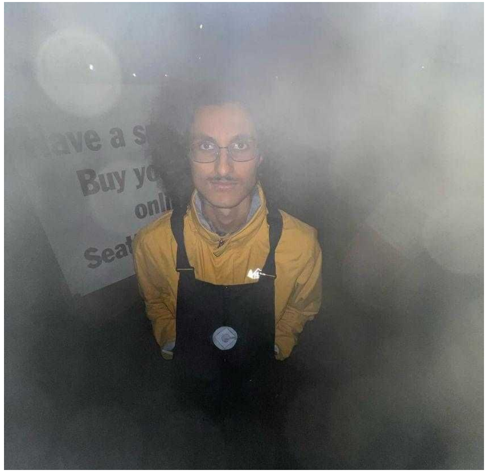
# Section 1: Sockets API + HW 1

CSE 461 Winter 2024

# Your TAs :)

- BS/MS student!
- First-time 461 TA
- Hobbies: learning italian

- BS/MS student–just started the MS!
- Research assistant in syslab (I do OS things)
- Hobbies: trivia, violin, hiking/travel



# Administrivia - Course Structure

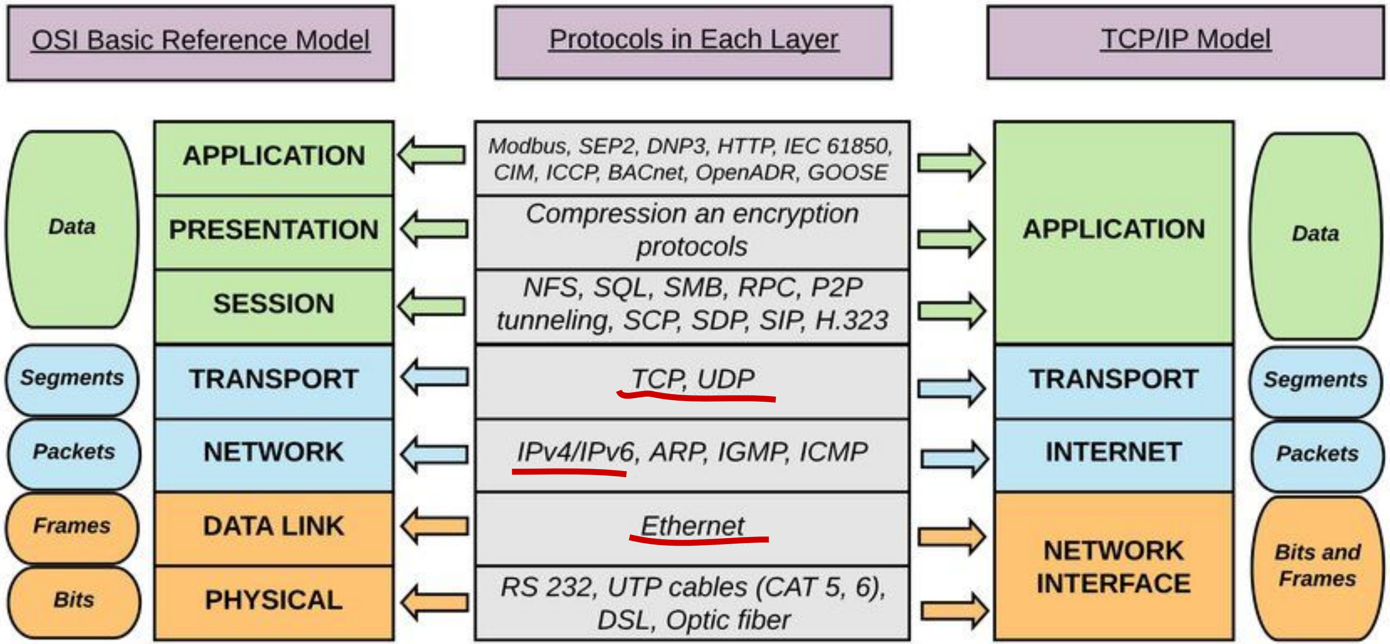
- Assignments
  - 3 group projects
    - P1: Building a client and server application
    - P2: Practicing with Software-Defined Networking (SDN)
    - P3: Experimenting to learn about latency in real-world networks (Bufferbloat)
  - About 5 homework assignments (Gradescope)
    - Detailed practice with the concepts discussed in textbook & lecture
    - Conceptual overview
  - In-person Midterm & Final Exam
  - Occasional “surprise” quizzes
- Quiz Sections
  - Intro to labs (helpful hints!) + networking software
  - Reviewing and clarifying conceptual topics (e.g. various protocols)
  - More practices with mechanics (e.g. calculations, algorithms, etc.)

