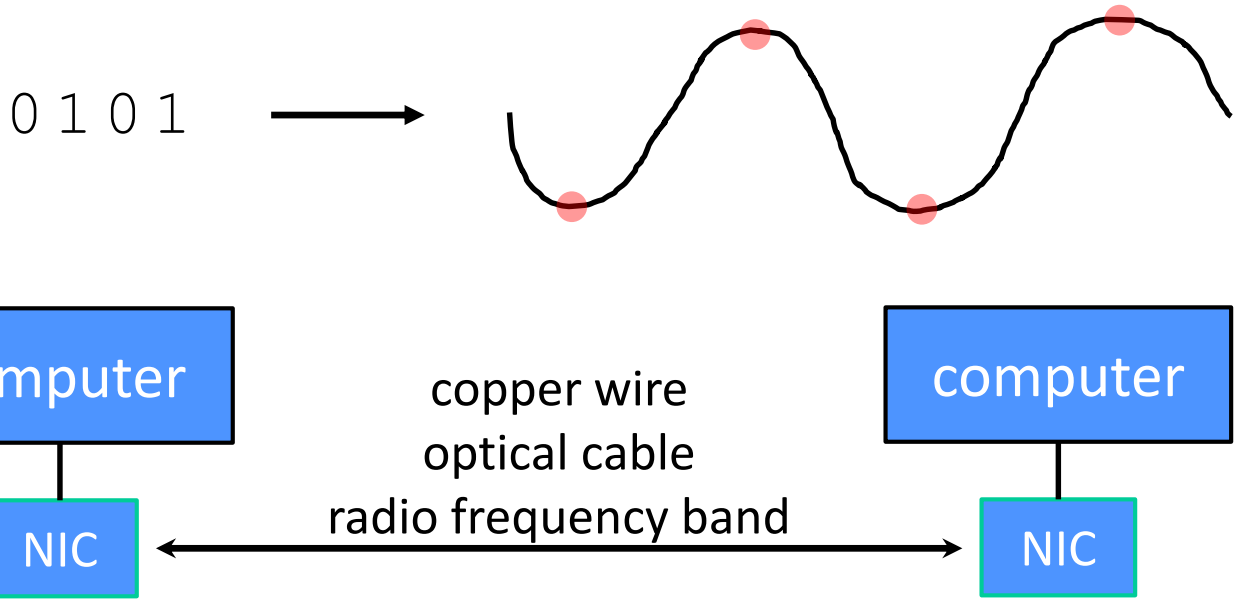
"Network" Latency is Highly Variable

- 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, …



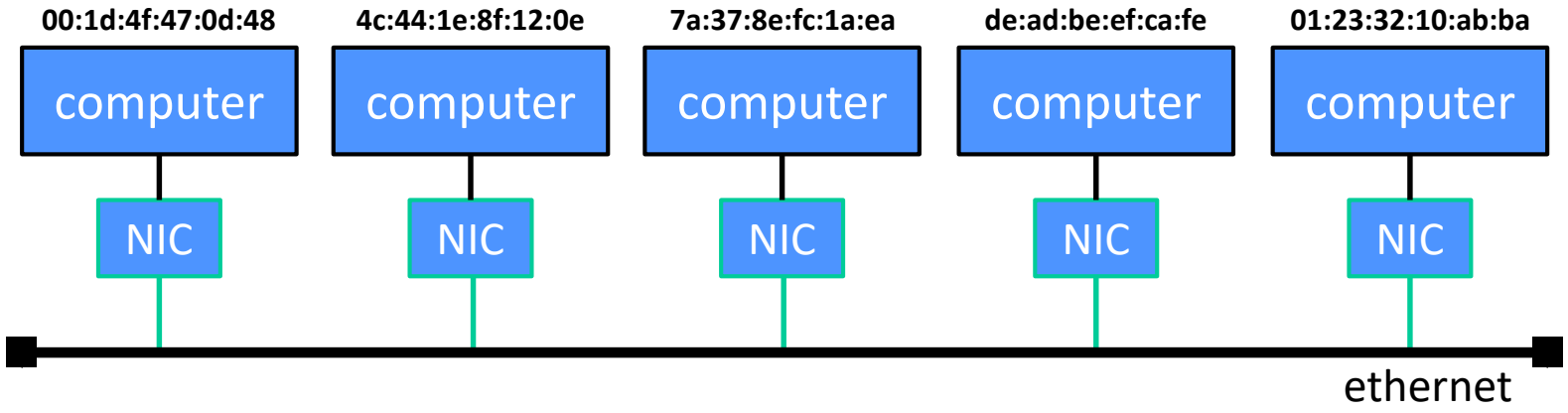
Materials Matter – Latency

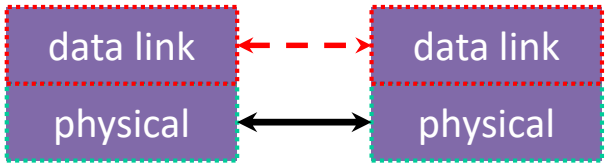
- Fiber optic cables are lower-latency and higher-bandwidth than traditional copper wiring
  - Much of the internet's "long haul" data is transmitted on these
  - (signal attenuation is much better too)

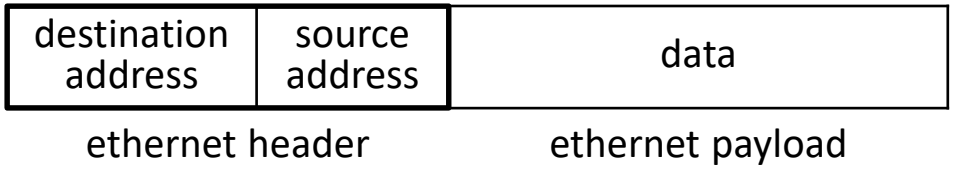
- Is it faster to send 1 person from UW to …
  - Downtown Seattle?
  - Downtown Ballard?

