Networking Introduction

CSE 333

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Teaching Assistants:

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Administrivia

- Exercise 13 was due this morning
- Exercise 14 is due **Wednesday (August 6th)**

- HW3 due this **Thursday (August 7th), 11 pm**
  - Usual reminders: don't forget to tag, then be sure to clone elsewhere and recompile / retest
  - Usual late days apply (*if* you have any left – don't run over)

- Midterm grades are released
  - Median: 83%
  - There will still be some curve up in overall grades at the end

Administrivia

- We're done with core C++!

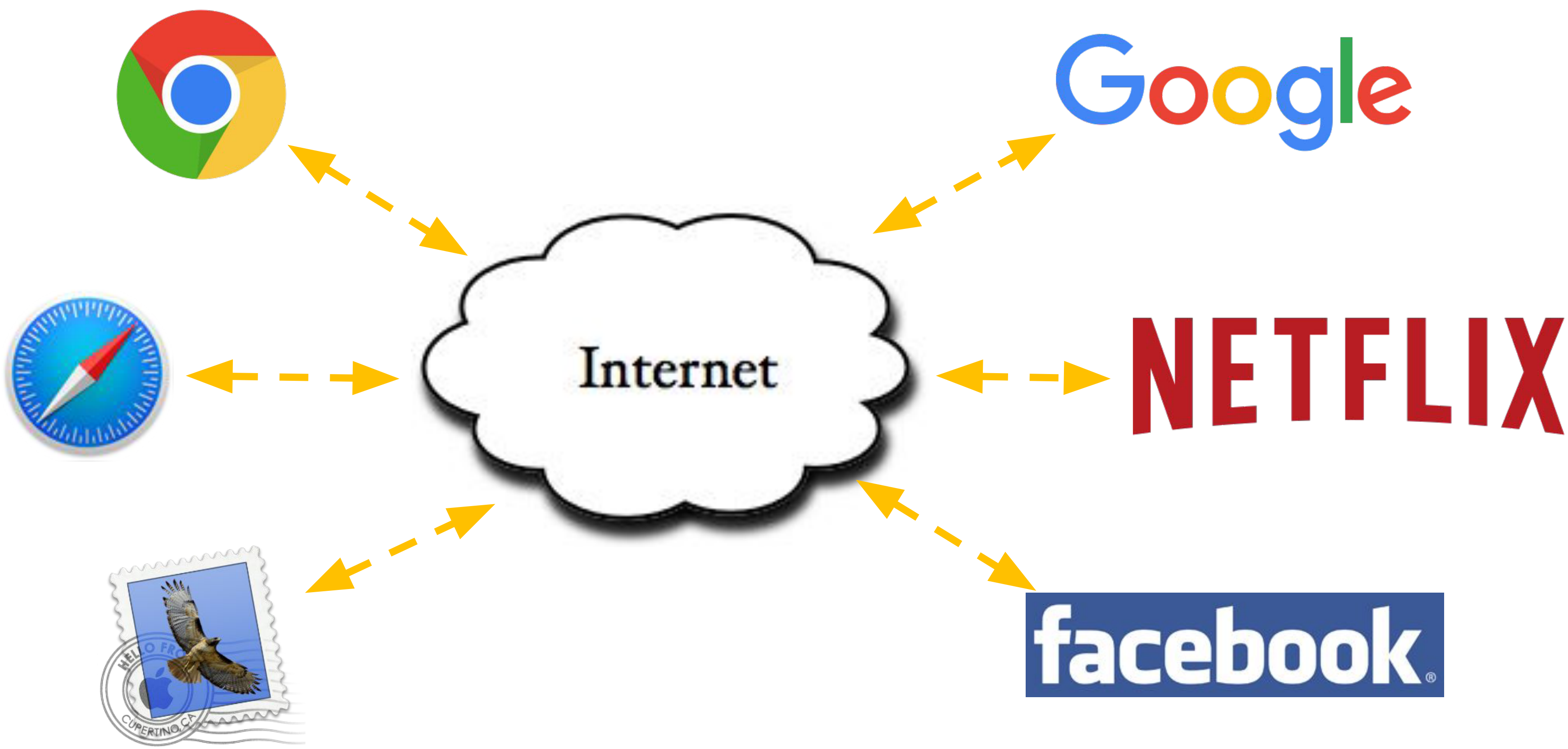
- Rest of the quarter:
  - Topics: Networking and Concurrency
  - Lectures will be shorter
  - A few (4) more exercises
    - Networking client side, server side, concurrency
  - hw4: file-search web server
    - Out Friday; due Wednesday, August 20th (last week of classes)
    - Demo in class Friday or Monday
  - final exam…