# Administrivia

- Project 1 is out, **due Jan. 25**
  - Can be done in groups of 2-3
  - Can be done in any language (recommend Python/Java)
    - But future labs will be fully in Python
  - Goal is to help you get familiar with some language's Socket API
  - **NEW THIS QUARTER**: 10% of points on style
    - modularity, readability, consistent naming scheme..... just good programming practices in general
    - we'll provide some guidelines on Ed/spec

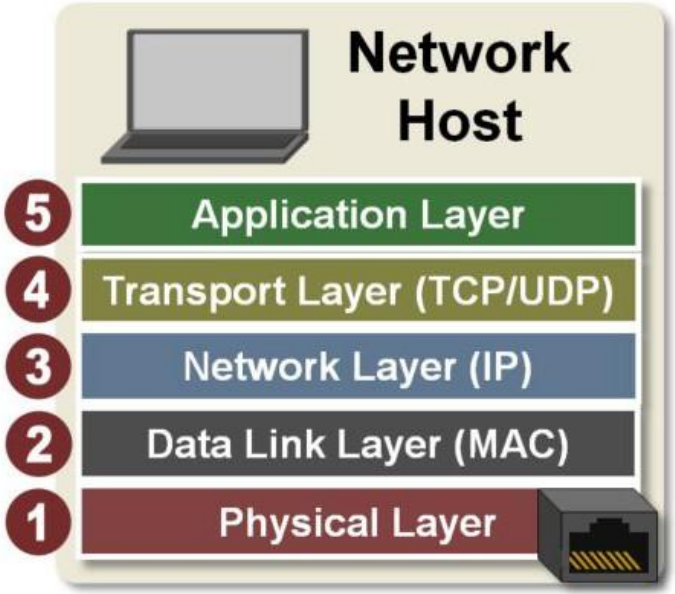
# Socket API & Project 1

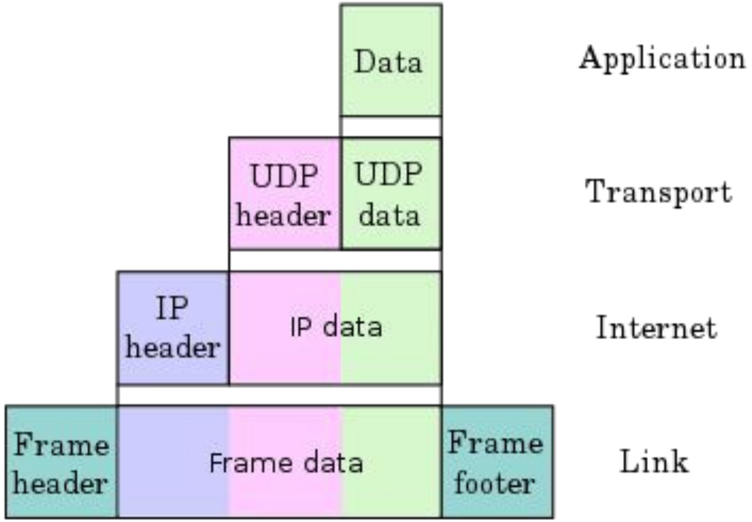
# Network Stack - OSI Model vs TCP/IP Model




