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 (July 31st)**

- HW3 due **Thursday (August 1st), 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)

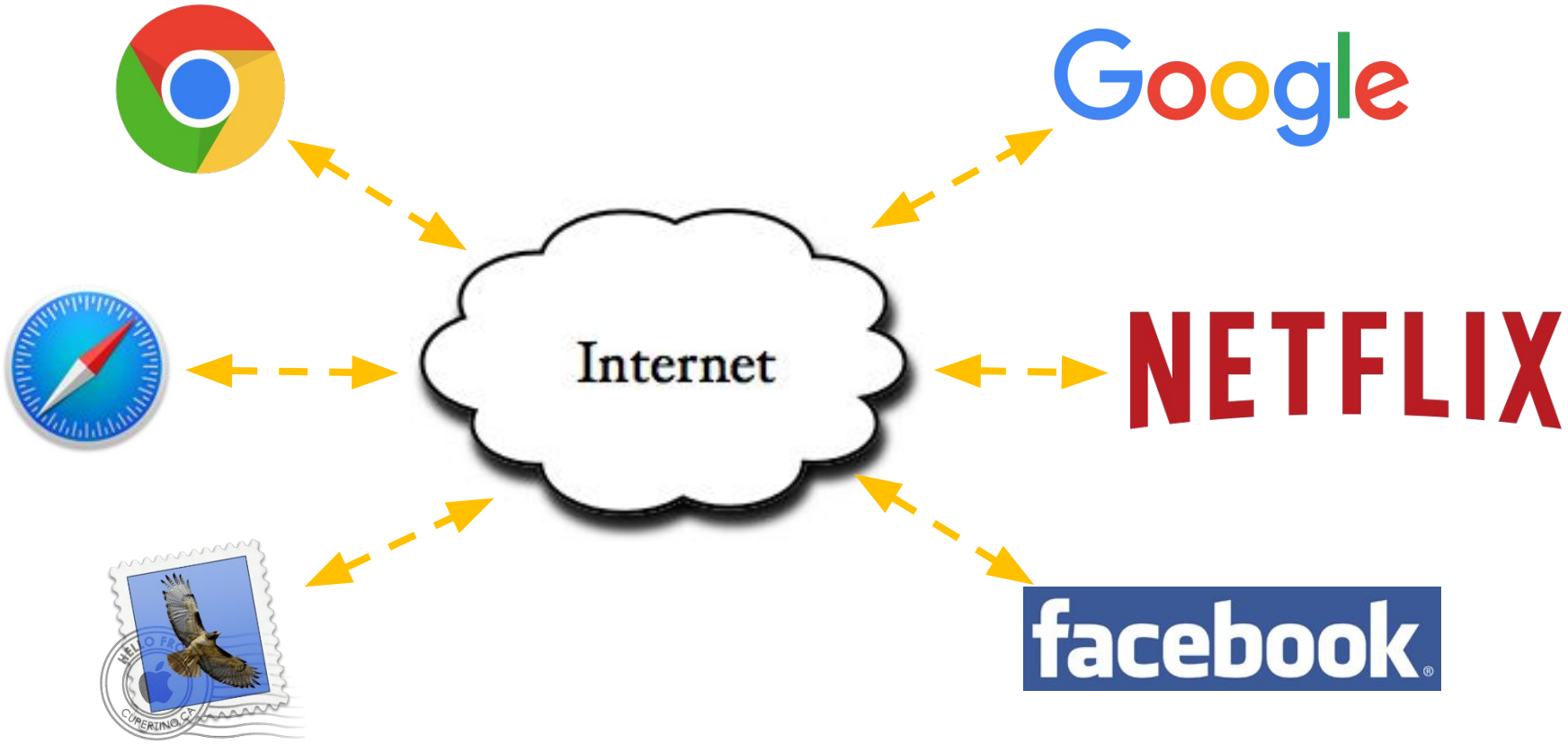
Administrivia

- Rest of the quarter:
  - Topics: Networking; Concurrency, Processes, and Threads
  - A few more exercises
    - Networking client side, server side, concurrency
  - hw4: file-search web server
    - Out Friday; due Wednesday, July 14th (last week of classes)
    - Demo in class Friday or Monday
  - final exam…

Lecture Outline

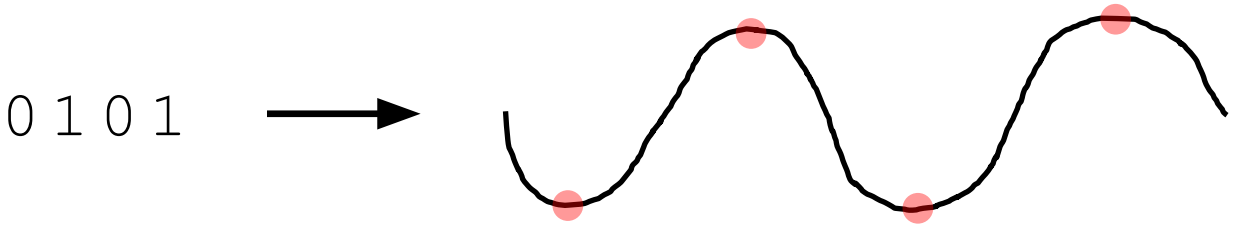
- **Introduction to Networks**
  - **Layers upon layers upon layers…**