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

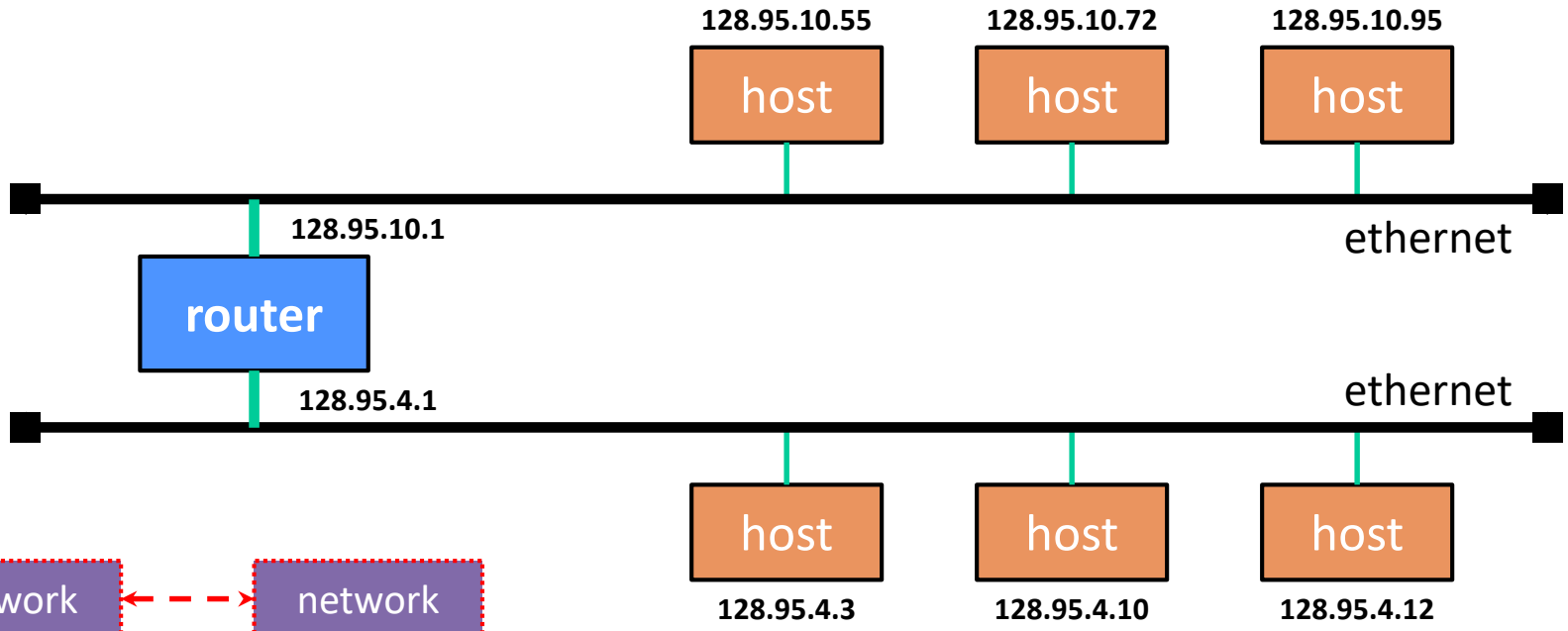


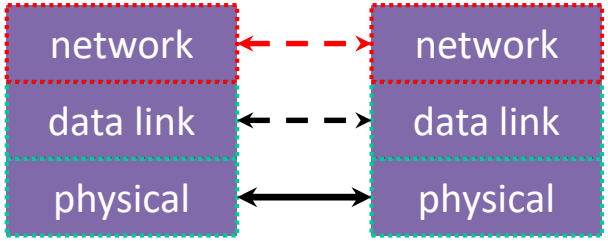




The Network Layer (IP)