Lecture Outline

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

more awesome pictures at THEMETAPICTURE.COM

Networks From 10,000 ft

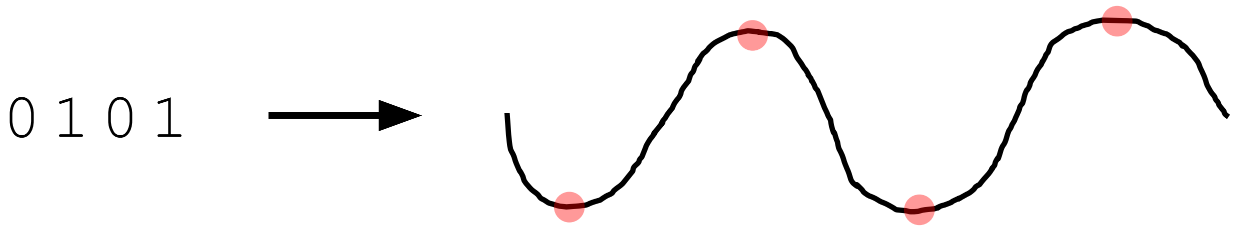


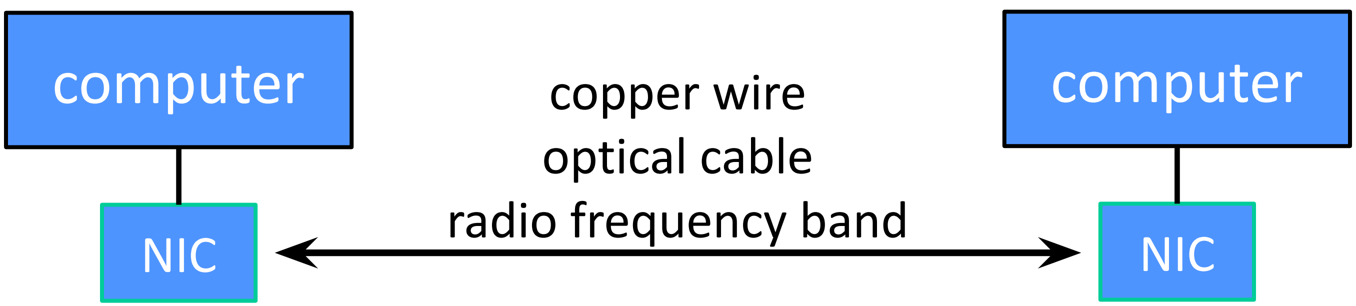
clients

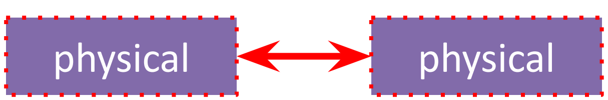
servers

The Physical Layer

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

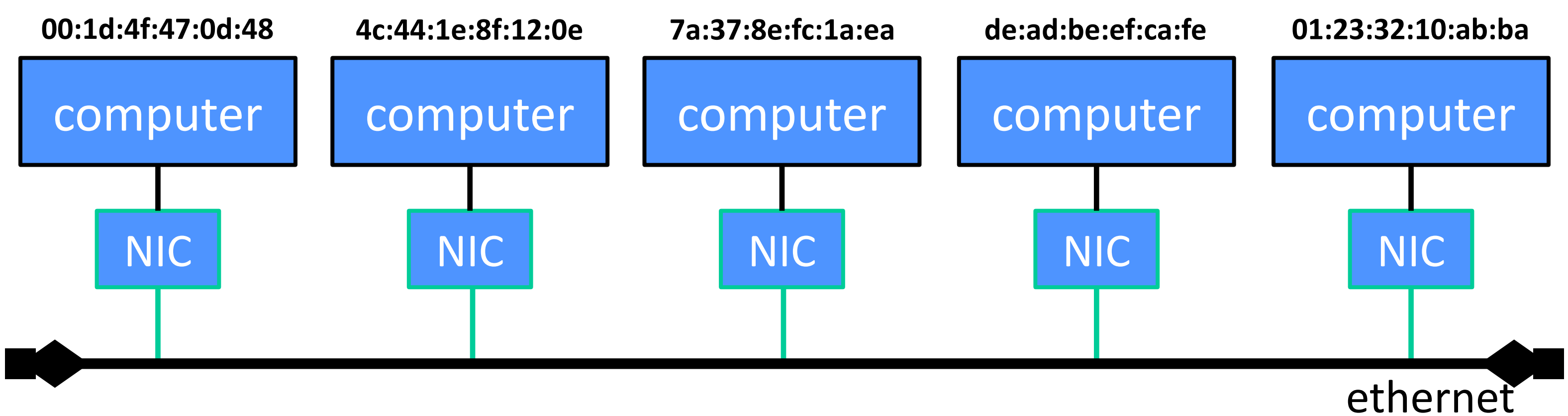


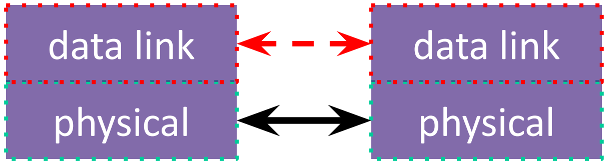


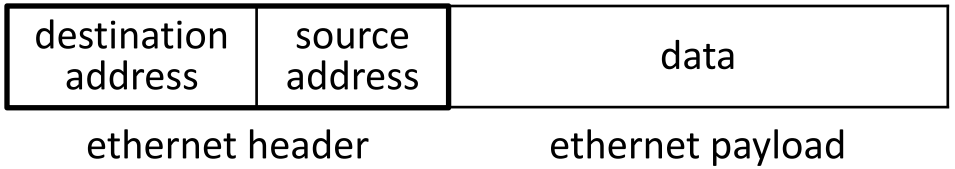


The Data Link Layer

- Multiple computers on a LAN contend for the network medium
  - Media access control (MAC) specifies how computers cooperate and network interface controllers (NICs) are addressed.
  - Data link layer also specifies how bits are "packetized" into **frames**