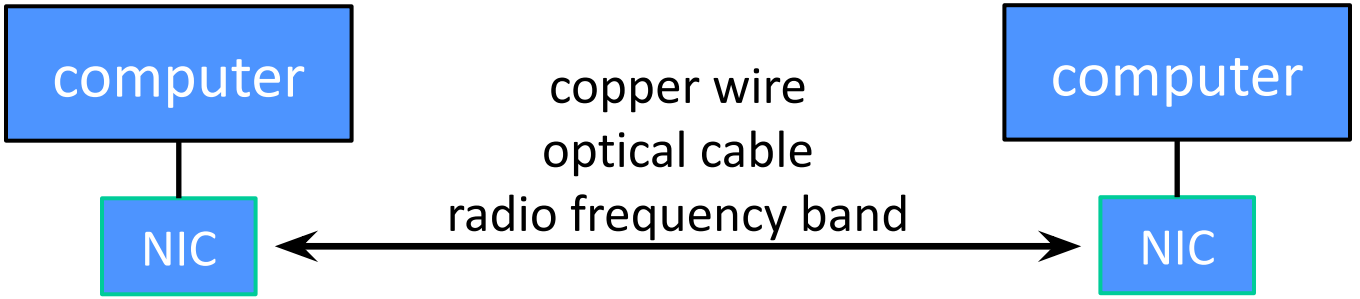
Networks From 10,000 ft

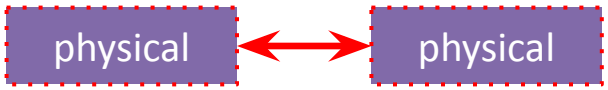


The Physical Layer

- 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, …

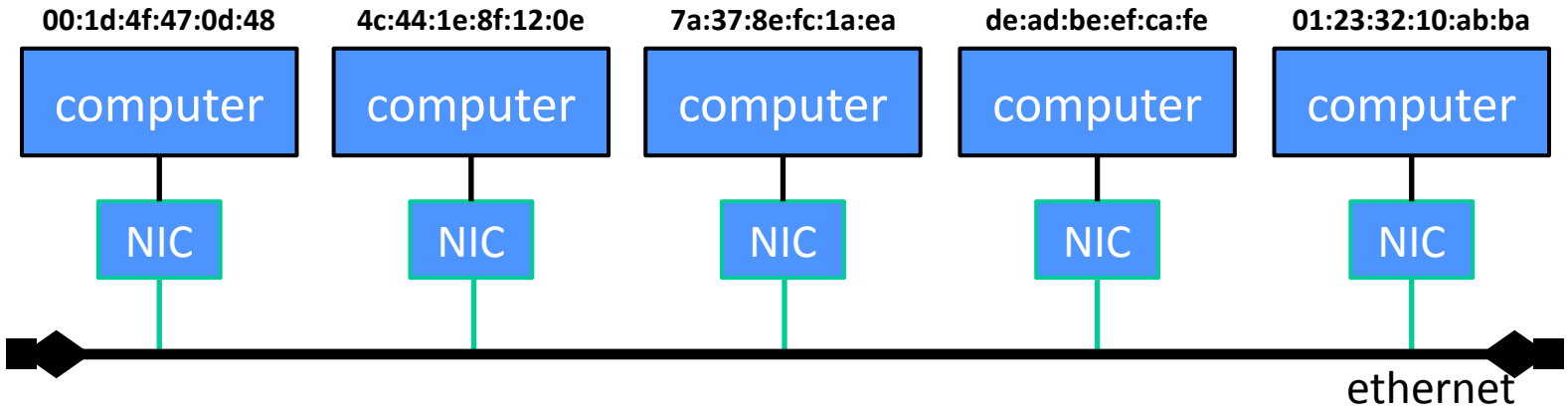


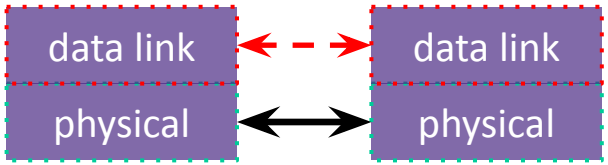


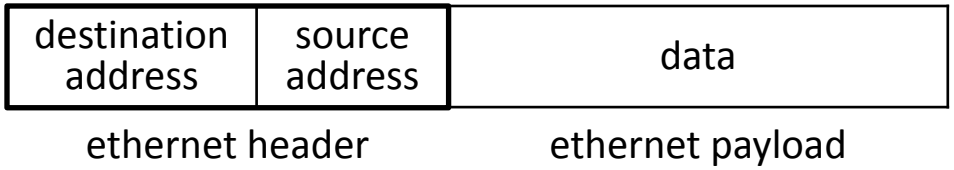


The Data Link Layer

- 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.
  - Link layer also specifies how bits are "packetized"