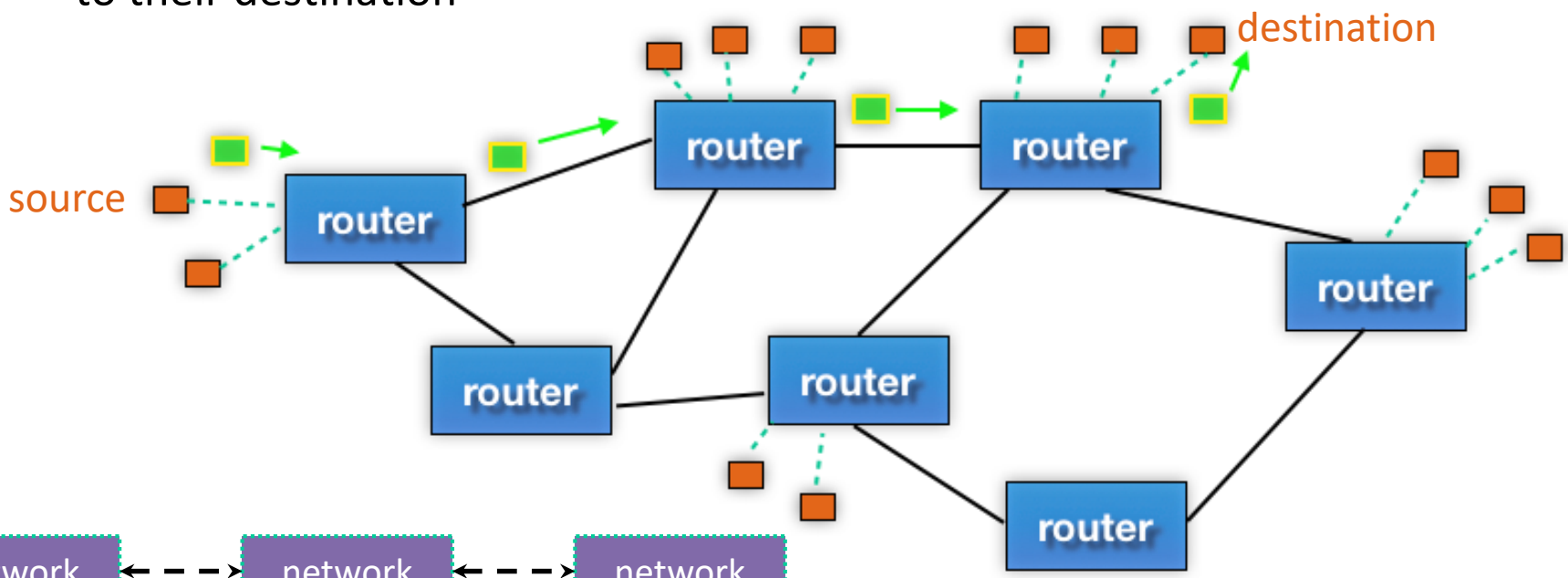
- Internet Protocol (IP) routes packets across multiple networks
  - Every computer has a unique IP address
  - Individual networks are connected by routers that span networks

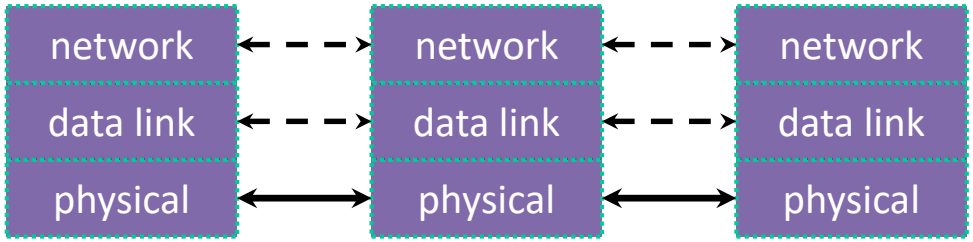




The Network Layer (IP)

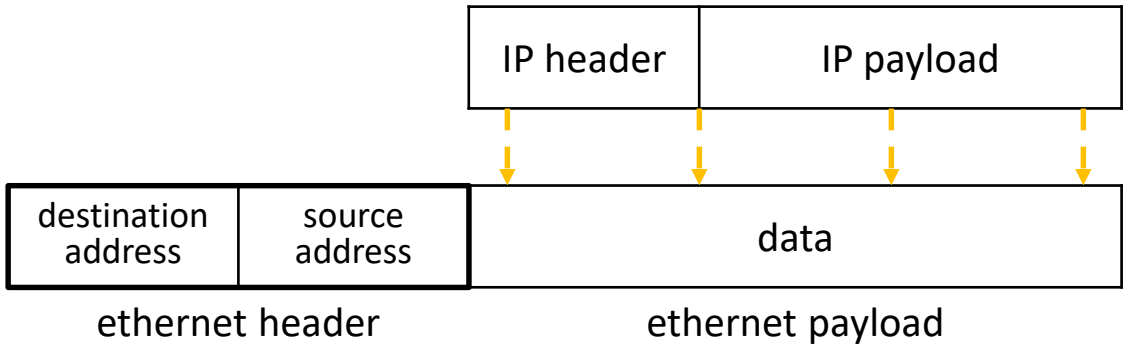
- There are protocols to:
  - Let a host map an IP to MAC address on the same network
  - Let a router learn about other routers to get IP packets one step closer to their destination

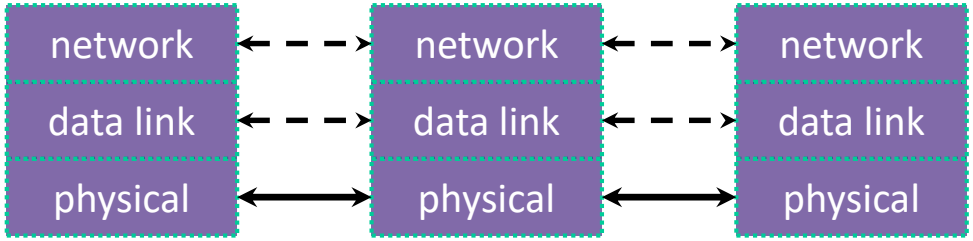




The Network Layer (IP)