7 layers vs. 5 layers

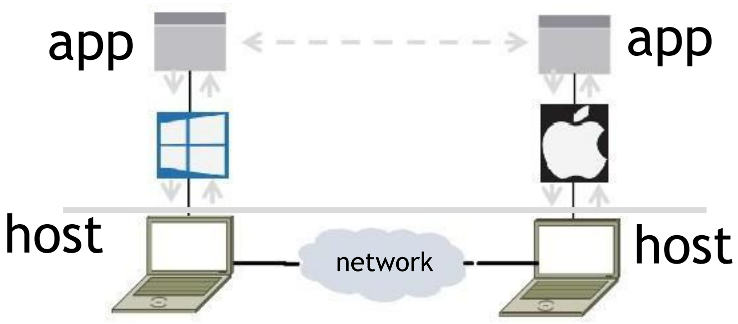
# Network Stack - Packet Encapsulation

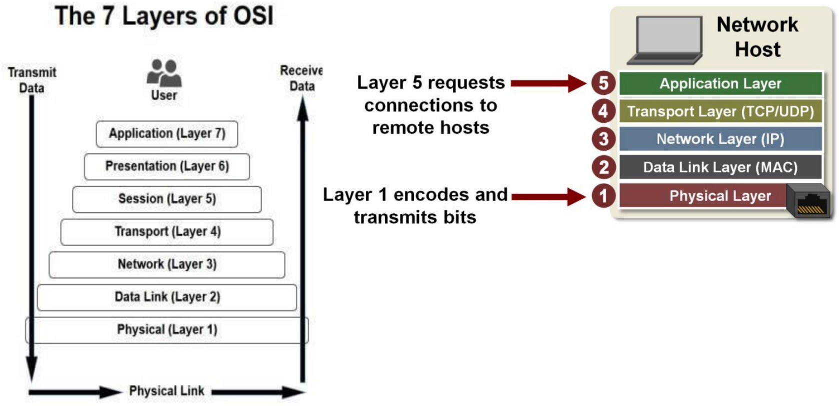


# Network-Application Interface

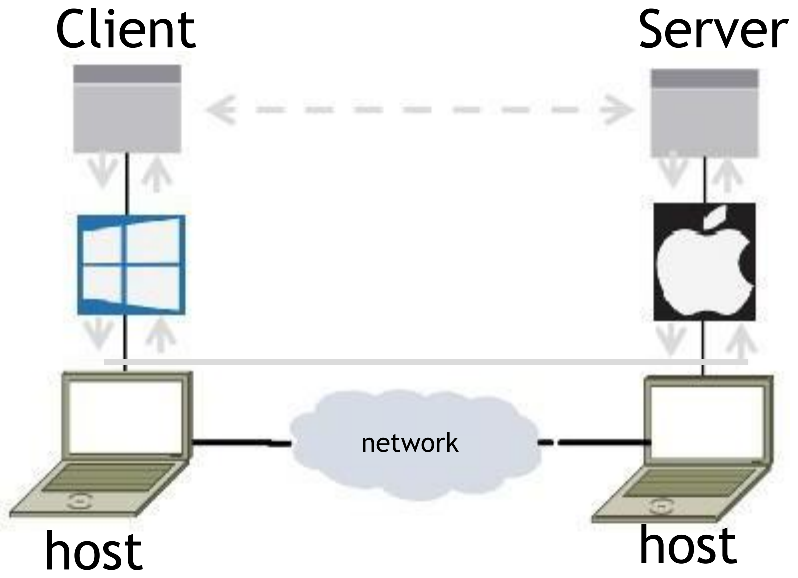
- Defines the operations that programs (apps) call to use the network
  - Application Layer API
  - Defined by the Operating System
    - These operations are then exposed through a particular programming language
    - All major Operating Systems support the Socket API
  - Allows two computer programs potentially running on different machines to talk
  - Hides the other layers of the network



# Project 1 - Overview

- Part 1: Simple Client
  - Send requests to attu server
  - Wait for a reply
  - Extract the information from the reply
  - Continue…
- Part 2: Simple Server
  - Server handles the Client requests
  - Multi-threaded
- This is the basis for many apps!
  - File transfer: send name, get file
  - Web browsing: send URL, get page
  - Echo: send message, get it back

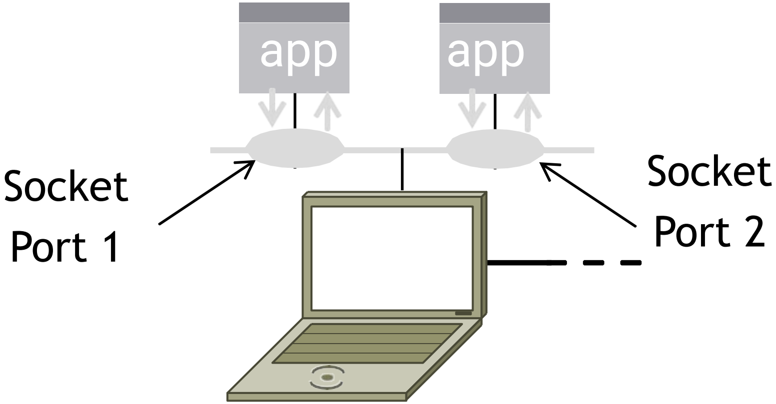


# Socket API

- Simple application-layer abstractions (APIs) to use the network
    - The network service API used to write all Internet applications
    - Part of all major OSes and languages; originally Berkeley (Unix) ~1983
- Two kinds of sockets
    - Streams (TCP): reliably send a stream of bytes
        - Detects packet loss with timeouts (uses adaptive timeout protocol)
        - Uses flow control: similar to selective repeat
    - Datagrams (UDP): unreliably send separate messages

# Ports

- Sockets let apps attach to the local network at different ports
  - Ports are used by OS to distinguish services / apps all using the same physical connection to the internet
  - Think of ports like apartment numbers, allowing mail sent to a shared building address (IP) to be sorted into the correct destination unit (application)