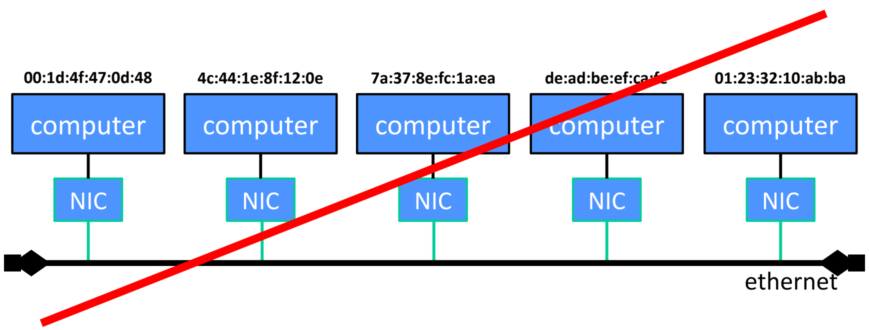


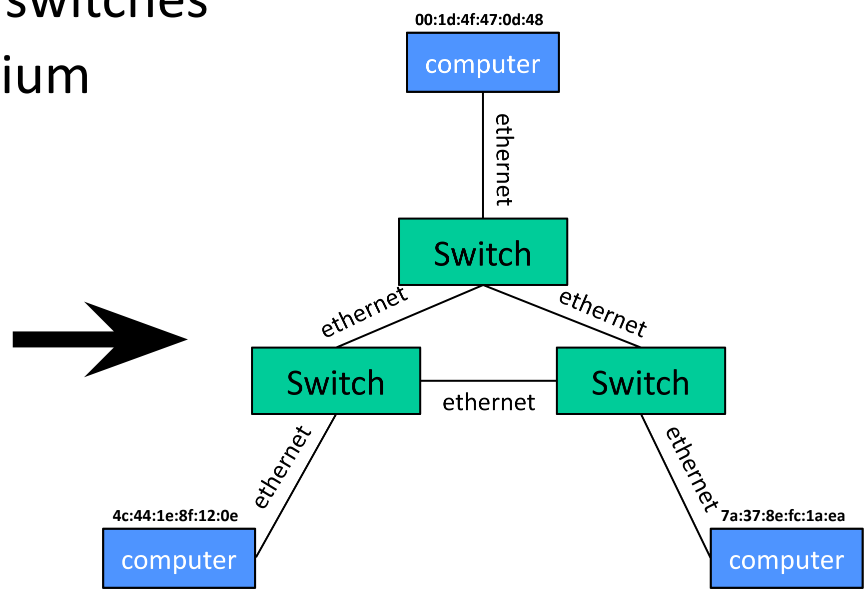


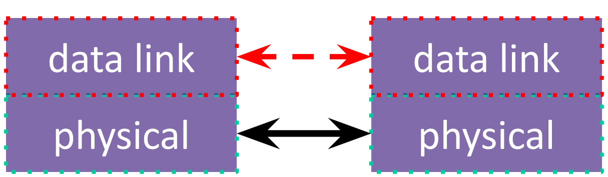


What’s Wrong With This Picture?

- In modern ethernet, you don’t connect multiple devices to the same ethernet cable
- Instead, switches are used so that each cable only has two devices connected (one on each end)
- MAC is still used for routing across switches
- Wi-Fi still uses a single shared medium

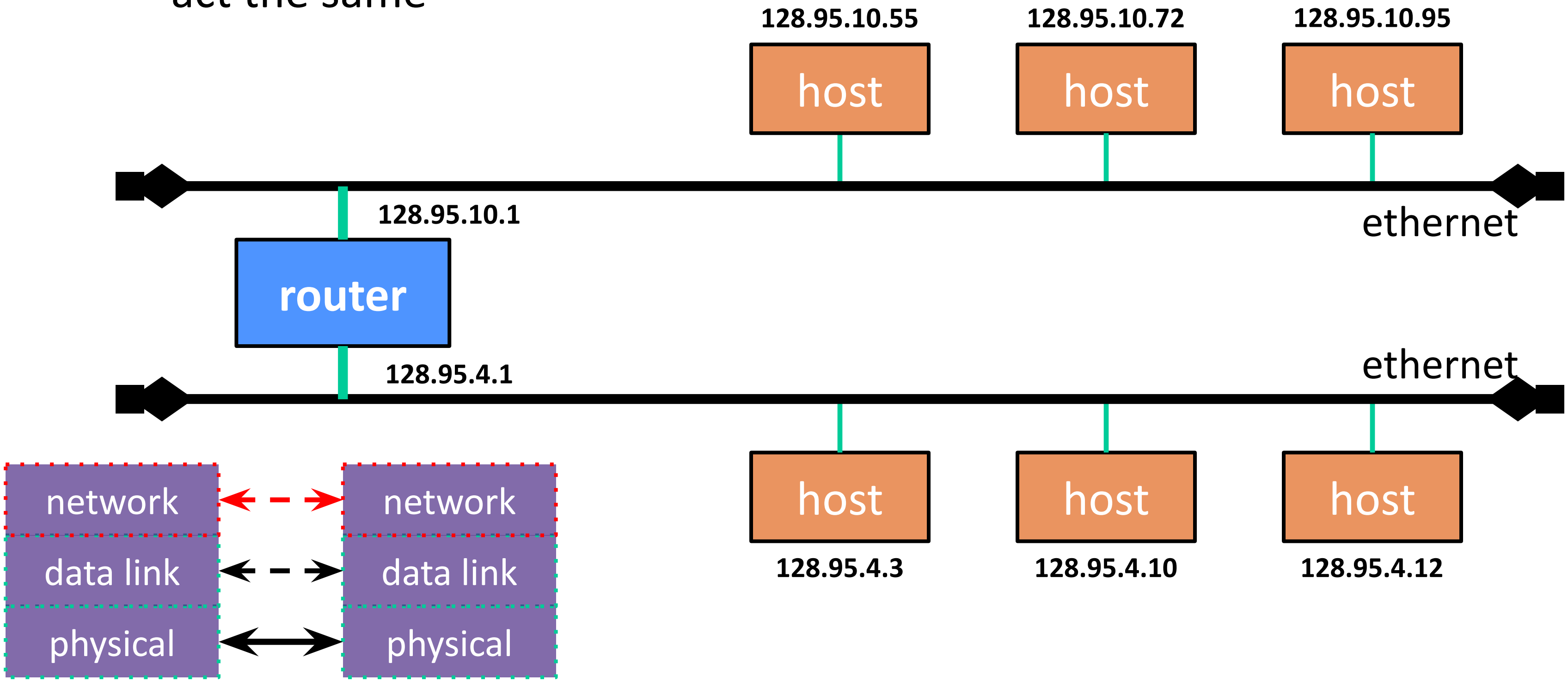






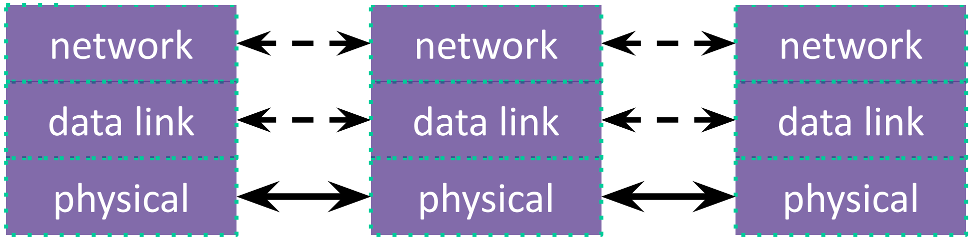
The Network Layer (IP)

- Internet Protocol (IP) routes packets across multiple networks
  - Every computer has a unique IP address (sort of)
  - Individual networks are connected by routers that span networks
  - The first layer where different mediums (e.g. wifi vs ethernet) act the same