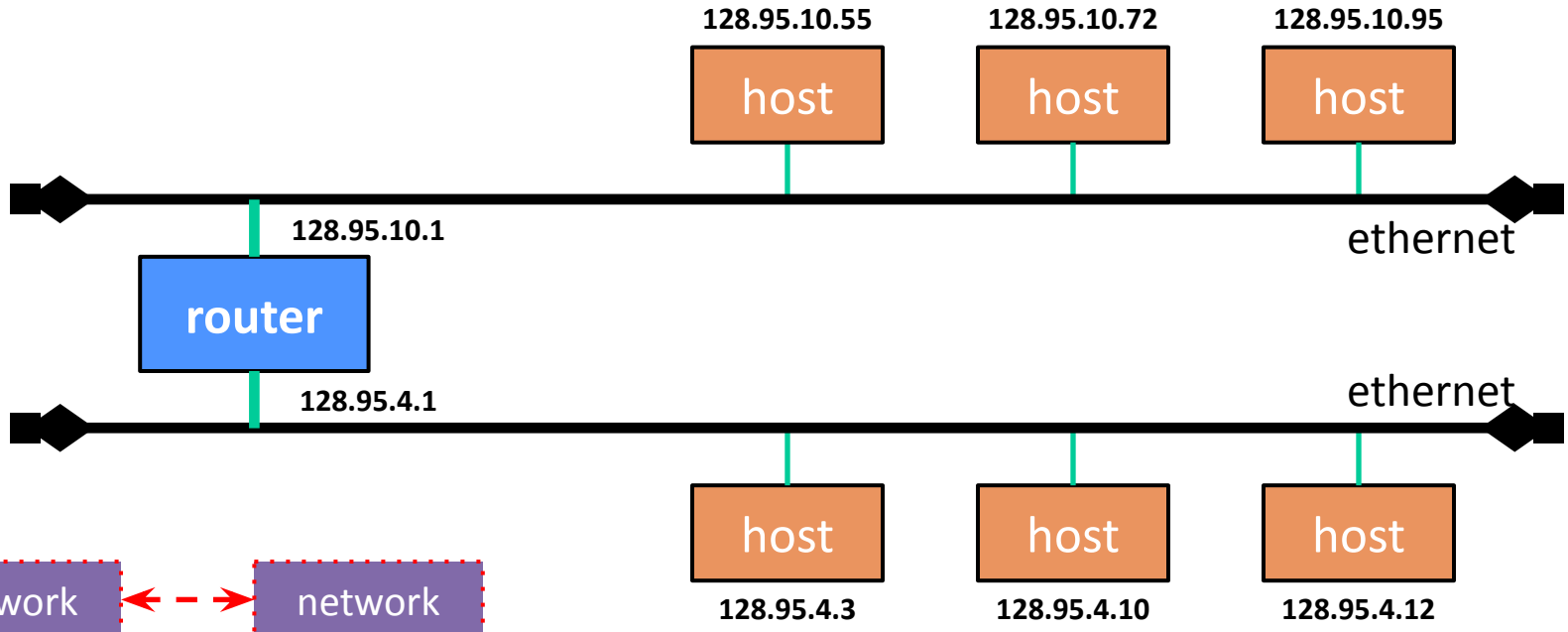


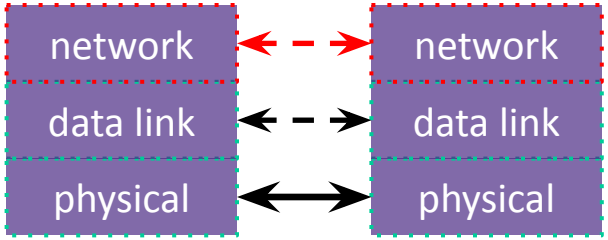




The Network Layer (IP)

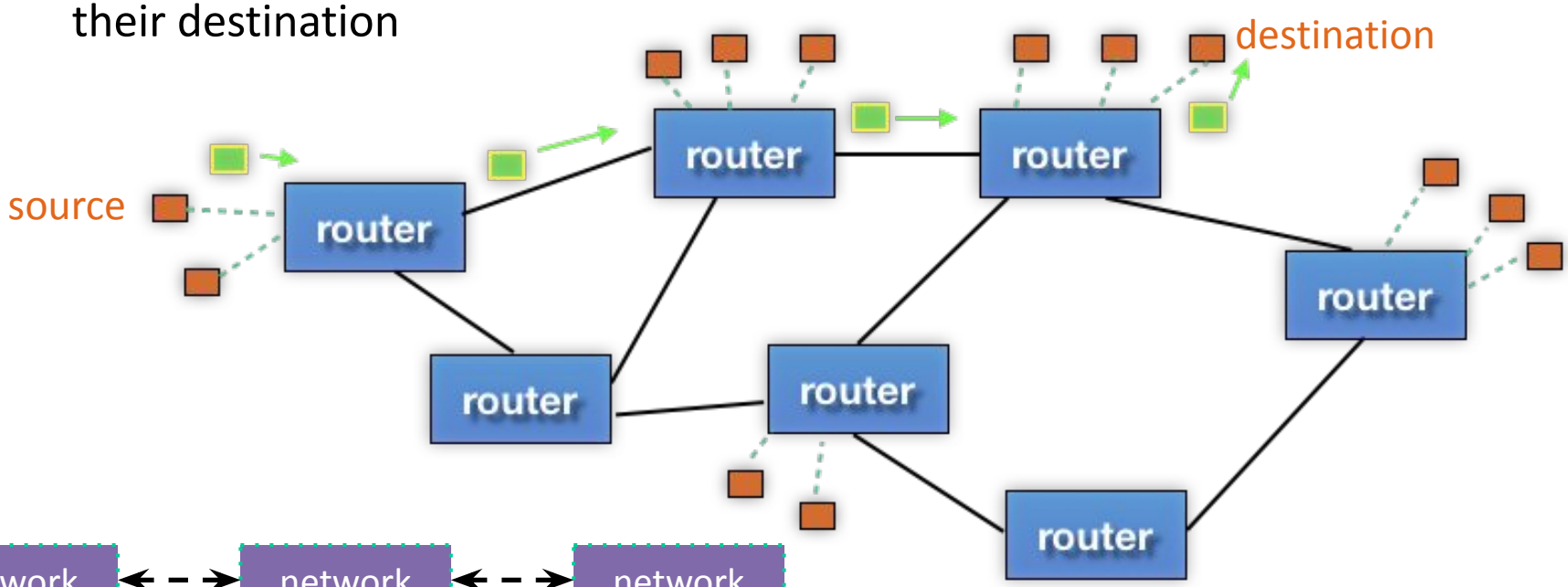
- Internet Protocol (IP) routes packets across multiple networks
  - Every computer has a unique IP address (sort of)
  - Individual networks are connected by routers that span networks

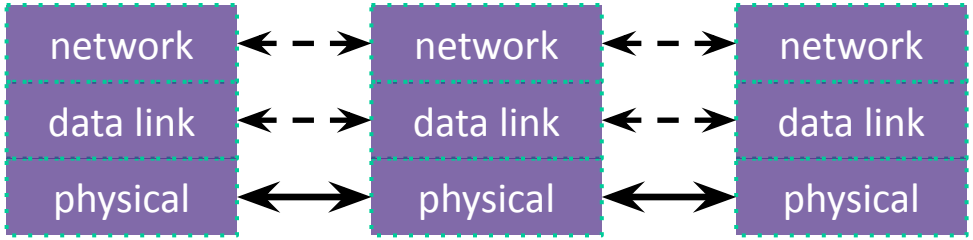




The Network Layer (IP)

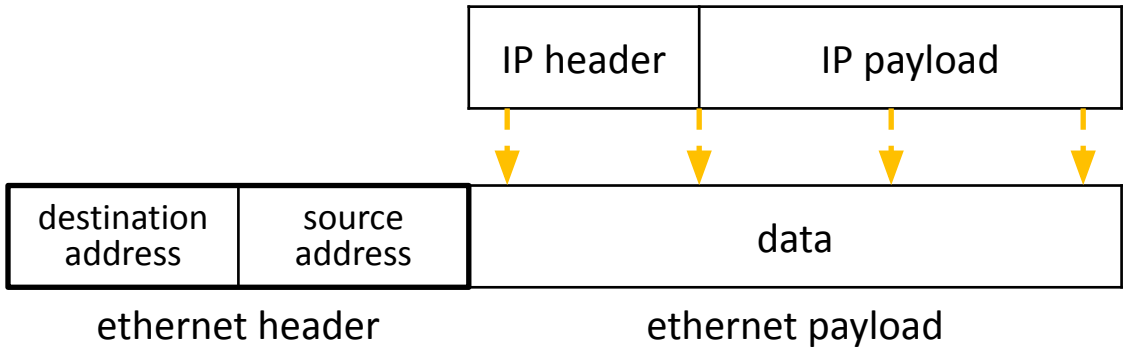
- There are protocols to:
  - Let a host map an IP to MAC address on the same network
  - Let a router learn about other routers to get IP packets one step closer to their destination