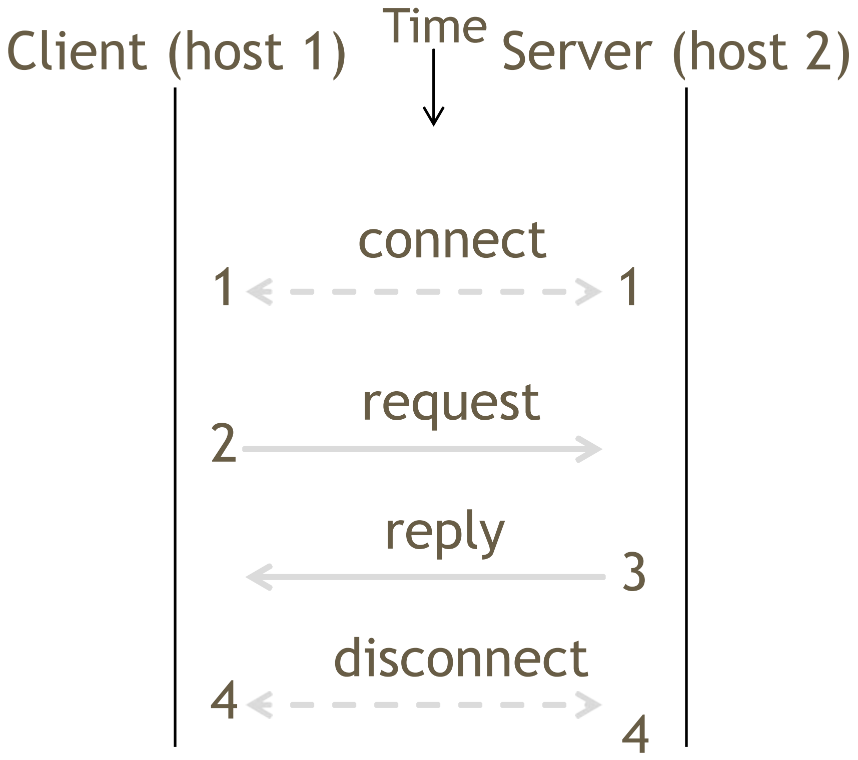


# Socket API Operations

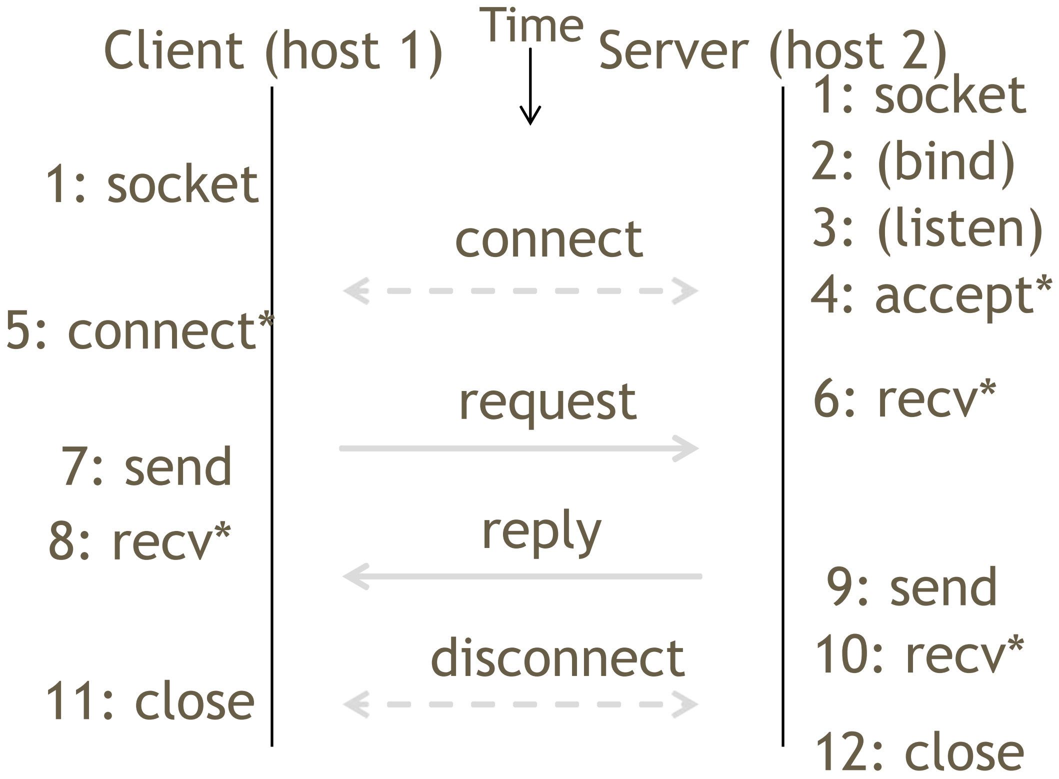
| Primitive | Meaning |
| --- | --- |
| SOCKET | Create a new communication endpoint |
| BIND | Associate a local address (port) with a socket |
| LISTEN | Announce willingness to accept connections; (give queue size) |
| ACCEPT | Passively establish an incoming connection |
| CONNECT | Actively attempt to establish a connection |
| SEND | Send some data over the connection |
| RECEIVE | Receive some data from the connection |
| CLOSE | Release the connection |

https://docs.oracle.com/javase/8/docs/api/java/net/Socket.html
https://docs.oracle.com/javase/8/docs/api/java/net/ServerSocket.html