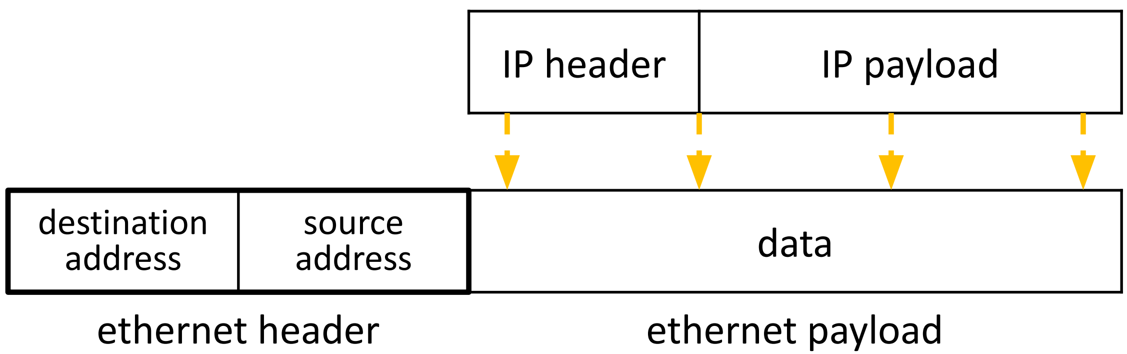
The Network Layer (IP)

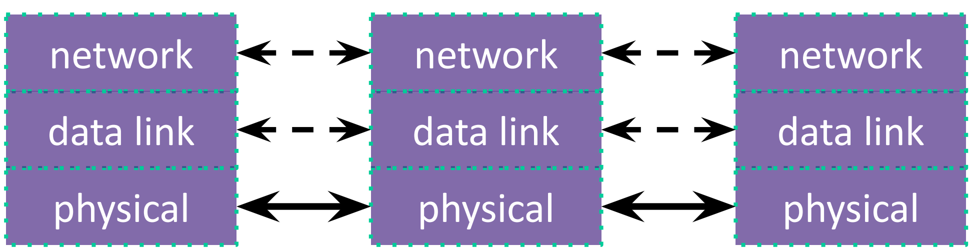
- There are protocols to:
  - Let a host map an IP to MAC address on the same network
  - Let a router learn about other routers to get IP packets one step closer to their destination



The Network Layer (IP)

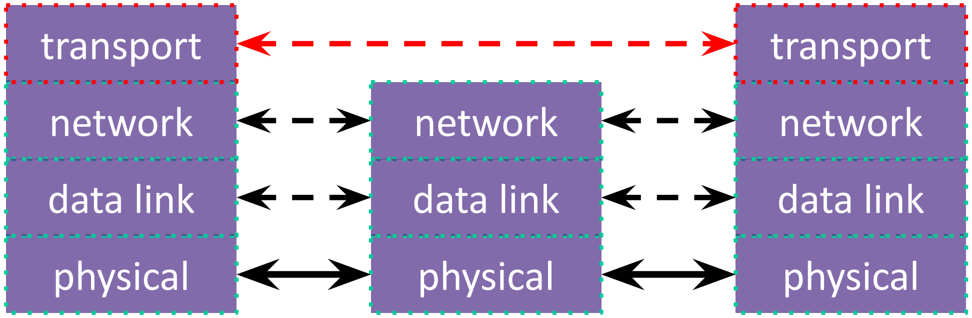
- Packet encapsulation:
  - An IP packet is encapsulated as the payload of an Ethernet frame
  - As IP packets traverse networks, routers pull out the IP packet from an Ethernet frame and plunk it into a new one on the next network





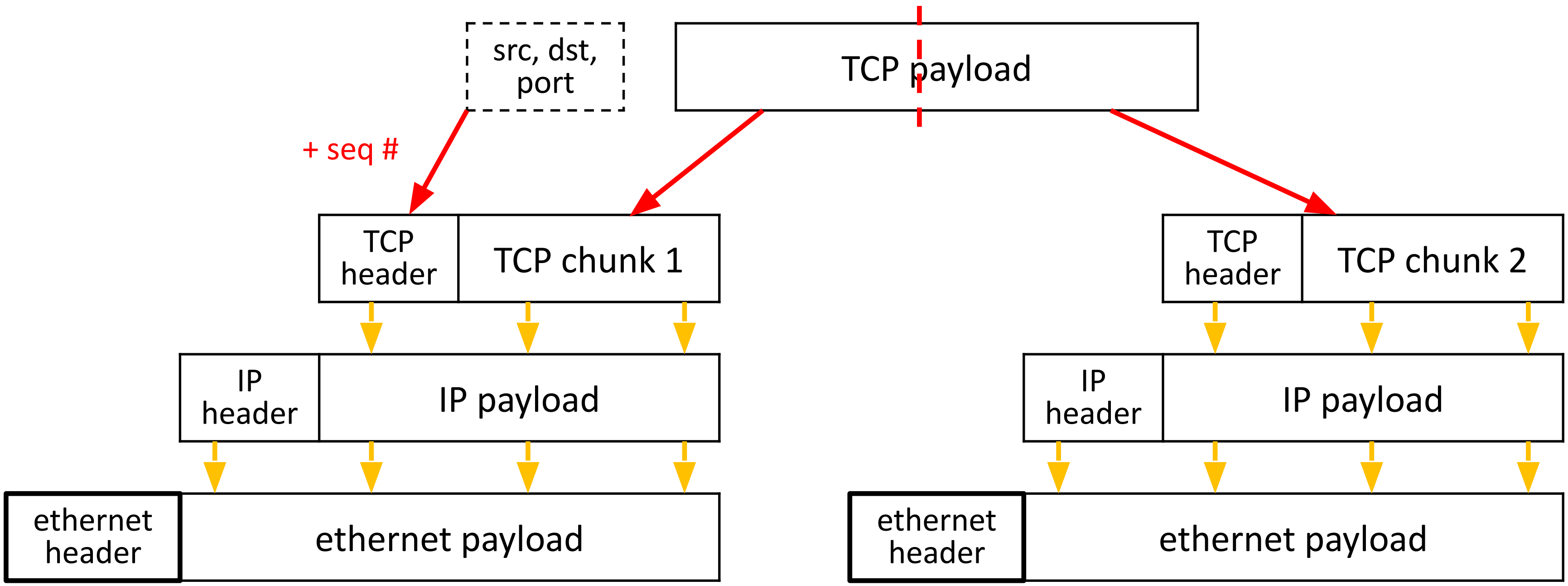
The Transport Layer (TCP)