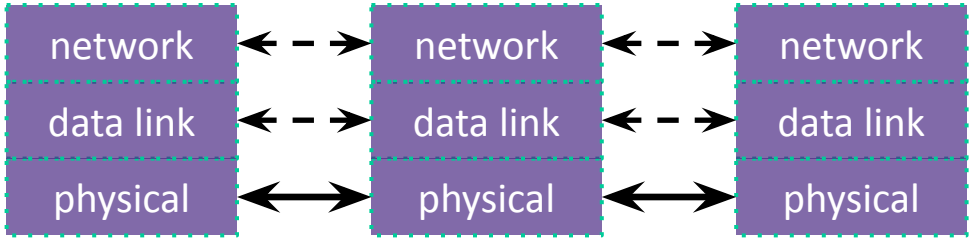




The Network Layer (IP)

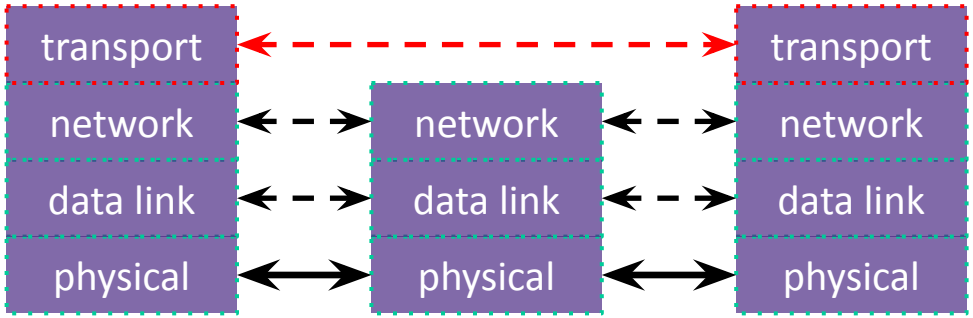
- Packet encapsulation:
  - An IP packet is encapsulated as the payload of an Ethernet frame
  - As IP packets traverse networks, routers pull out the IP packet from an Ethernet frame and plunk it into a new one on the next network





The Transport Layer (TCP)

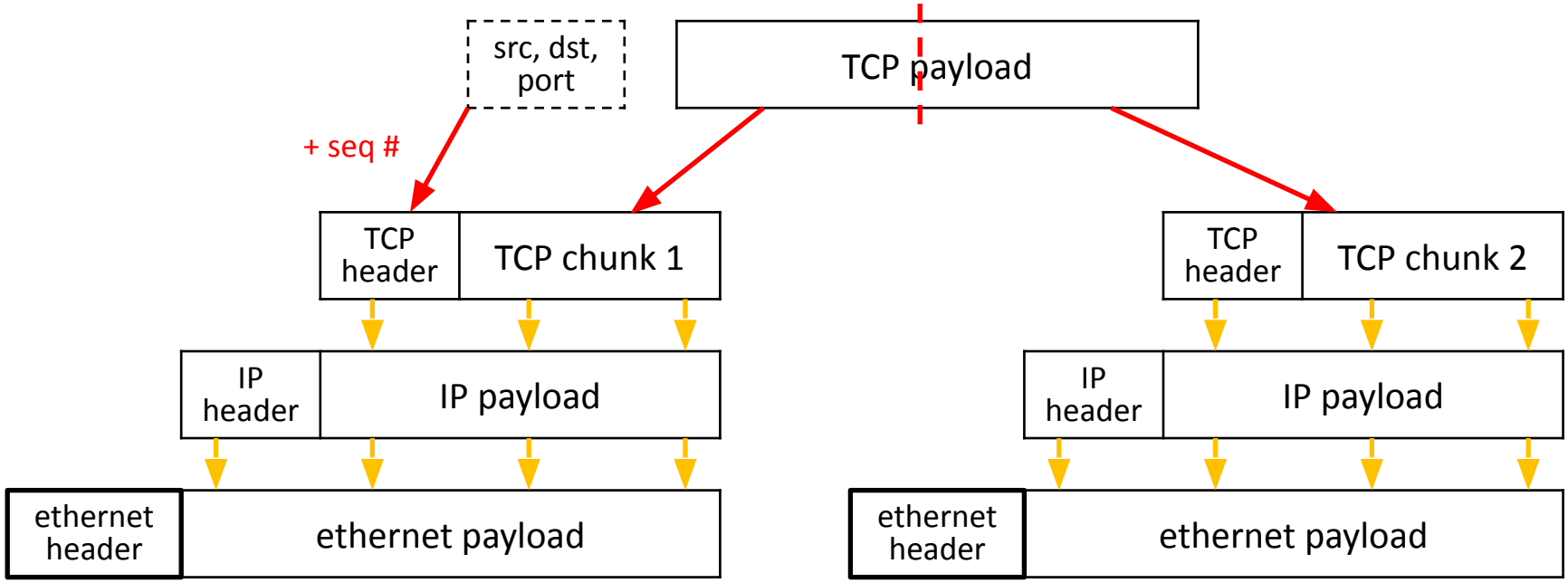
- Transmission Control Protocol (TCP):
  - Provides applications with reliable, ordered, congestion-controlled byte streams
    - Sends stream data as multiple IP packets (differentiated by sequence numbers) and retransmits them as necessary
    - When receiving, puts packets back in order and detects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

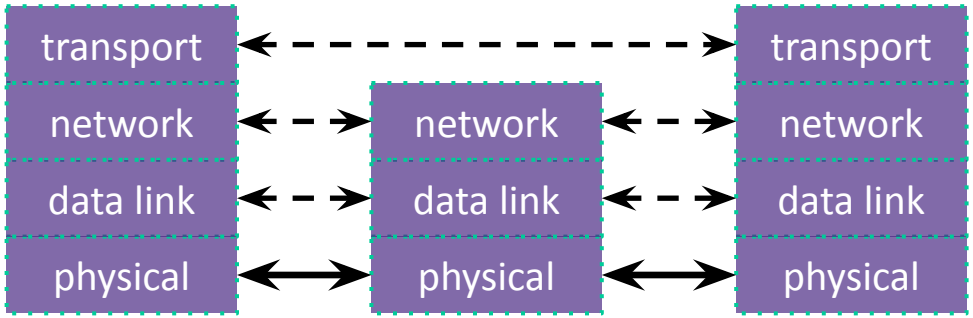


https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers

The Transport Layer (TCP)