# Using TCP Sockets

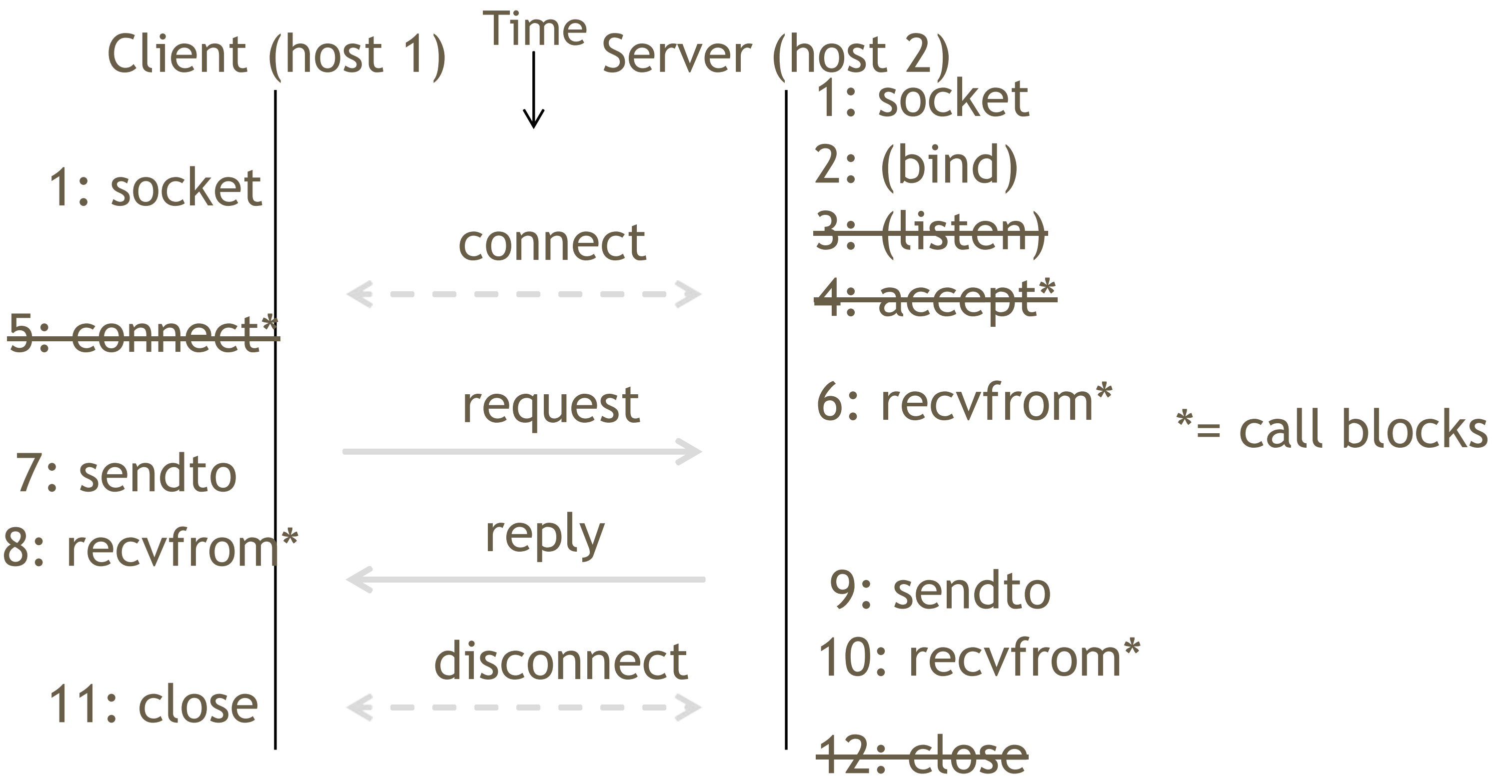


# Using TCP Sockets (cont.)




*= call blocks

# Using UDP Sockets



# Client Program Outline

```
socket()          // make socket
getaddrinfo()     // server and port name
                  // www.example.com:80
connect()         // connect to server
send()            // await reply [block]
recv()            // do something with data!
…
close()           // done, disconnect
```

# Server Program Outline

```
socket()          // make socket
getaddrinfo()     // for port on this host
bind()            // associate port with socket
listen()          // prepare to accept connections
accept()          // wait for a connection [block]
...
recv()            // wait for request [block]
...
send()            // send the reply
close()           // eventually disconnect
```

**create a new thread for new client connection!**

# Python Examples with socket

## Server

```
listener = socket.socket(socket.AF_INET,
                         socket.SOCK_STREAM)
listener.bind(server_address)

while True:
    try:
        connection, client_addr = listener.accept()
        try:
            connection.recv(n_bytes)
        finally:
            connection.close()
    except:
        listener.close()
```

## Client

```
socket = socket.socket(socket.AF_INET,
                       socket.SOCK_STREAM)
socket.connect(server_address)
socket.sendto(message, server_address)
socket.close();
```

- Python socket documentation
- UDP socket example
- socketserver (a little overkill)

# Java Examples with Socket & ServerSocket

## Server

```
ServerSocket listener = new ServerSocket(9090);
try {
    while (true) {
        Socket socket = listener.accept();
        try {
            socket.getInputStream();
        } finally {
            socket.close();
            }
        }
} finally {
            listener.close();
}
```

## Client

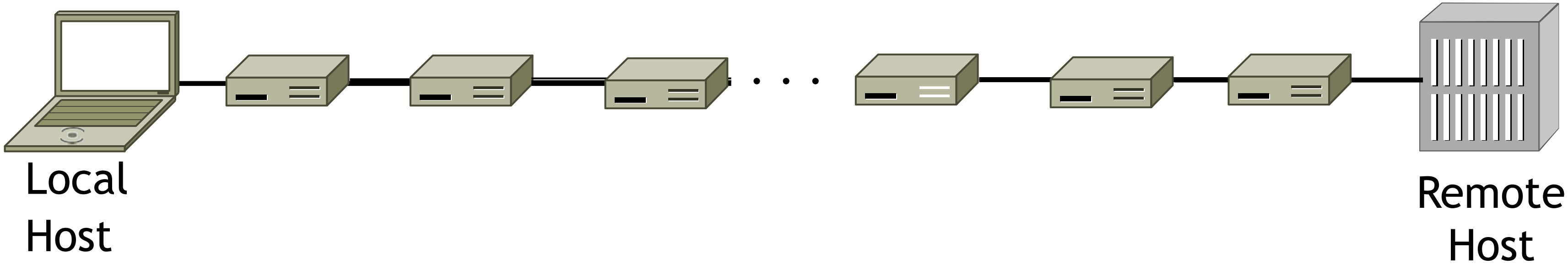
```
Socket socket = new Socket(server, 9090);
out = new PrintWriter(socket.getOutputStream(), \
                                    true);
socket.close();
```