- 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





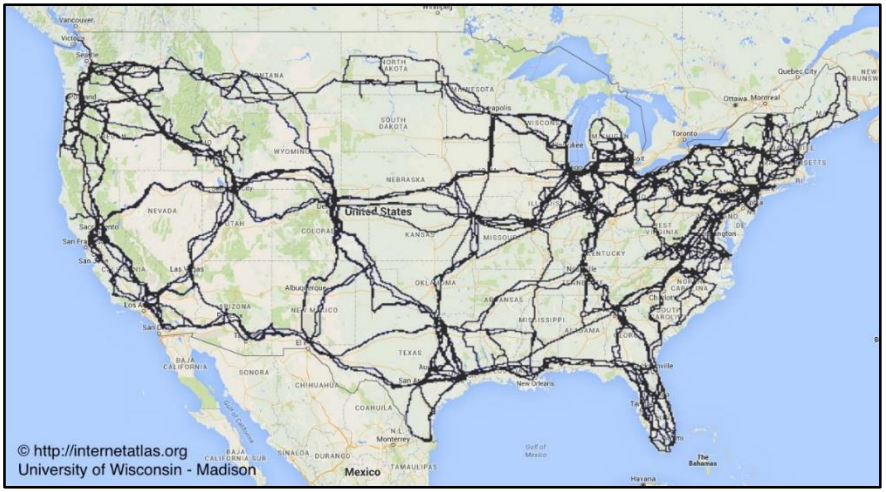
Distance Matters – Latency

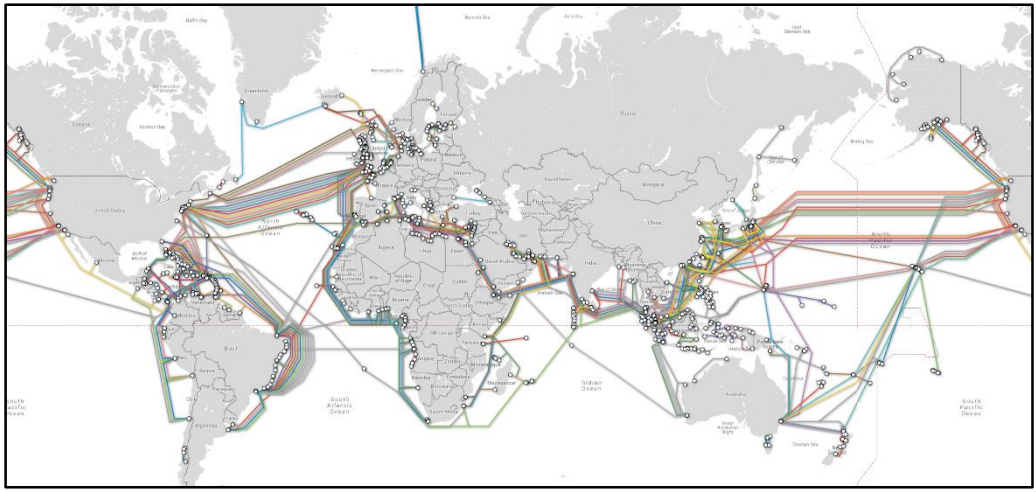
- Distances within a single datacenter are smaller than distances across continents
- Even within a datacenter, distances can sometimes matter

123Net Data Center, Wikimedia

Topology Matters – Latency and Reliability

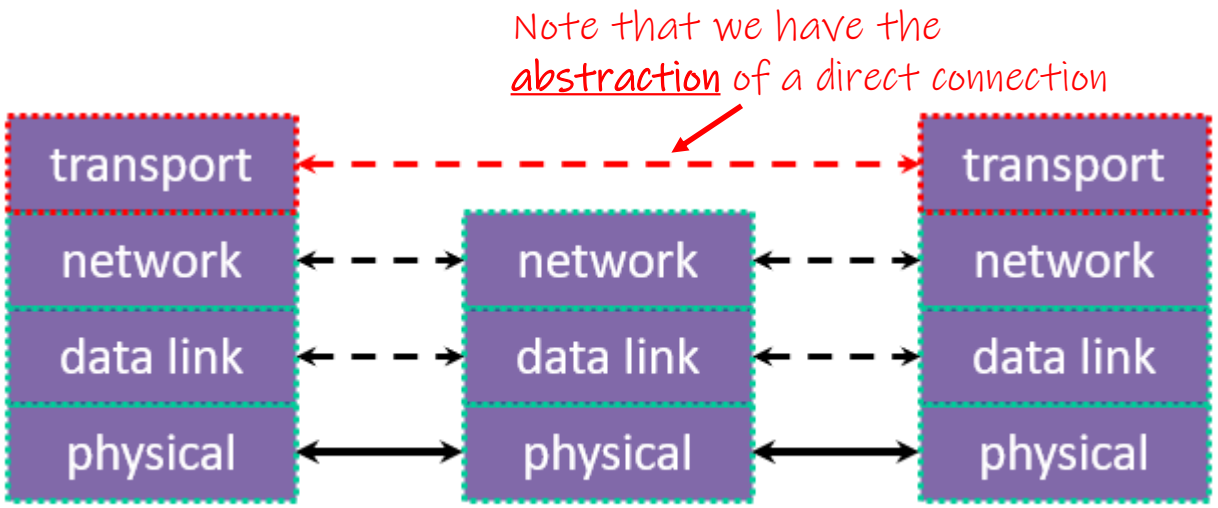
- Some places are surprisingly well- or poorly-connected to "backbone" infrastructure like fiber optic cables
- Unintuitive topology can create interesting failures
  - *e.g.*, 2006 7.0-magnitude Hengchun Earthquake disrupted communications to Singapore, Philippines, Thailand, China, etc. for a month