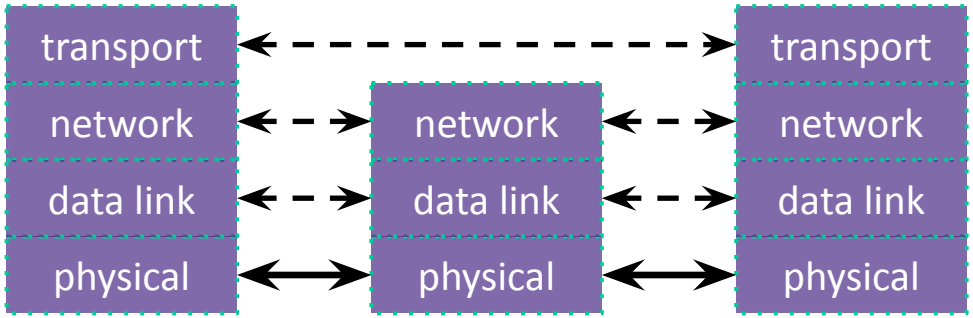
- Packet encapsulation – one more nested layer!





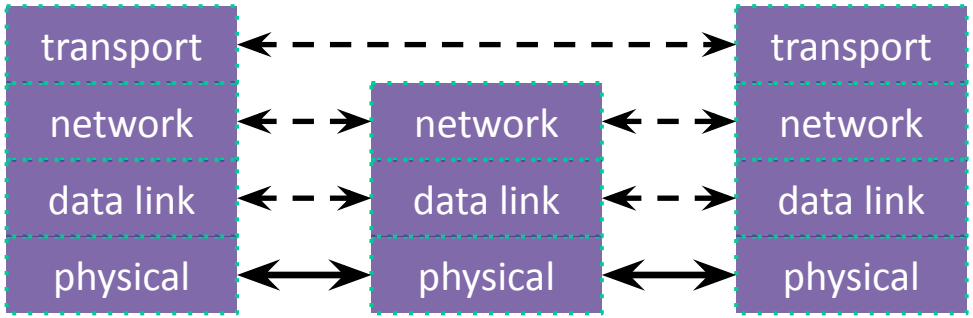
The Transport Layer (TCP)

- 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)

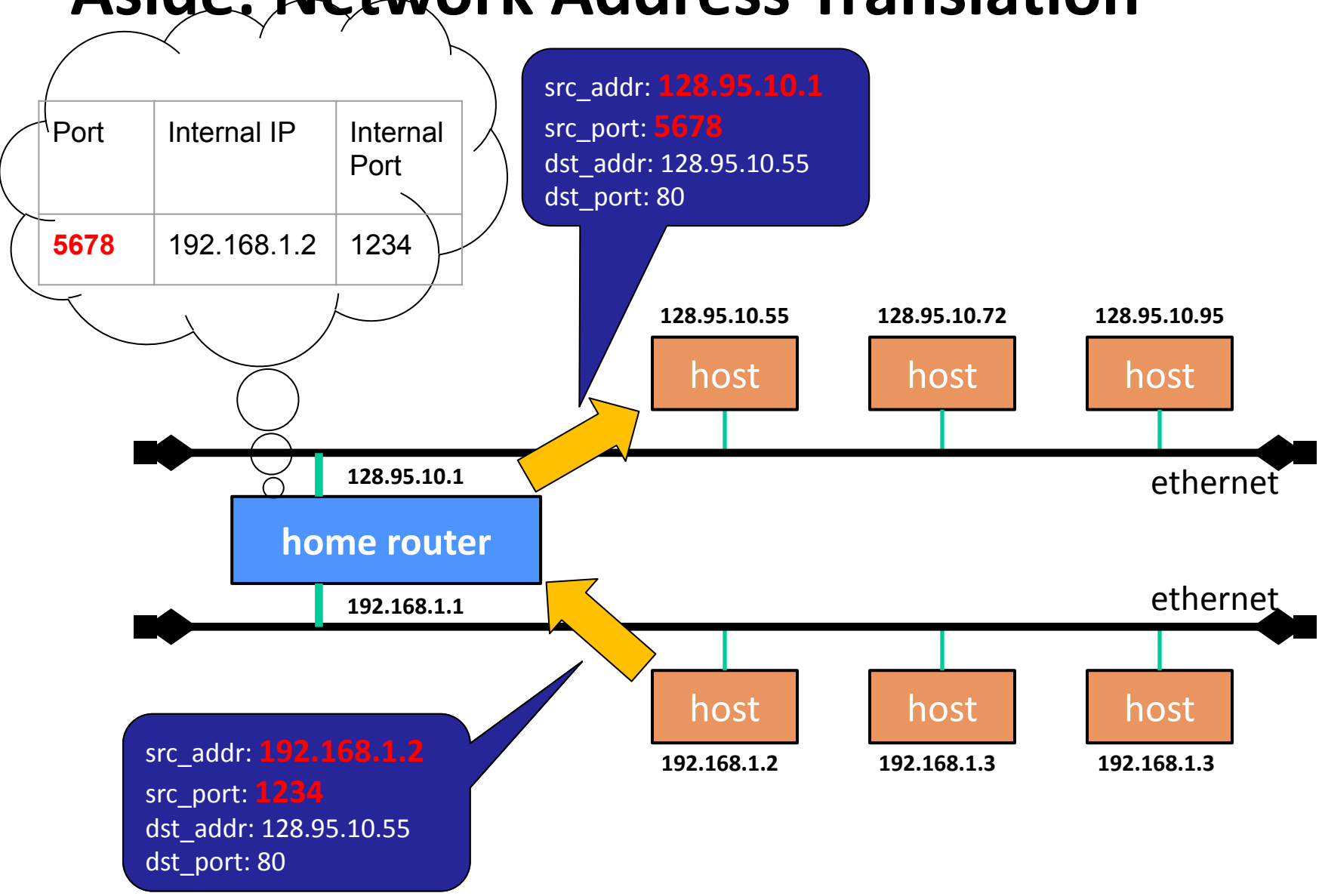
- User Datagram Protocol (UDP):
  - Provides applications with *unreliable* packet delivery
  - UDP is a really thin, simple layer on top of IP
    - Datagrams still are fragmented into multiple IP packets