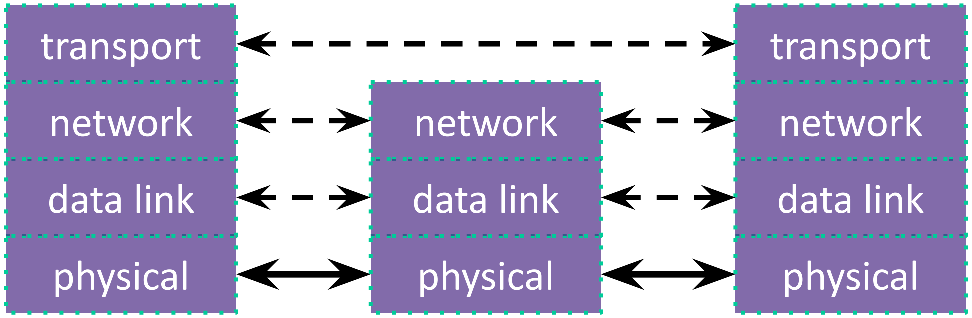
- Transmission Control Protocol (TCP):
  - Provides applications with reliable, ordered, congestion-controlled byte streams
    - Sends stream data as multiple IP packets (differentiated by sequence numbers) and retransmits them as necessary
    - When receiving, puts packets back in order and detects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

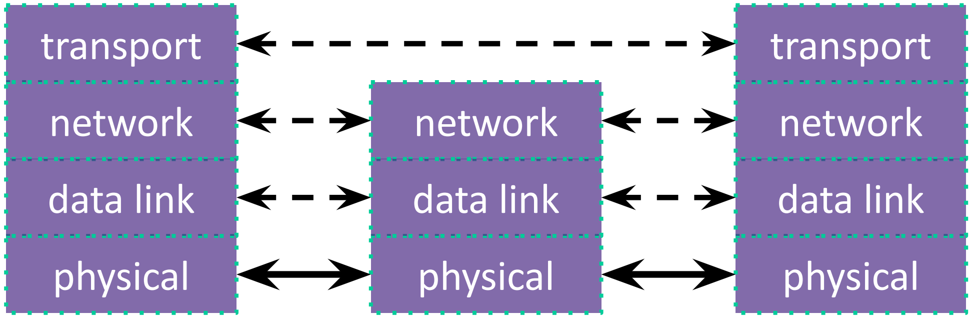
- Packet encapsulation – one more nested layer!





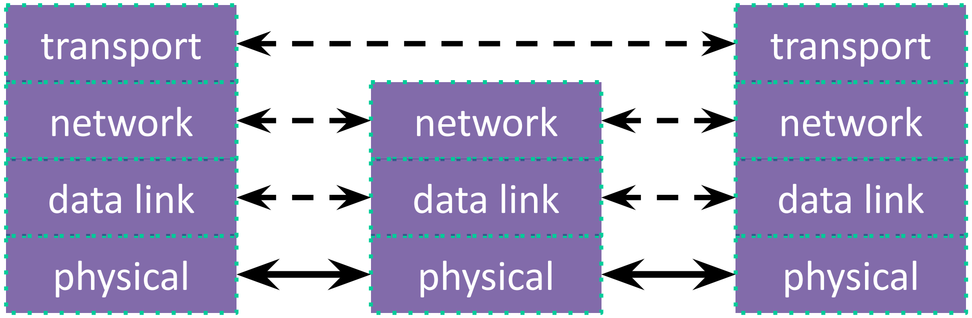
The Transport Layer (TCP)

- 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):
  - An alternative to TCP
  - 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



Aside: IP Exhaustion

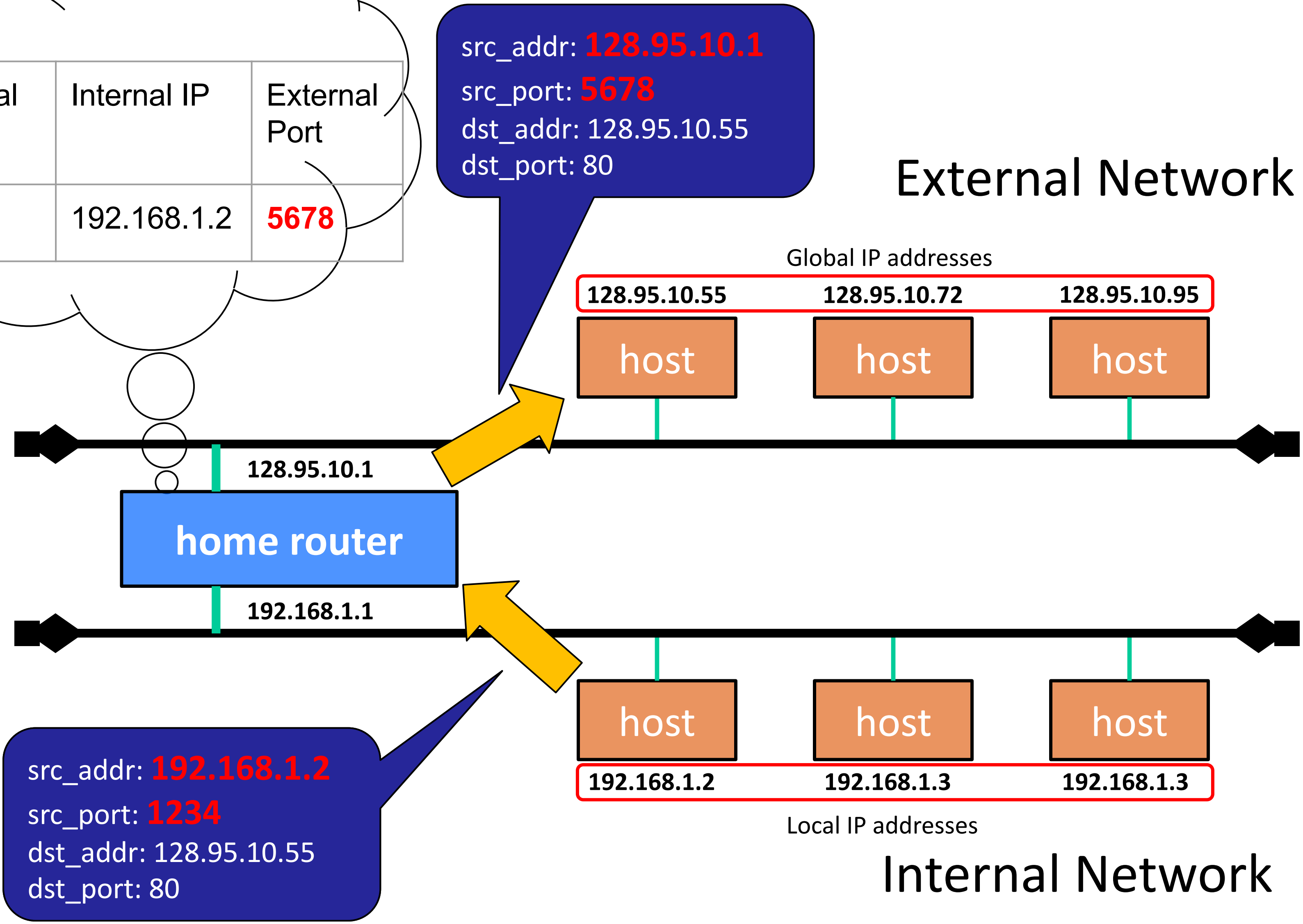
- IPv4 addresses are four bytes (32-bits), giving ~4 billion unique addresses
- Large blocks are reserved for special purposes
  - All addresses that start with 127 are “loopback” addresses
  - 192.0.0.<x> is for local network addresses
- Other large blocks allocated to early user organizations
  - MIT has 16 million IP addresses
- There are an estimated ~33 billion internet connected devices; many more than the number of IPv4 addresses!