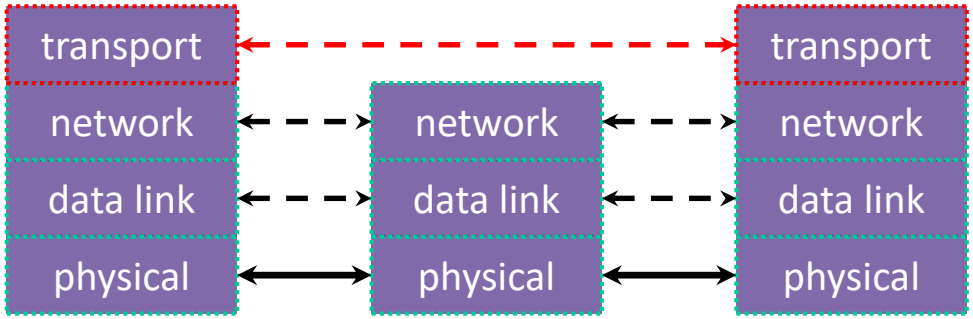
The Transport Layer

- 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…



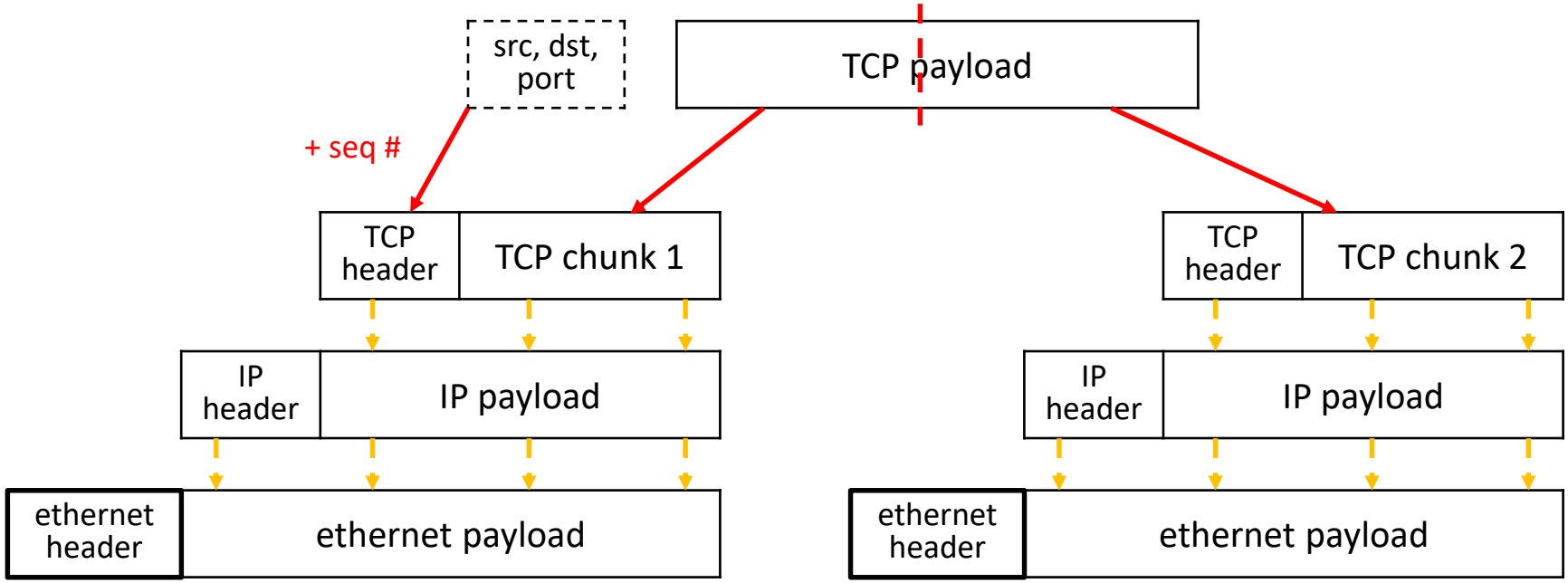
The Transport Layer (TCP)