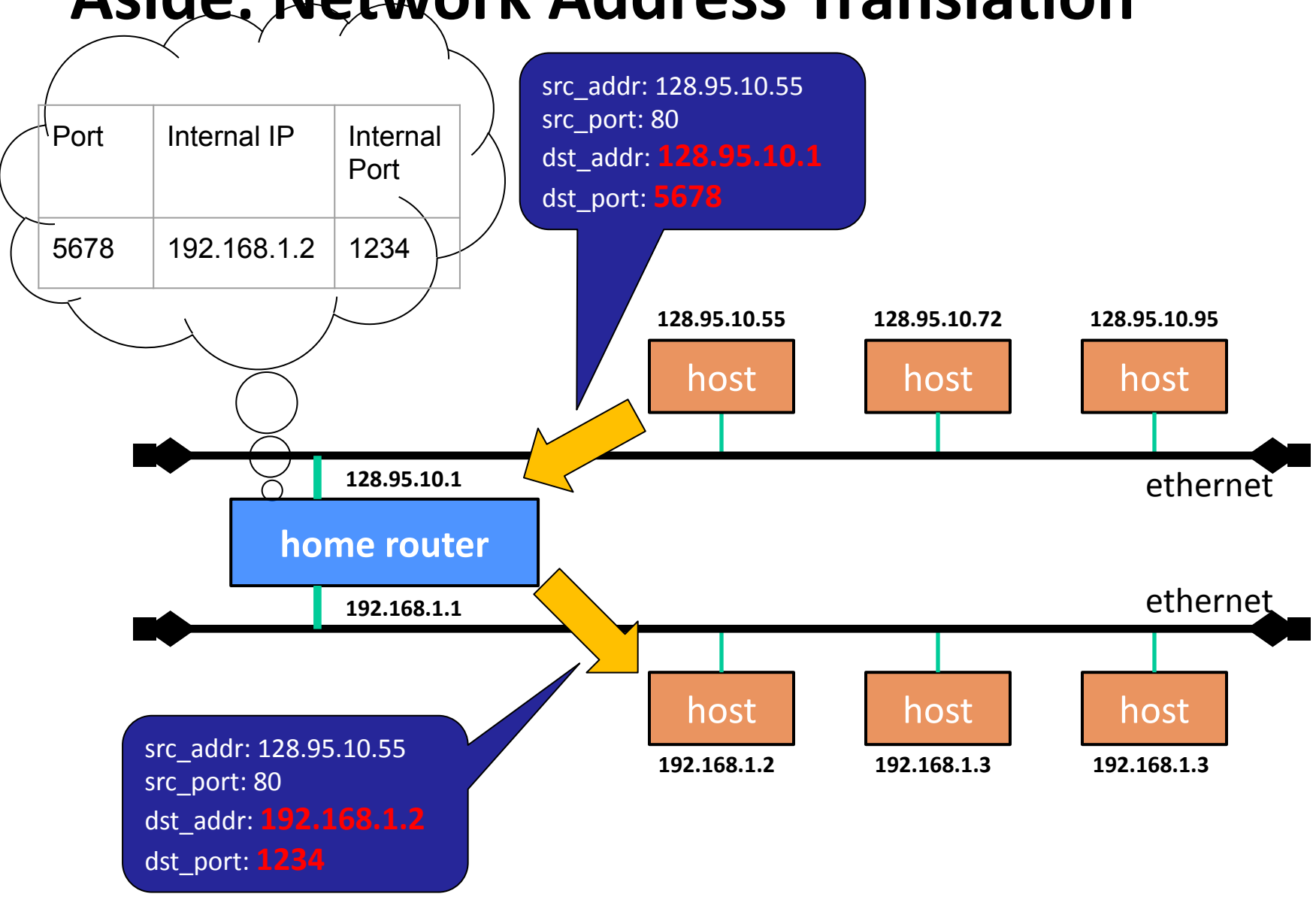
Aside: Network Address Translation

- There aren't enough IPv4 addresses for all the internet users!
- IPv6 solves this problem, but requires changing lots of infrastructure
- Backwards compatible solution: Network Address Translation (or "NAT")

