Introduction to Networking

CSE 333 Winter 2021

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Intro to Networking

- How the Internet is Designed / Works
  - CSE 461

- Problems in Writing Distributed Programs and Their Solutions
  - CSE 452

- This Course
  - Experience with the simplest, most straightforward distributed application
  - “Client/Server” when not much can go wrong

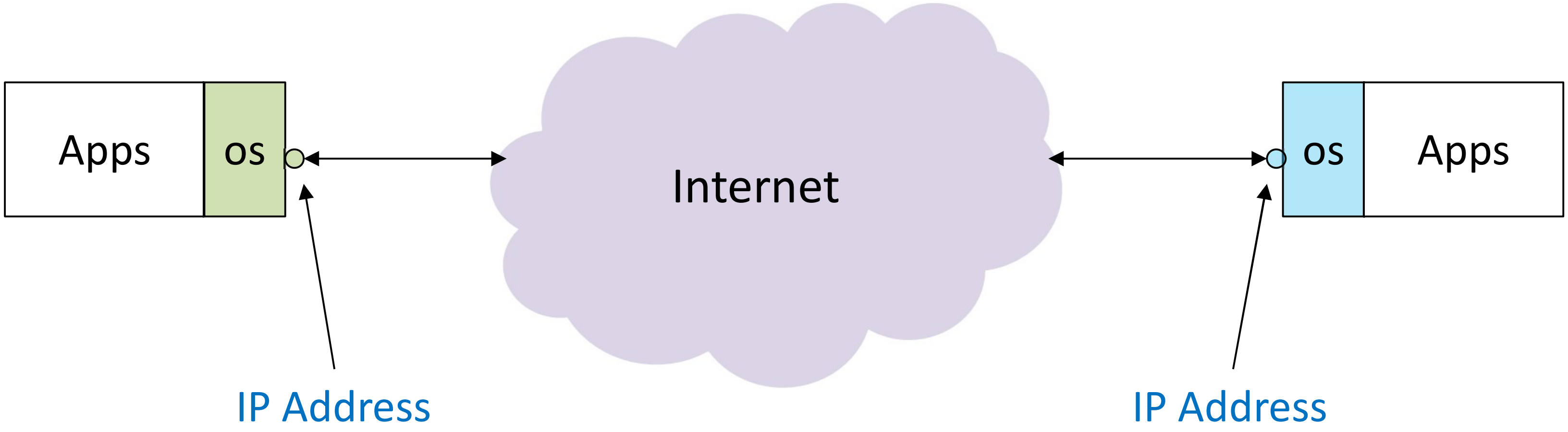
- I’m going to take a lot of liberty simplifying things here

First, Some Demos (Then, Some Explanation)

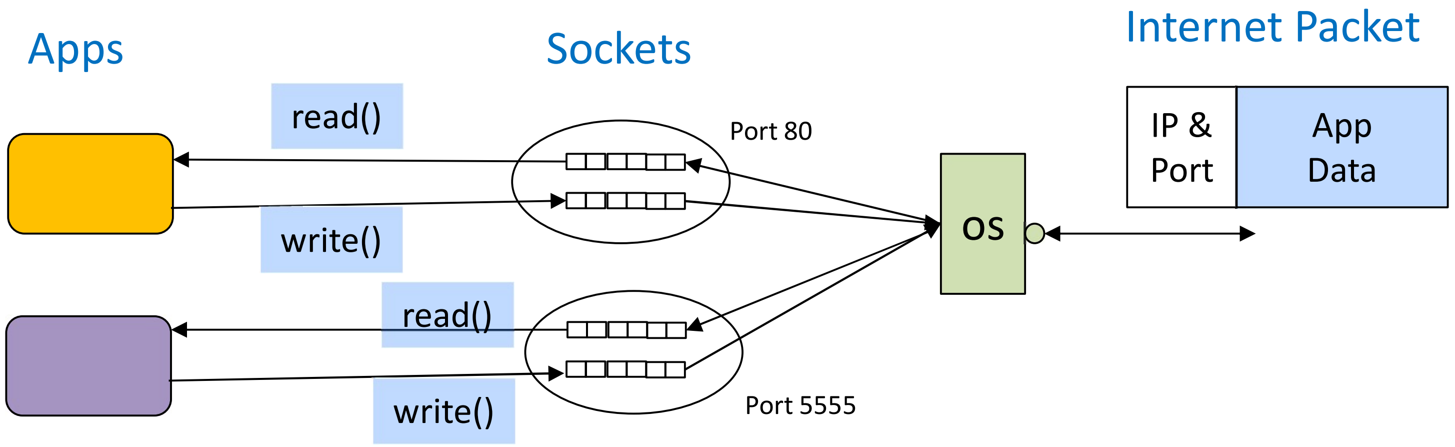
- ifconfig (Linux) to list network addresses
- nc utility launched as server and as client
- nc server and browser as client
- HTTP
- persistent connection