Aside: IP Exhaustion

- IPv6 solves this problem (2 x 10^{19} possible addresses) but requires changing lots of infrastructure
- Backwards compatible solution: Network Address Translation (or “NAT”)

Aside: Network Address Translation

Internal Port	Internal IP	External Port
1234	192.168.1.2	5678



Aside: Network Address Translation

Internal Port	Internal IP	External Port
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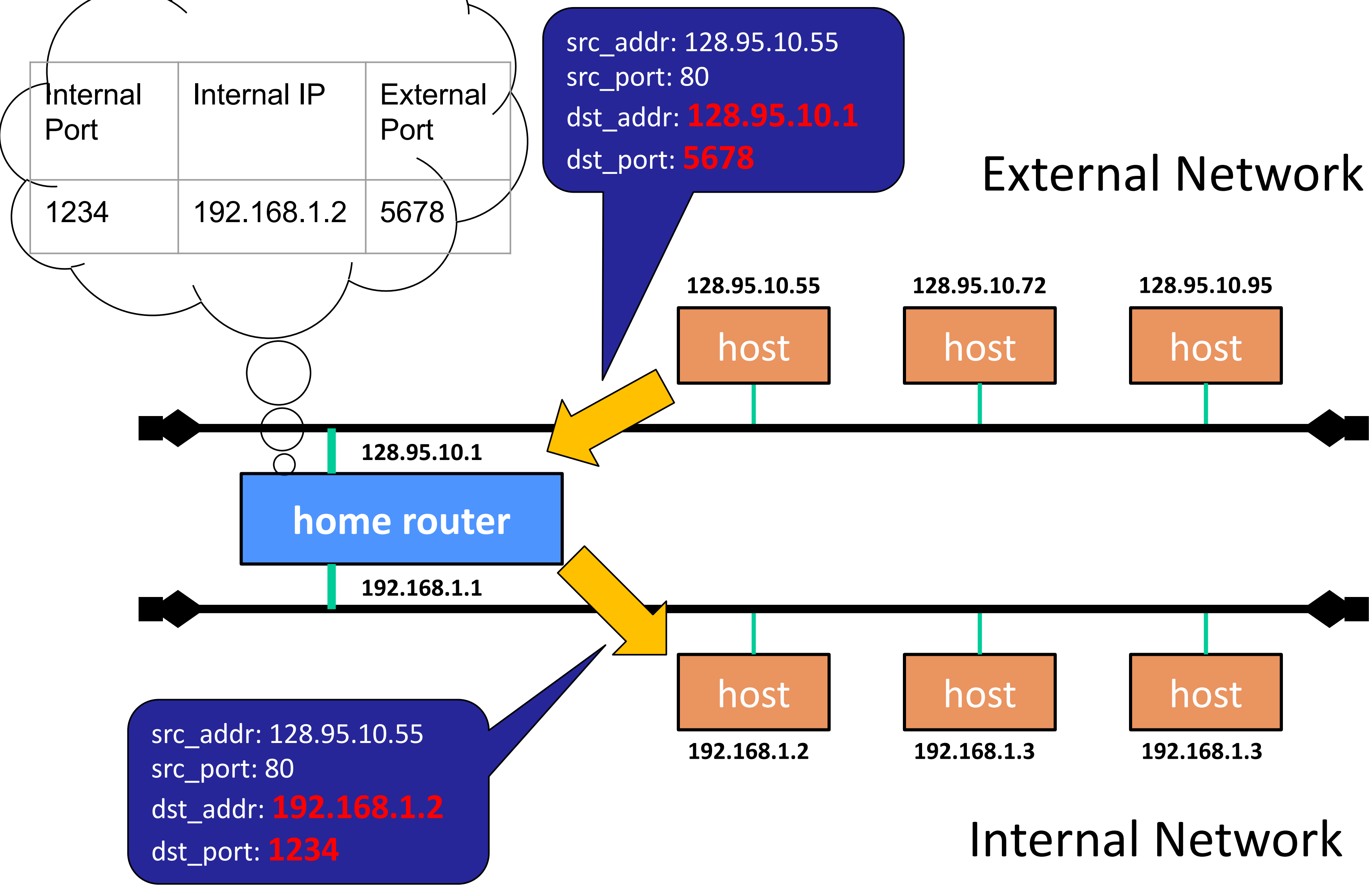
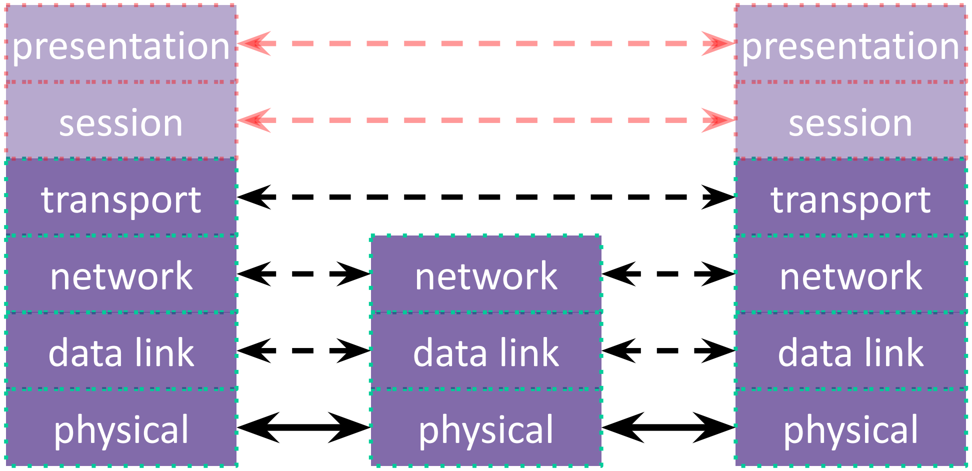