Aside: Network Address Translation

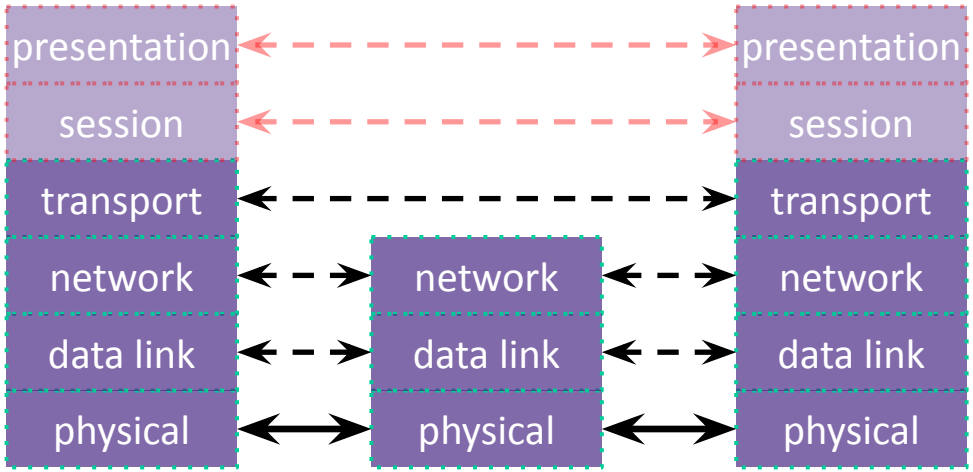


Aside: Network Address Translation



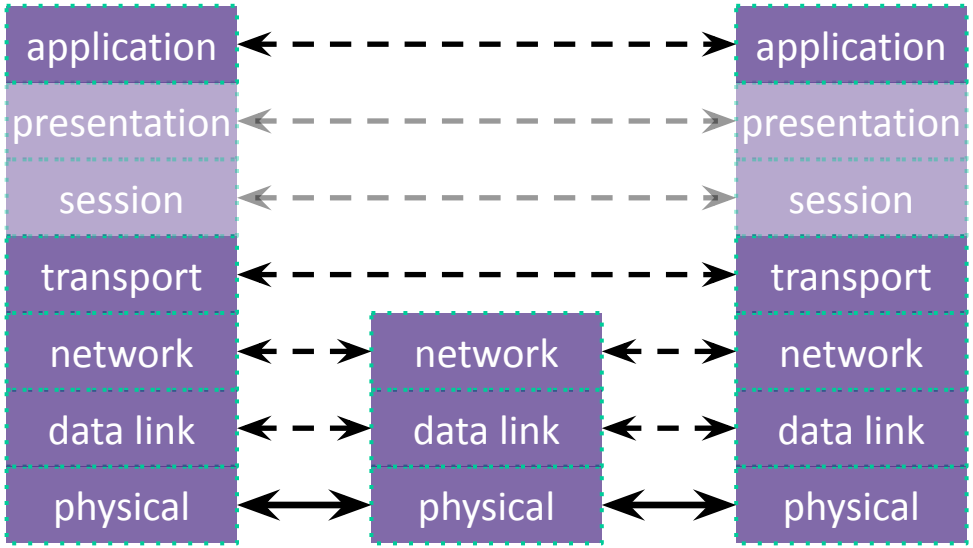
The (Mostly Missing) Layers 5 & 6

- 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



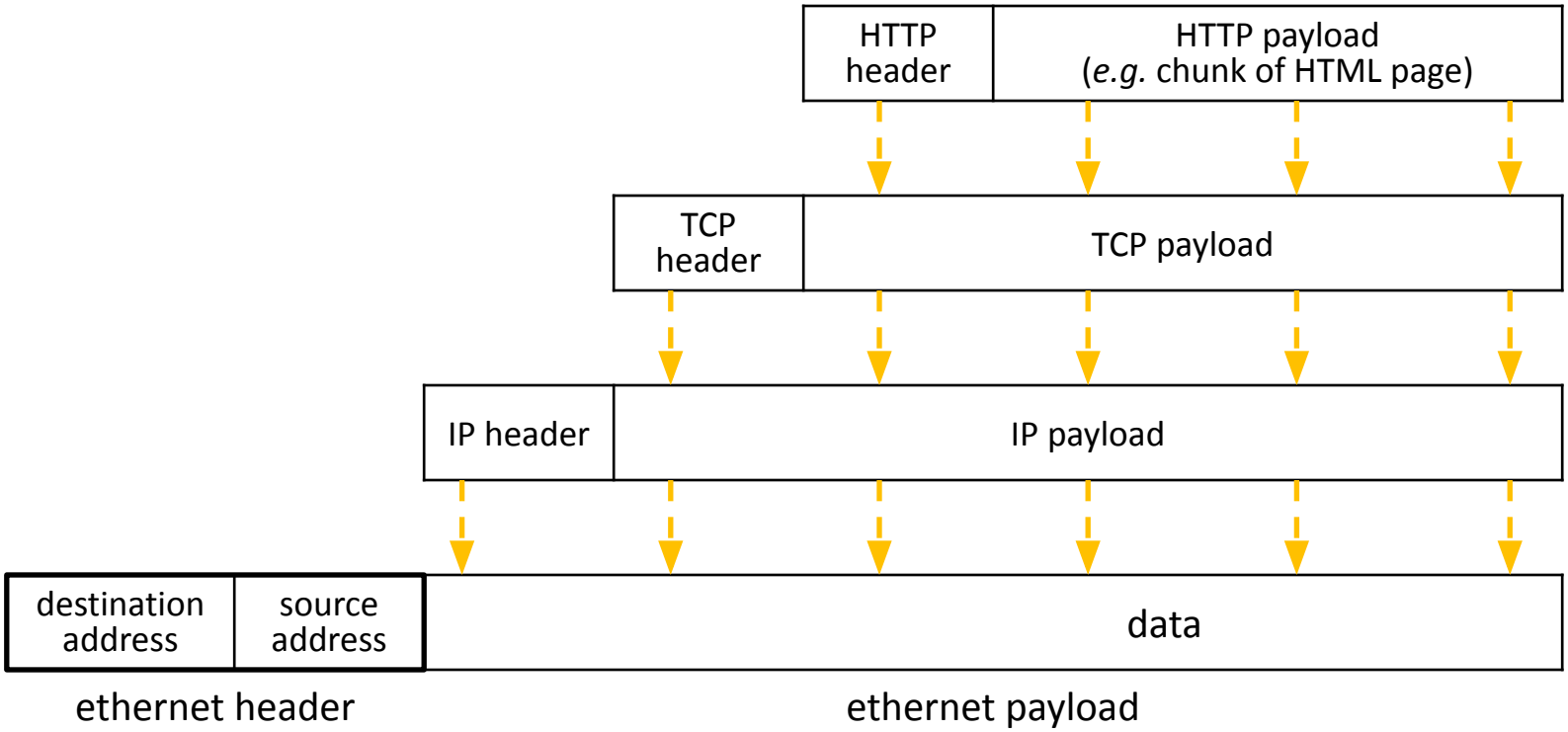
The Application Layer

- Application protocols
  - The format and meaning of messages between application entities
  - Example: 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

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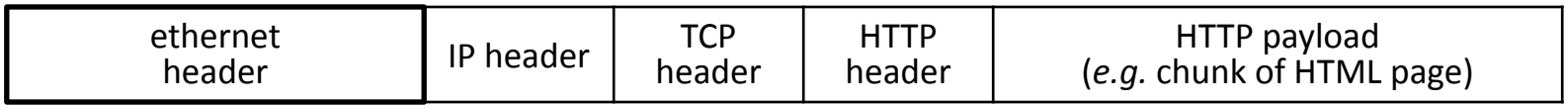

The Application Layer

- 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

What network layer would you change if you want to:

- Make packets bigger
  - Network Layer (IP)
- Mark some packets as reliable and others as not
  - Transport Layer (TCP/UDP
- Implement a multiplayer game
  - Application Layer
- Use carrier pigeons to transmit data
  - Physical Layer
- Use different routes based on the contents of the packet
  - Network Layer

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.