- http://cs.lmu.edu/~ray/notes/javanetexamples/
- https://docs.oracle.com/javase/tutorial/networking/sockets/clientServer.html

# HW1 Fundamentals

# Traceroute

- Goal: find network path from our system to a given remote host
- Core mechanism: **Time-To-Live** (TTL)
  - TTL defines the number of hops a packet will travel through until it is dropped
    - TTL is decremented every hop
    - Once TTL is 0 then the packet is dropped and a report is sent to the source

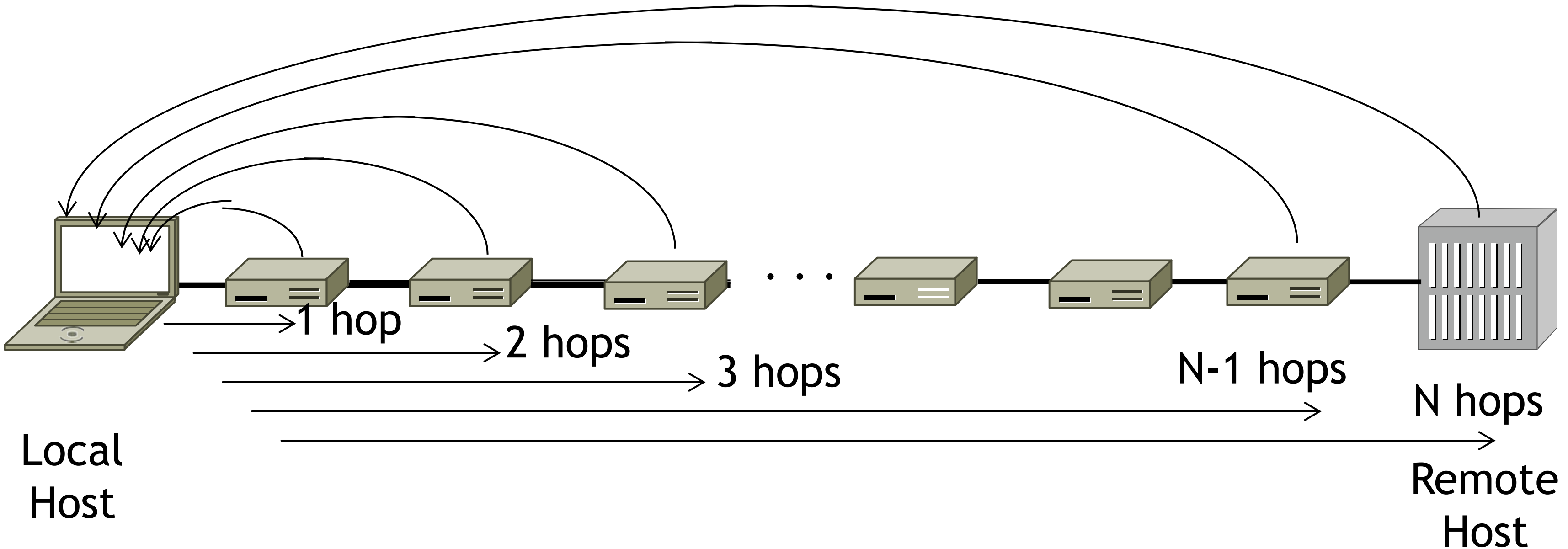



Resources:

- https://serverfault.com/questions/6403/what-do-the-three-columns-in-traceroute-output-mean

# Traceroute

- Traceroute sends out three packets per TTL increment
  - To have 3 trials of data for each hop distance
- Each data point corresponds to the total RTT time