IP (Internet Protocol)

- IP carries data from one IP address (network adapter/machine) to another
  - From one OS to another

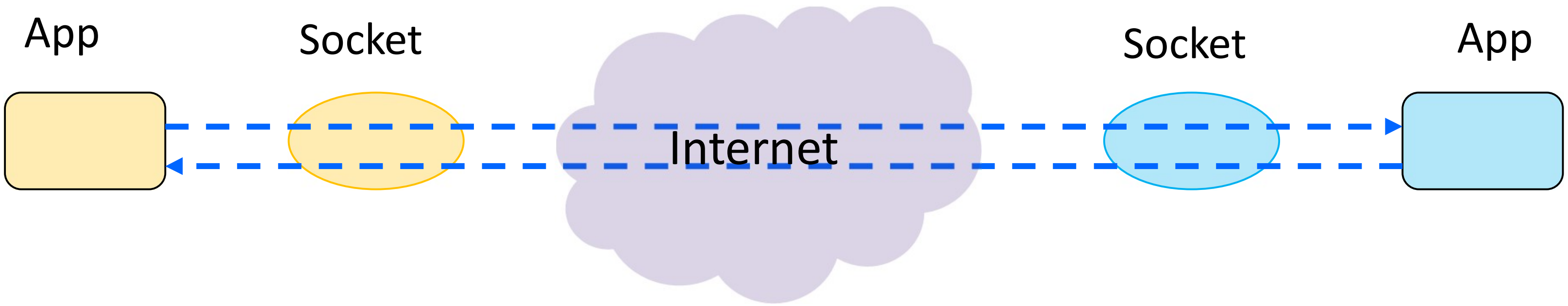


Sockets / Ports



- Internet packets carry IP address and port number
- IP address is used to name host to which packet is delivered
- Ports are used by destination OS to determine to which socket's buffer to add incoming data
  - Sockets are *bound* to ports

TCP (Stream) Sockets



- TCP is a reliable, stream protocol

- stream: it's a linear sequence of bytes, just like a file
- reliable: bytes read are in the same order as they were sent
  - IF they arrive

Client / Server Architecture

- The server is always running and has bound a socket to a "well known port"
  - Example: web server sockets are usually bound to port 80

- The client comes up, establishes a TCP connection to the server's socket, and sends requests