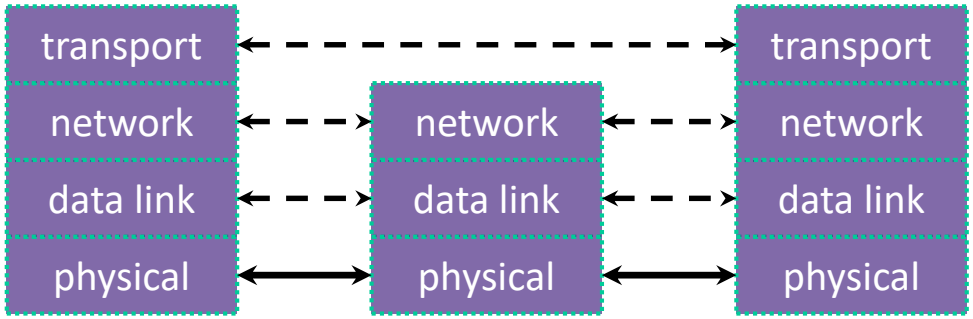
- Transmission Control Protocol (TCP):
  - Provides applications with reliable, ordered, congestion-controlled byte streams
    - Sends stream data as multiple IP packets (differentiated by sequence numbers) and retransmits them as necessary
    - When receiving, puts packets back in order and detects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

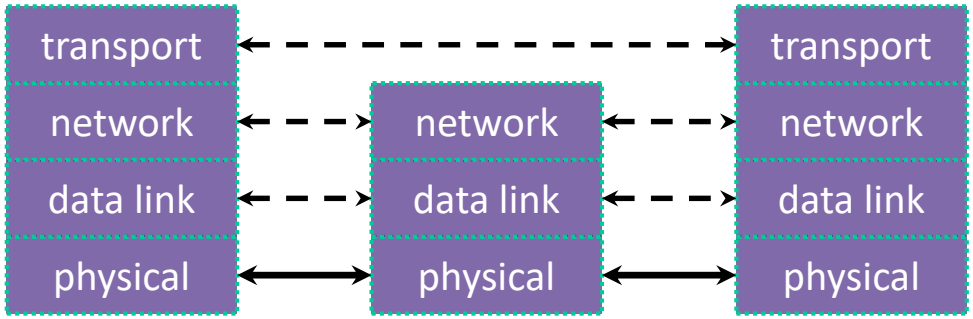
- Packet encapsulation – one more nested layer!





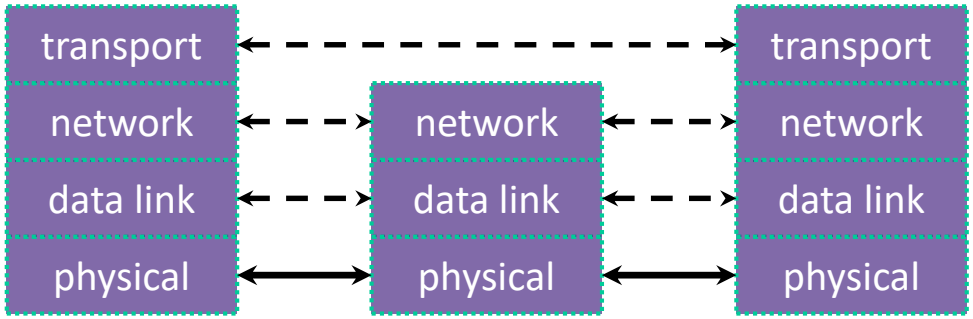
The Transport Layer (TCP)

- 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)

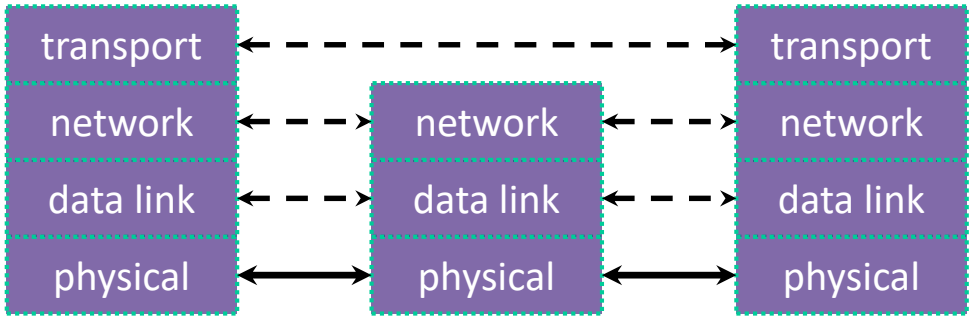
- User Datagram Protocol (UDP):
  - Provides applications with *unreliable* packet delivery
  - UDP is a really thin, simple layer on top of IP
    - Datagrams still are fragmented into multiple IP packets



The Transport Layer

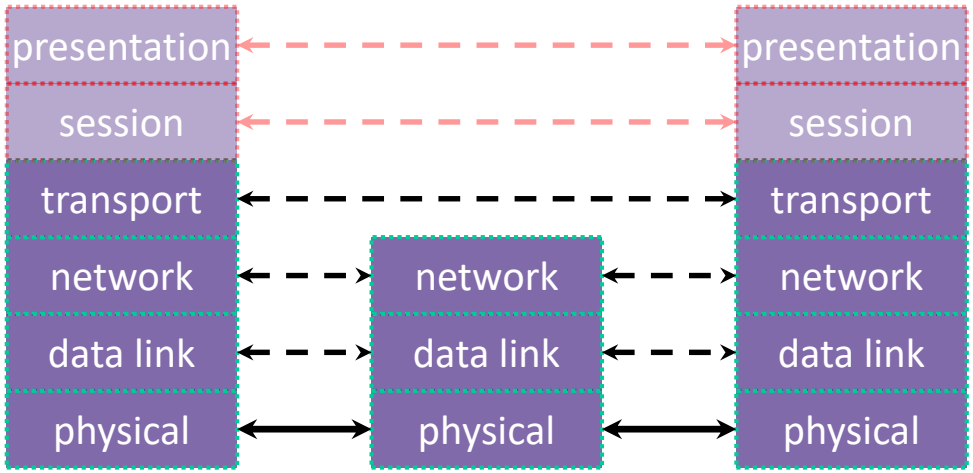
TCP:

UDP:



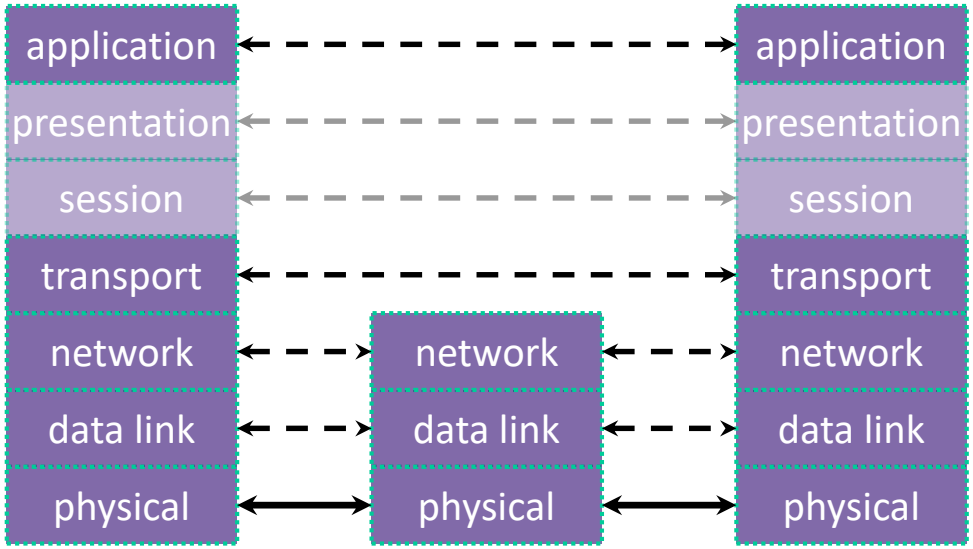
The (Mostly Missing) Layers 5 & 6

- 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



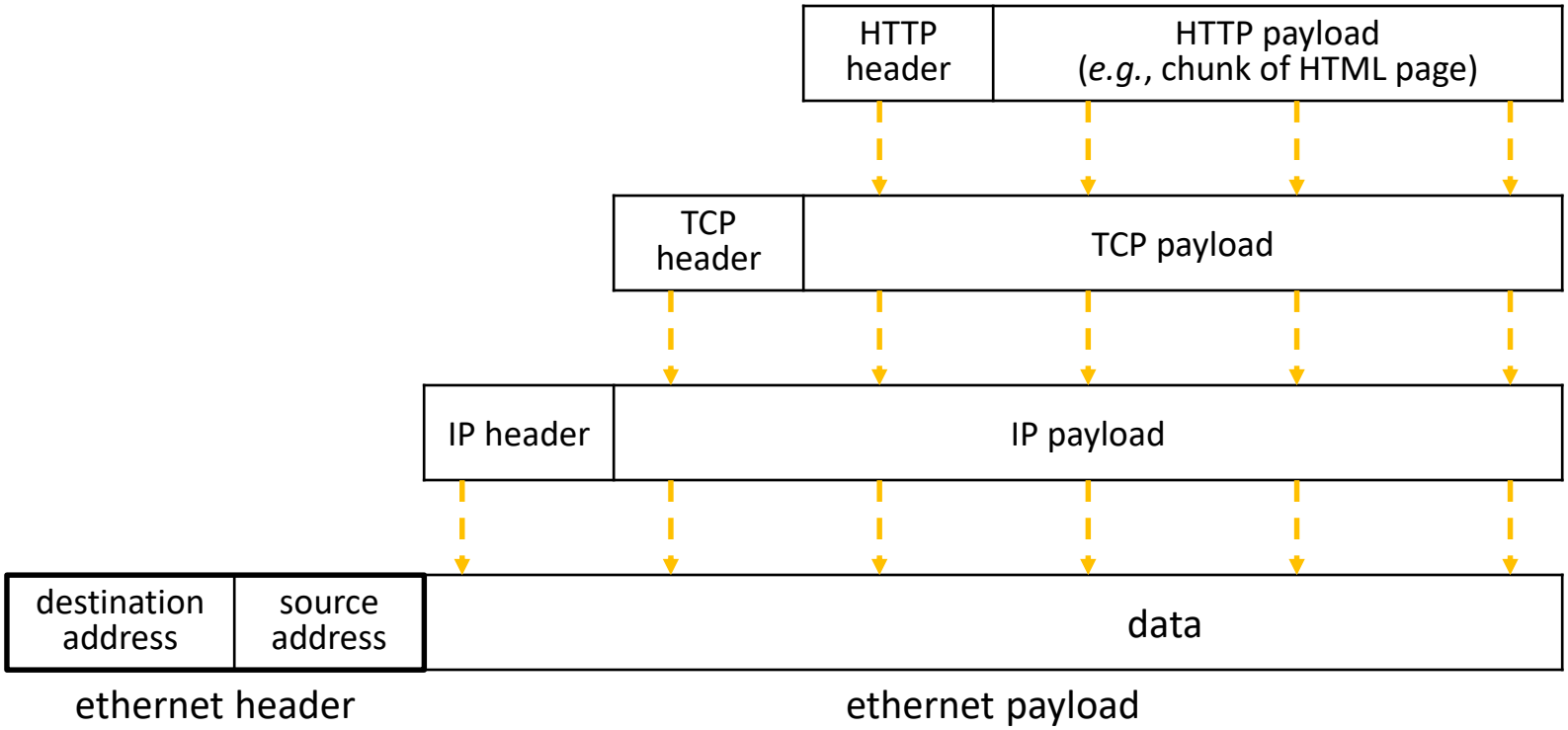
The Application Layer

- 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



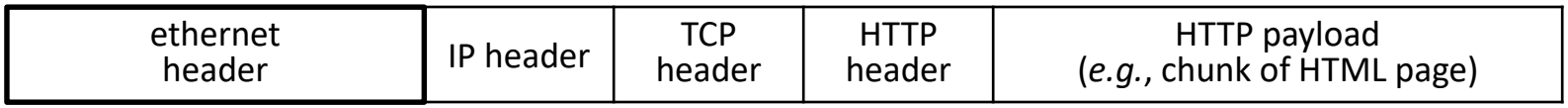
The Application Layer

- Packet encapsulation:



The Application Layer

- Packet encapsulation:



The Application Layer