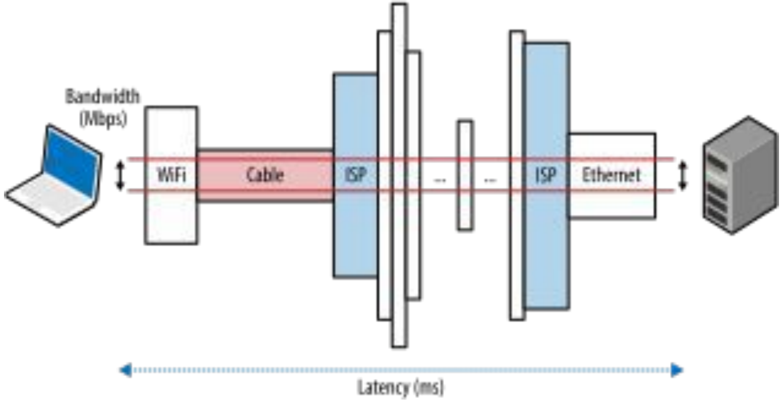
# Using Traceroute

```
dominickta@Prota ~
   traceroute edstem.org
traceroute: Warning: edstem.org has multiple addresses; using 172.66.40.189
traceroute to edstem.org (172.66.40.189), 64 hops max, 52 byte packets
 1  10.18.0.2 (10.18.0.2)  6.327 ms  6.836 ms  8.570 ms
 2  lo0--5.uwcr-ads-1.infra.washington.edu (198.48.65.5)  6.998 ms  4.229 ms  11.492 ms
 3  10.132.5.66 (10.132.5.66)  11.876 ms  9.706 ms  5.816 ms
 4  10.132.255.17 (10.132.255.17)  11.205 ms  4.184 ms  3.535 ms
 5  10.132.255.18 (10.132.255.18)  15.567 ms  5.217 ms  2.527 ms
 6  ae20--4000.icar-sttl1-2.infra.pnw-gigapop.net (209.124.188.132)  7.411 ms  5.022 ms  20.059 ms
 7  six.as13335.com (206.81.81.10)  29.820 ms  105.949 ms  11.541 ms
 8  172.71.140.3 (172.71.140.3)  25.781 ms
    172.71.144.3 (172.71.144.3)  10.867 ms
    172.71.140.3 (172.71.140.3)  9.835 ms
 9  172.66.40.189 (172.66.40.189)  17.161 ms  9.327 ms  7.720 ms
```

# Latency & Bandwidth

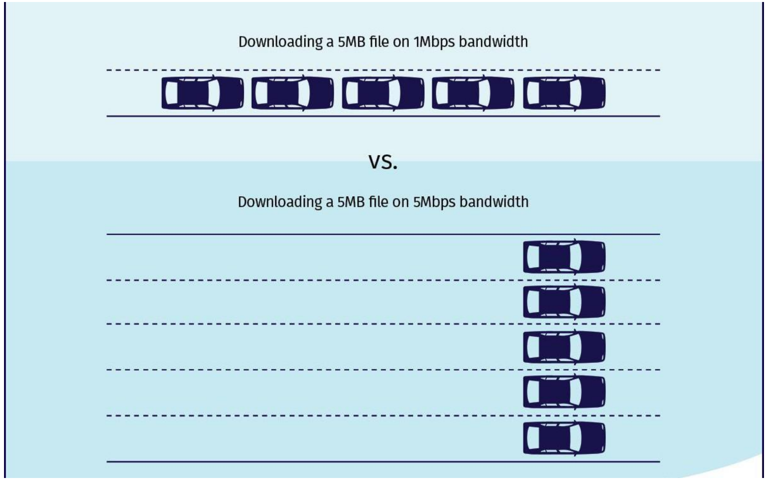
# Latency

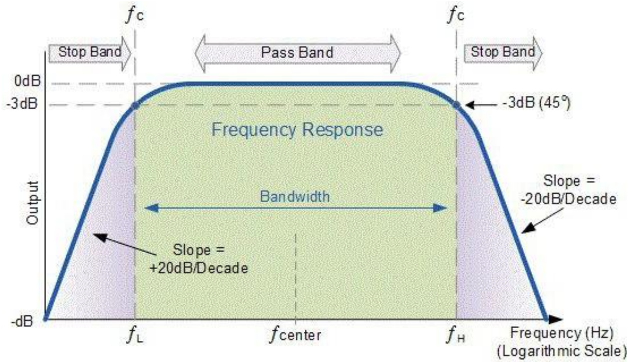
- Latency: Total time for a message to arrive on a network
  - Round trip time (RTT) is the latency for travel from source to destination to source
- **Latency = Propagation + Transmit + Queue**
  - **Propagation = Distance / "Speed Of Light"**
    - How long it takes for information to travel a distance from source to destination
    - Speed varies by medium
  - **Transmit = Size / Bandwidth**
    - How long it takes for information to be put onto the wire before travelling
  - **Queue time**
    - How long data has to wait until it's their turn to be transmitted



# Bandwidth

- **Bandwidth** (data rate): The number of bits that can be transmitted over a period of time
    - Units of bits per second (bps)
    - Confusingly also used to refer to the frequency range of a signal
        - In this case the units are given as hertz (Hz)
- **Throughput:** The measured performance of a system
    - Units of bits per second (bps)
- Analogy: bandwidth is a pipe and throughput is the water



# Bandwidth & Transmission Time

**Transmission time = Size of data / Bandwidth**

- Transmission time of 1 bit of data at a bandwidth of 1 Mbps?
  - 1 bit / 1,000,000 bps = 1/1,000,000 seconds = 1 microsecond
- Transmission time of 1 bit of data at a bandwidth of 2 Mbps?
  - 1 bit / 2,000,000 bps = 1/2,000,000 seconds = 0.5 microseconds