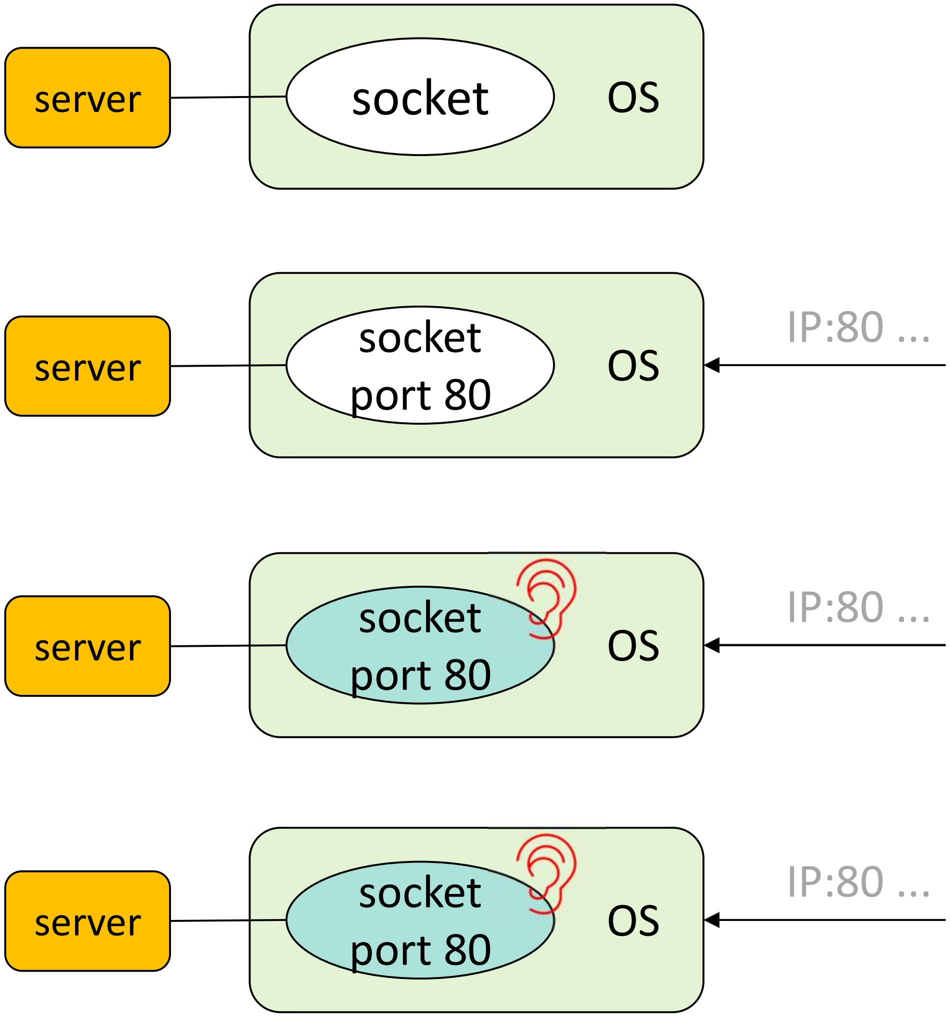
Server Socket Setup

1. Server creates a socket

2. Server binds socket to a port

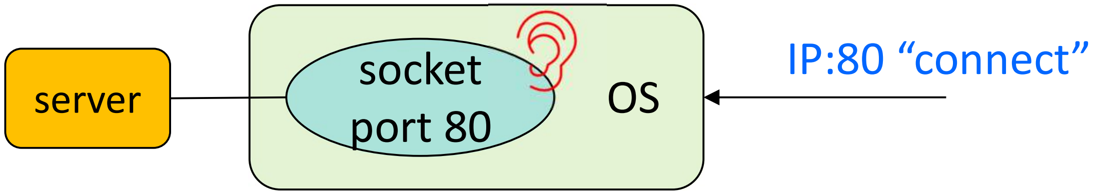
3. Server invokes listen()

4. Server thread blocks on accept()



Server Socket Setup

5. Client connects



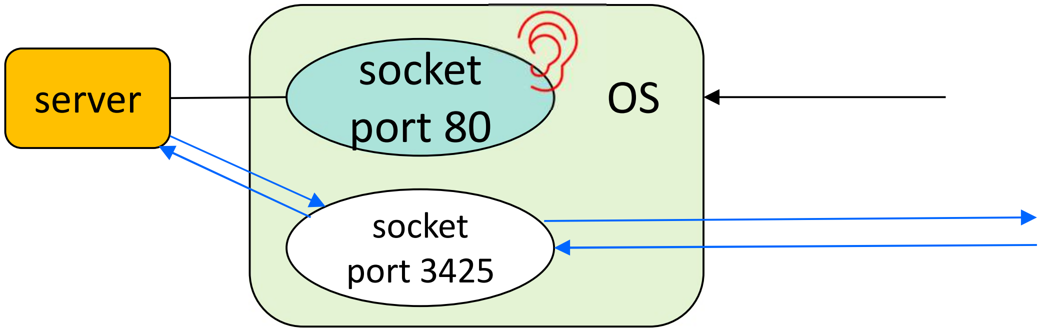
server

socket
port 80

OS

IP:80 “connect”

6. OS creates new socket, connects remote client streams to it, and returns it (from accept())



server

socket
port 80

OS

socket
port 3425

7. The new socket is “connected” to the client’s socket on their machine.
Writing to the socket sends data that can be read by the client.
Reading from the socket reads data the client has sent, or blocks.

The server ends up with a distinct socket for each client connection.
More than one client can be connected at the same time.