Aside: Network Address Translation

- With NAT, neither clients nor servers need to know anything beyond IPv4
  - Only routers need special logic
- But, NAT is one-sided
  - Local network clients can connect to global network servers, but not the other way around
  - Makes it hard to host your own website or game server
- Managed by manual port forwarding
  - Explicitly adding a permanent entry to the translation table

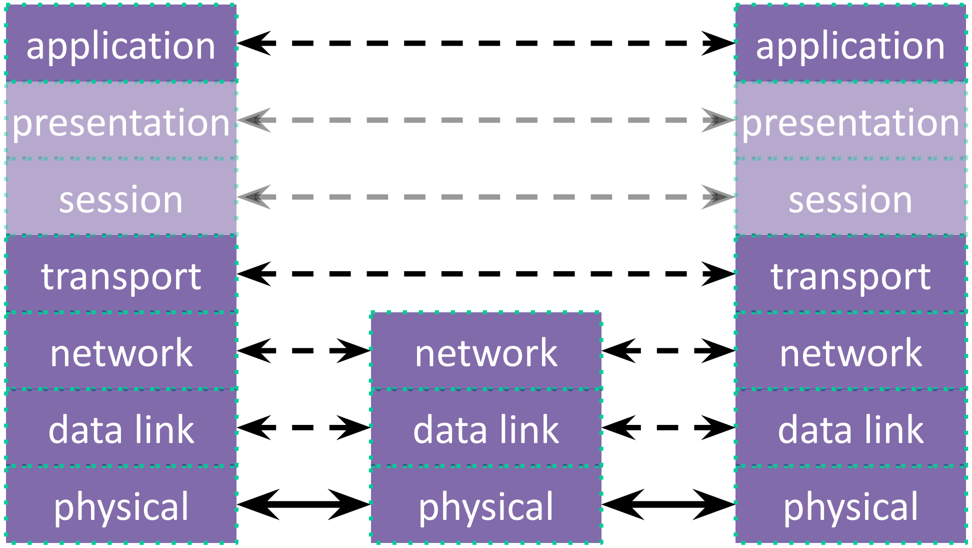
The (Mostly Missing) Layers 5 & 6

- 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
  - SSL (encryption) kind of fits in here