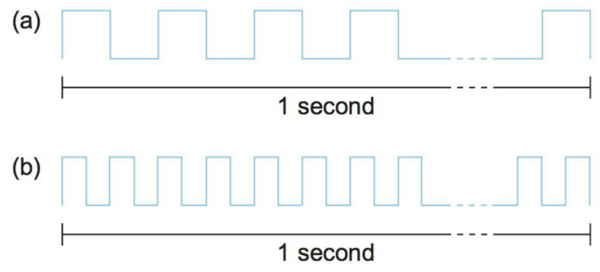
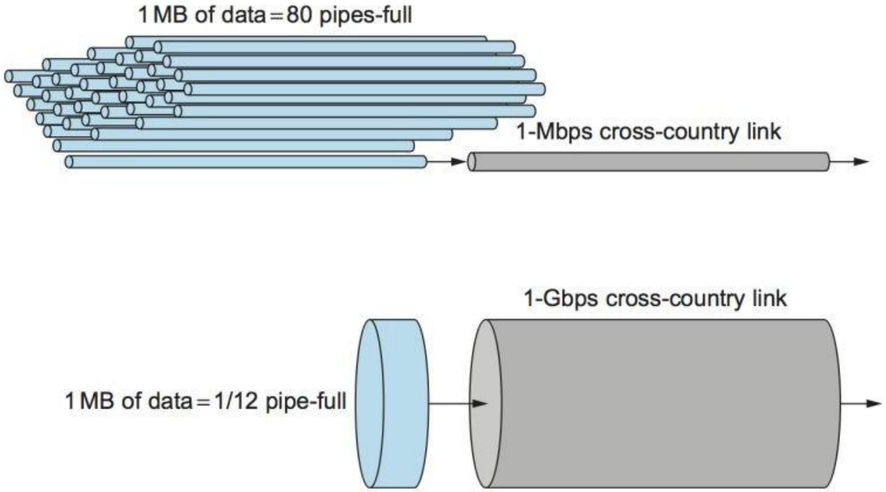



Figure 1.16.: Bits transmitted at a particular bandwidth can be regarded as having some width: (a) bits transmitted at 1 Mbps (each bit is 1 microsecond wide); (b) bits transmitted at 2 Mbps (each bit is 0.5 microseconds wide).

# Bandwidth-Delay Product

- Product between bandwidth and propagation delay
  - Units in bits (bps * s = b)
- Propagation delay is either **one way latency** or **RTT**
  - Usually RTT
- Conceptually defines the maximum amount of data that can be "in-flight" at a given time
  - think the amount of water in a pipe



# Exercises!

# Exercise 1

Suppose we have a network link with a **bandwidth of 10 Mbps**. We want to send a **100 KB file** to a friend somewhere else in the network. The RTT from us to our friend is **20 ms**. How long does it take for the entire file to be delivered?

- Transmit time = 100 KB / 10 Mbps = 100,000 B / 10 Mbps
  = 800,000 b / 10,000,000 bps = 0.08 seconds = 80 ms
- At t=80ms, the final bit of data is transmitted onto the wire.
  - This bit still needs to actually travel to the destination (**propagation delay**)
- At t=90ms, the final bit of data arrives at the destination
  - Note that we added ½ of the RTT!

# Exercise 2

Consider a point to point link **50 km in length**. Suppose the **propagation speed is 2 * $10^8$ m/s**. At what bandwidth in Mbps would the propagation delay equal the transmit delay for **100 B packets**?

- Propagation delay = Distance / Speed Of Light (varies by medium)
  - = 50 * $10^3$ m / (2 * $10^8$ m/s) = .00025 seconds = **250 microseconds**
- Transmit = Size / Bandwidth
  - 250 microseconds = 100 B / x Mbps (solve for X)
  - 100 * 8 = 800 bits -> 800 bits / 250 μs = 3.2 Mbps

What about for 512 byte packets?

- 512 * 8 bits / 250 μs = 16.4 Mbps

# Exercise 3

Suppose a **128-kbps** point-to-point link is set up between Earth and a SpaceX colony on Mars. The distance from Earth to Mars (when they are closest together) is approximately **55 Gm**, and data travels over the link at the speed of light **(3 * 108 m/s)**

- Calculate the minimum RTT for the link.
- Calculate the delay x bandwidth product for the link.
- Say your aunt Betty takes a selfie on Olympus Mons, and sends a 5 MB picture to you on Earth. How quickly after the picture is taken can you receive the image from Betty?

# Exercise 3

Suppose a **128-kbps** point-to-point link is set up between Earth and a SpaceX colony on Mars. The distance from Earth to Mars (when they are closest together) is approximately **55 Gm**, and data travels over the link at the speed of light **(3 * 108 m/s)**

- Calculate the minimum RTT for the link.
  - RTT = 2 * Propagation delay = 2 * 55 * $10^9$ m / (3 * $10^8$ m/s) = 2 * 184 = 368 seconds
- Calculate the delay x bandwidth product for the link.
  - delay x bandwidth = 368 seconds * (128 * $10^3$ bps) = 5.888 MB
- Say your aunt Betty takes a selfie on Olympus Mons, and sends a 5 MB picture to you on Earth. How quickly after the picture is taken can you receive the image from Betty?
  - Transmit delay for 5 MB = 40,000,000 bits / (128 * $10^3$ bps) = 312.5 seconds
  - Total time = transmit delay + propagation delay = 312.5 + 184 = 496.5 seconds = about 9 minutes

# That’s it!