Request / Response Application Protocol

- The applications send messages to each other
- The rules about what messages can be/must be sent, how to format them, are set by the application level protocol

- Request/Response Protocol
  - Simple two message exchange
    - Client sends a request to the server
    - Server responds with normal response or an error indication
  - *Similiar* to procedure call

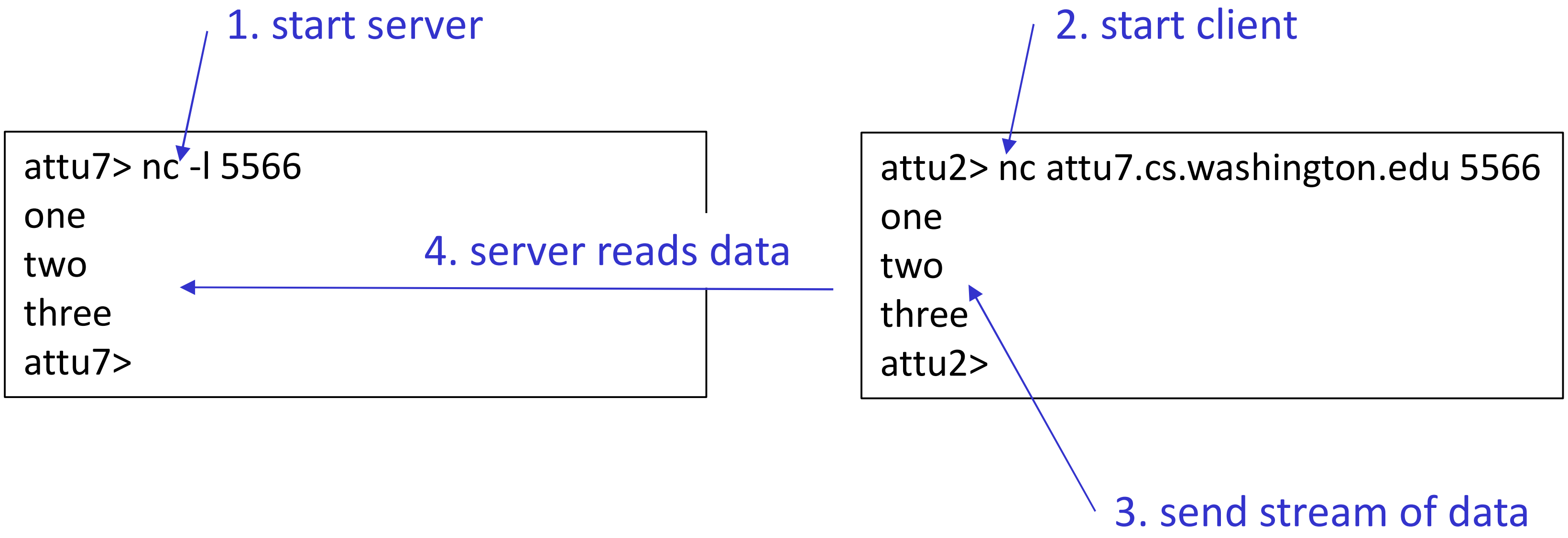
Let’s See All This in Action

- We’ll do this live, but what we’re doing is on the following slides

ifconfig: attu2

```
attu2> ifconfig
eno1: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
      inet 128.208.1.138  netmask 255.255.255.0  broadcast 128.208.1.255
      inet6 fe80::46a8:42ff:fe4a:76a8  prefixlen 64  scopeid 0x20<link>
      inet6 2607:4000:200:10::8a  prefixlen 64  scopeid 0x0<global>
      ether 44:a8:42:4a:76:a8  txqueuelen 1000  (Ethernet)
      RX packets 9787460872  bytes 11437771351898 (10.4 TiB)
      RX errors 0  dropped 41  overruns 0  frame 0
      TX packets 5065166238  bytes 3366916108204 (3.0 TiB)
      TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
      device interrupt 18

lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
      inet 127.0.0.1  netmask 255.0.0.0
      inet6 ::1  prefixlen 128  scopeid 0x10<host>
      loop  txqueuelen 1000  (Local Loopback)
      RX packets 115725209  bytes 64235696673 (59.8 GiB)
      RX errors 0  dropped 0  overruns 0  frame 0
      TX packets 115725209  bytes 64235696673 (59.8 GiB)
      TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

nc utility as client and server



1. start server