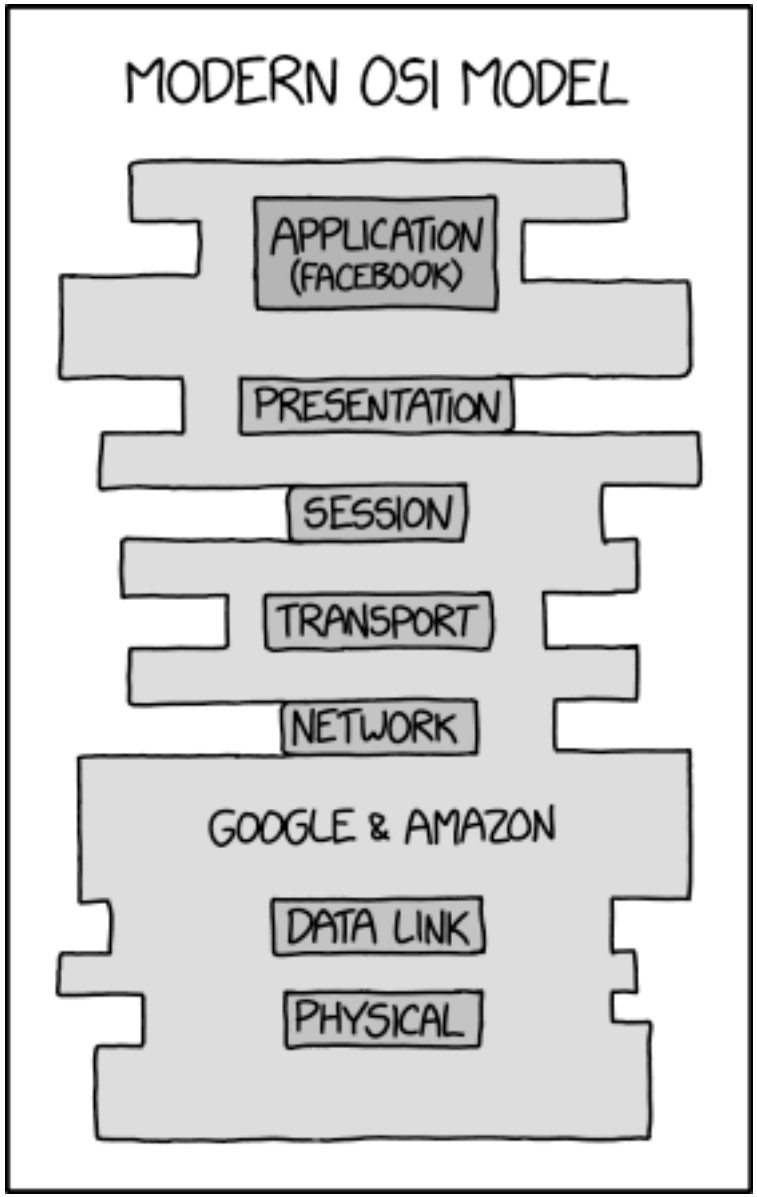
- Popular application-level protocols:
  - **DNS:** translates a domain name (*e.g.*, www.google.com) into one or more IP addresses (*e.g.*, 74.125.197.106)
    - Domain Name System
    - An hierarchy of DNS servers cooperate to do this
  - **HTTP:** web protocols
    - Hypertext Transfer Protocol
  - **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`

In Other Words…



https://xkcd.com/2105/