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]

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

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`

```
> nc -l 1234

Hello world
Back at you!

^C
>
```

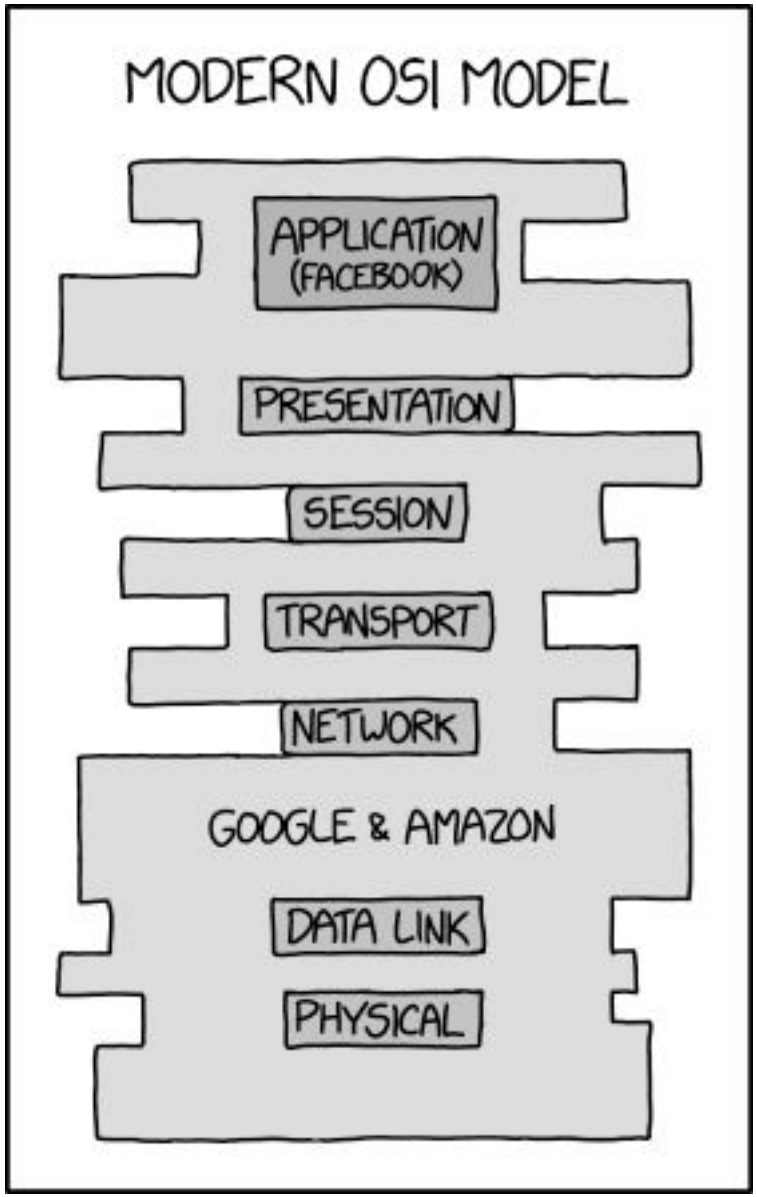
```
> echo "Hello world" | nc 127.0.0.1 1234


Back at you!

>
```

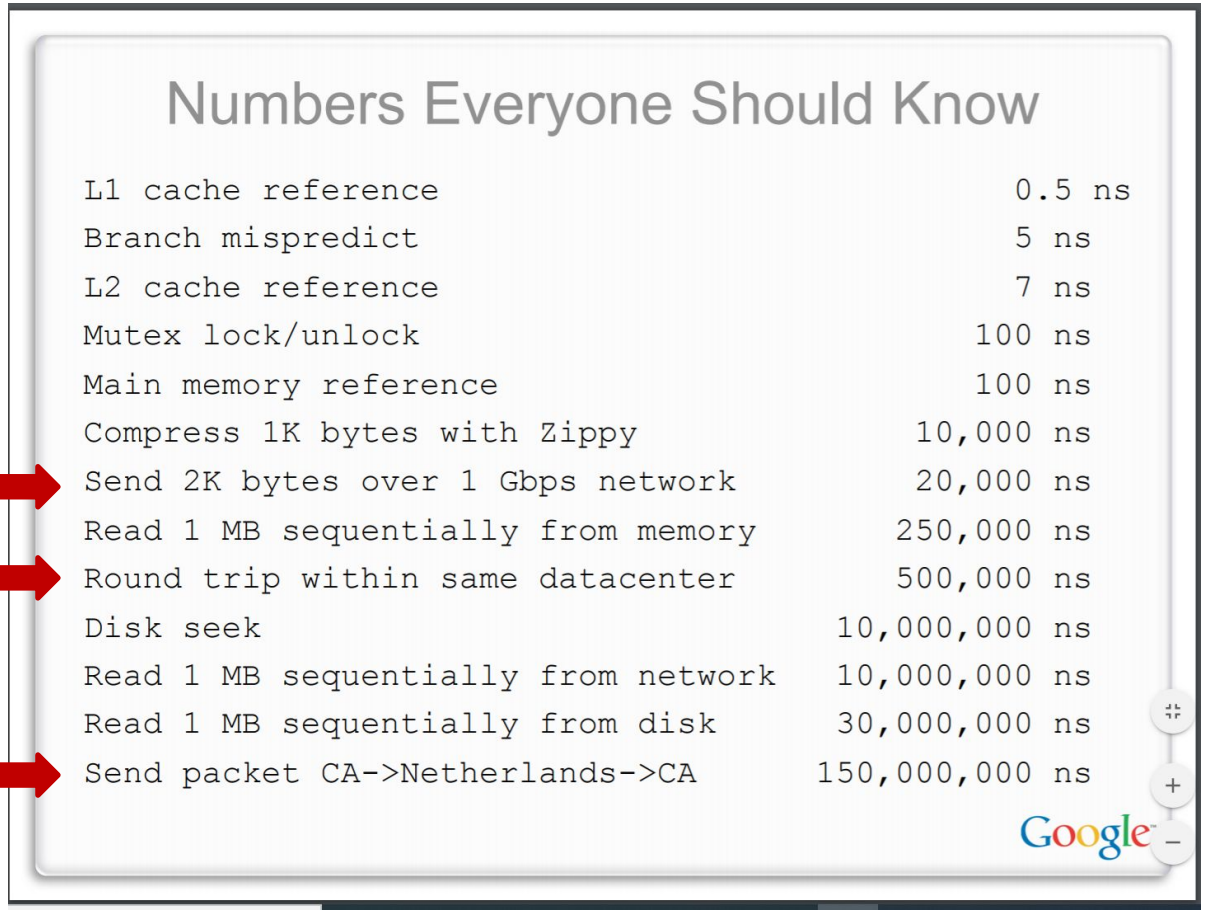
Spacing isn't accurate, it's for illustrative purposes

The Future of Networking?



"Network" Latency is Highly Variable

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



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!

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