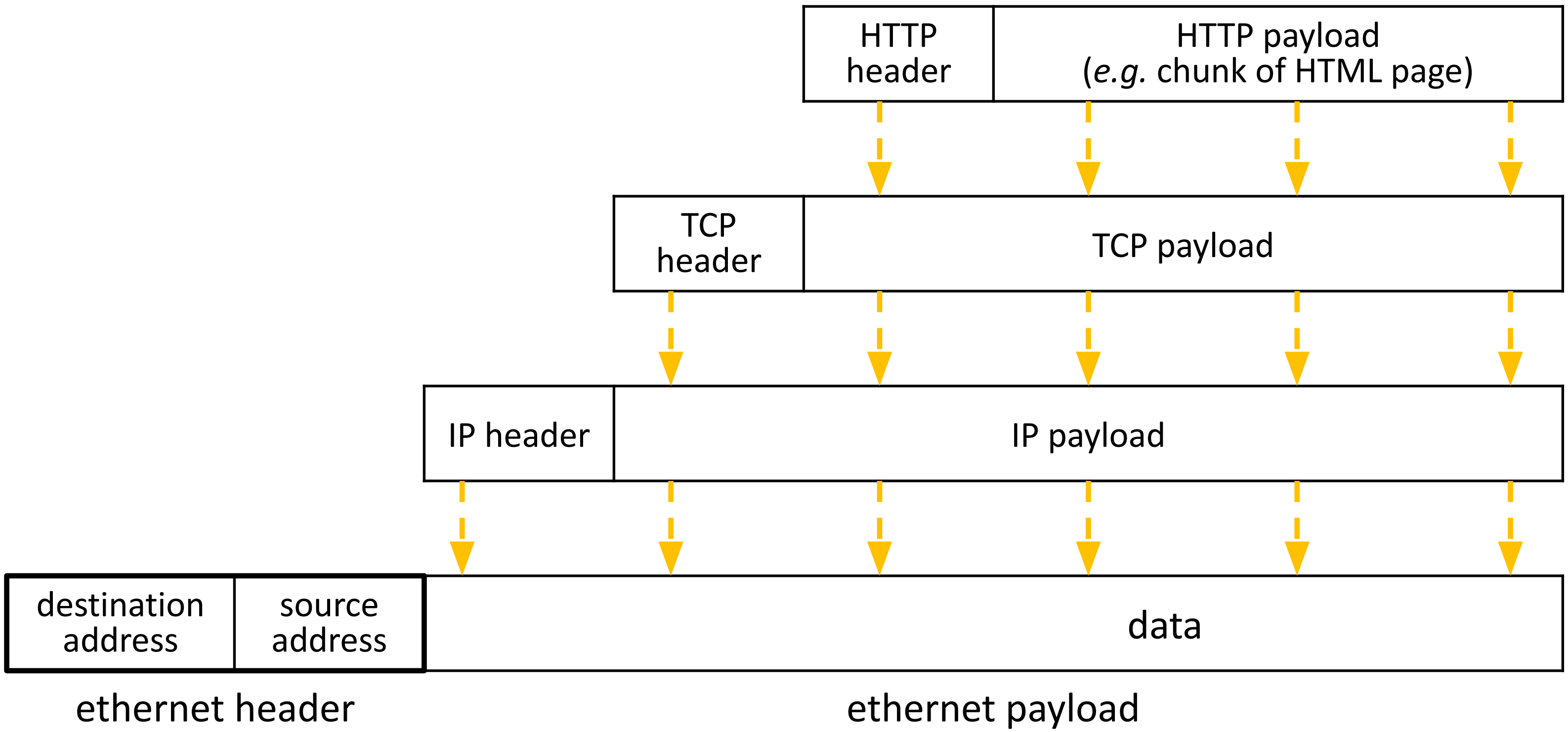
The Application Layer

- Application protocols
  - The format and meaning of messages between application entities
  - Example: HTTP is an application-level protocol that dictates how web browsers and web servers communicate
    - HTTP < 3.0 is implemented *on top of* TCP streams (transport layer)
    - But HTTPS is implemented on top of SSL (presentation layer)



The Application Layer

- Packet encapsulation:



The Application Layer

- Packet encapsulation:

ethernet header	IP header	TCP header	HTTP header	HTTP payload (*e.g.* chunk of HTML page)

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
  - https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers

IP over Avian Carriers

20 languages

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From Wikipedia, the free encyclopedia

In computer networking, **IP over Avian Carriers** (**IPoAC**) is a joke proposal to carry Internet Protocol (IP) traffic by birds such as homing pigeons. IP over Avian Carriers was initially described in RFC 1149 issued by the Internet Engineering Task Force, written by David Waitzman, and released on April 1, 1990. It is one of several April Fools' Day Request for Comments.

Under RFC 1149, a homing pigeon can carry Internet Protocol traffic.

Waitzman described an improvement of his protocol in RFC 2549, *IP over Avian Carriers with Quality of Service* (1 April 1999). Later, in RFC 6214—released on 1 April 2011, and 13 years after the introduction of IPv6—Brian Carpenter and Robert Hinden published *Adaptation of RFC 1149 for IPv6*.[1]

IPoAC has been successfully implemented, but for only nine packets of data, with a packet loss ratio of 55% (due to operator error),[2] and a response time ranging from 3,000 seconds (50 min) to over 6,000 seconds (100 min). Thus, this technology suffers from high latency.[3]

Real-life implementation

https://en.wikipedia.org/wiki/IP_over_Avian_Carriers

netcat

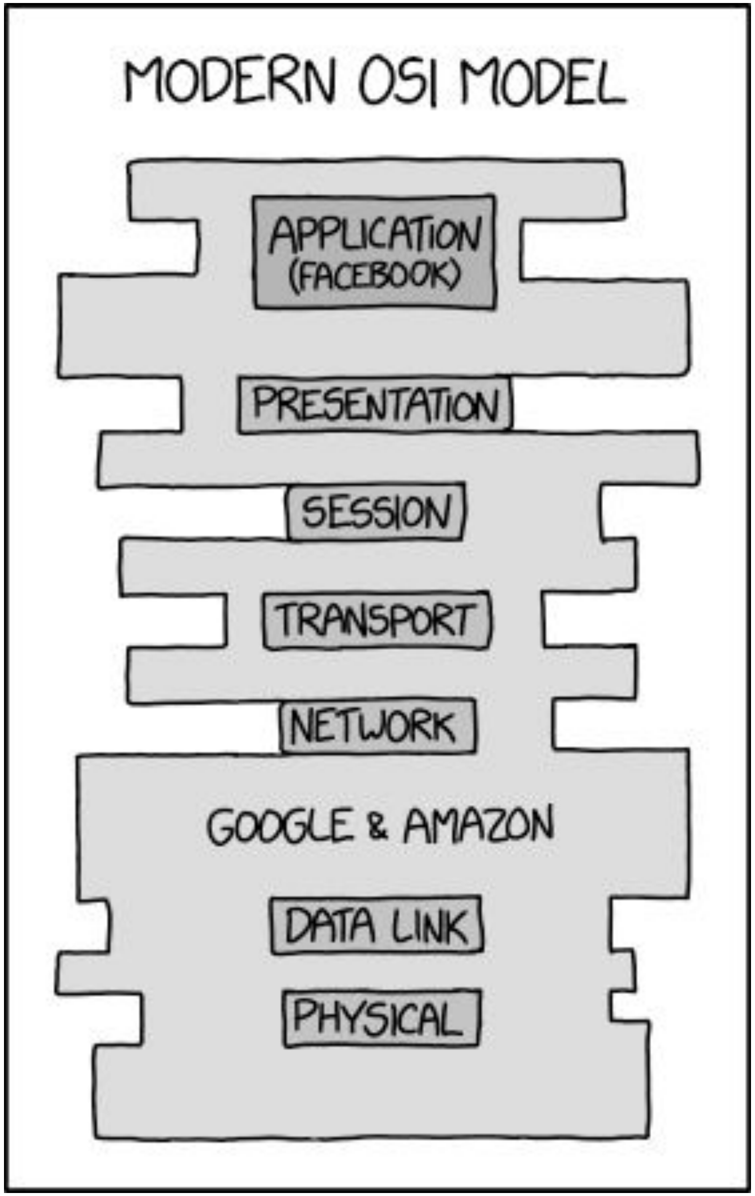
- netcat (nc) is "a computer networking utility for reading from and writing to network connections using TCP or UDP"
  - Listen on port: nc -l <port>
  - Connect: nc <IPaddr> <port>
    - Local host: 127.0.0.1

Spacing isn't accurate, it's for illustrative purposes

```
> nc -l 1234

Hello world
Back at you!

^C
>
```

```
> echo "Hello world" | nc 127.0.0.1 1234


Back at you!

>
```

The Future of Networking?



“Network” Latency is Highly Variable

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

Numbers Everyone Should Know

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

Google

Latency: Distance Matters

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

123Net Data Center, Wikimedia

Latency: Materials Matter

- 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?

Latency: Topology Matters

- Some places are surprisingly well- or poorly-connected to "backbone" infrastructure like fiber optic cables

- Unintuitive topology creates interesting failures
  - Eg, 2006 Hengchun Earthquake disrupted communications to Singapore, Phillipines, Thailand, China, etc for a month

Don't Forget!

- Exercise 14 is due **Wednesday (August 6th)**

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