```
attu7> nc -l 5566
one
two
three
attu7>
```

2. start client

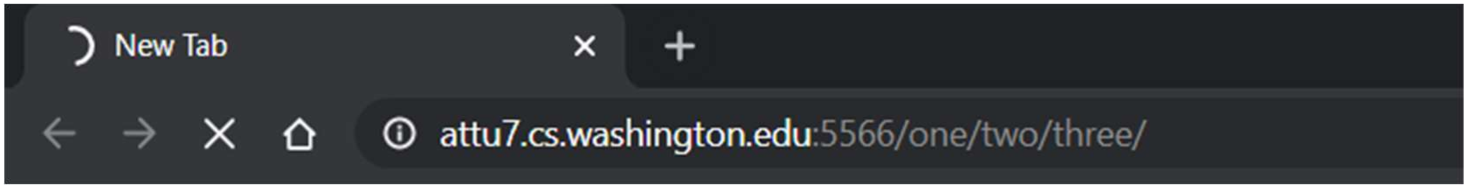
```
attu2> nc attu7.cs.washington.edu 5566
one
two
three
attu2>
```

3. send stream of data

4. server reads data

nc as server, browser as client

```
attu7> nc -l 5566
```



attu7.cs.washington.edu:5566/one/two/three/

```
GET /one/two/three/ HTTP/1.1
Host: attu7.cs.washington.edu:5566
Connection: keep-alive
DNT: 1
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like
Gecko) Chrome/88.0.4324.190 Safari/537.36
Accept:
text/html,application/xhtml+xml,application/xml;q=0.9,image/avif,image/webp,image/apng,*/*;
q=0.8,application/signed-exchange;v=b3;q=0.9
Accept-Encoding: gzip, deflate
Accept-Language: en-US,en;q=0.9

^C
attu7>
```

HTTP Protocol

Encoding: text
Framing: \r\n to end each line
empty line (\r\n\r\n) to end request

\r\n

```
GET /one/two/three/ HTTP/1.1
Host: attu7.cs.washington.edu:5566
Connection: keep-alive
DNT: 1
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36
(KHTML, like Gecko) Chrome/88.0.4324.190 Safari/537.36
Accept:
text/html,application/xhtml+xml,application/xml;q=0.9,image/avif,image/webp,imag
e/apng,*/*;q=0.8,application/signed-exchange;v=b3;q=0.9
Accept-Encoding: gzip, deflate
Accept-Language: en-US,en;q=0.9

```

\r\n\r\n

HTTP Request (Sent by Chrome)

The first line is the request line.
All following lines are key: value

```
GET /one/two/three/ HTTP/1.1
Host: attu7.cs.washington.edu:5566
Connection: keep-alive
DNT: 1
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36
(KHTML, like Gecko) Chrome/88.0.4324.190 Safari/537.36
Accept:
text/html,application/xhtml+xml,application/xml;q=0.9,image/avif,image/webp,imag
e/apng,*/*;q=0.8,application/signed-exchange;v=b3;q=0.9
Accept-Encoding: gzip, deflate
Accept-Language: en-US,en;q=0.9
```

HTTP Response (Sent by courses.cs)

```
HTTP/1.1 302 Found
Date: Sun, 28 Feb 2021 22:16:05 GMT
Server: Apache/2.4.6 (CentOS)
Expires: Wed, 01 Jan 1997 12:00:00 GMT
Cache-Control: private,no-store,no-cache,max-age=0
Location: https://courses.cs.washington.edu/courses/cse333/21wi/
Content-Length: 328
Connection: close
Content-Type: text/html; charset=iso-8859-1

<!DOCTYPE HTML PUBLIC "-//IETF//DTD HTML 2.0//EN">
<html><head>
<title>302 Found</title>
</head><body>
<h1>Found</h1>
<p>The document has moved <a
href="https://courses.cs.washington.edu/courses/cse333/21wi/">here</a>.</p>
<hr>
<address>Apache/2.4.6 (CentOS) Server at courses.cs.washington.edu Port 80</address>
</body></html>
```

HTTP response header

Empty line sentinel

HTML data

Persistent Connections

- The client can request that the server not close the TCP connection when it responds to the request
  - Because the client anticipates sending another request to the same server
- Connection: keep-alive
  - in HTTP request and response headers
- Pipelined request example:

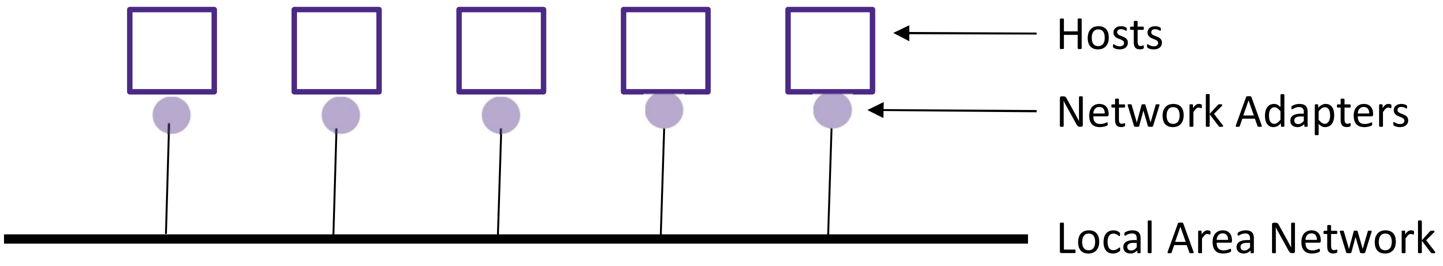
```
GET / HTTP/1.1
Host: www.cs.washington.edu:80
Connection: keep-alive

GET / HTTP/1.1
Host: www.cs.washington.edu:80
Connection: keep-alive

```

End of request sentinels

Okay, Now Some Networking Background

- This is not CSE 461...

Network Concepts: Local Area Network

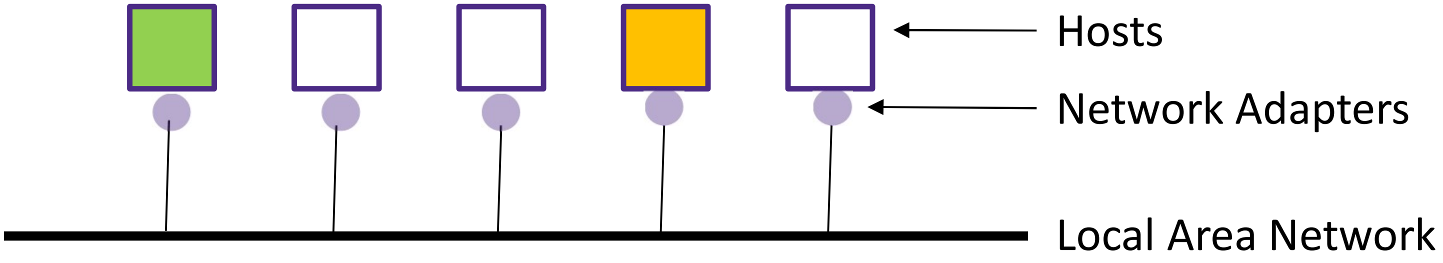


- Hosts
  - Computers, each running an OS

- Network Adapters
  - Ethernet card, Wifi card, cellular interface
  - Converts bits in memory into analog signals on the local area network when transmitting, and analog signals into bits when receiving

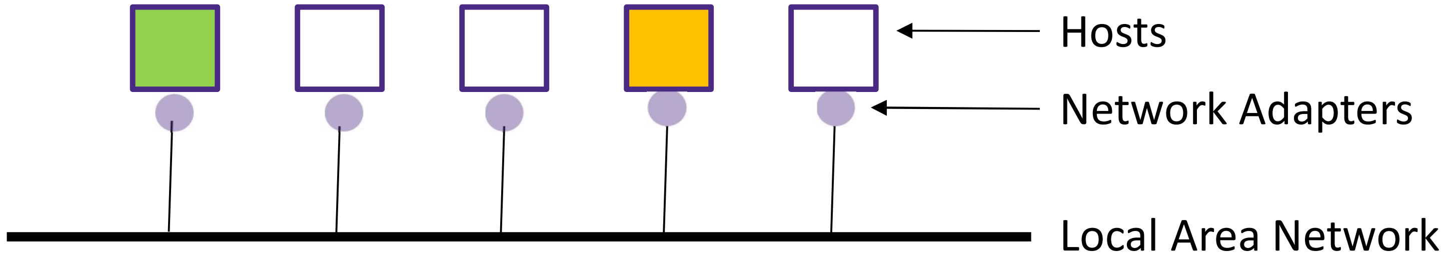
- Local Area Network
  - Wire or fiber or radio waves
  - Data sent by any the adapter of any host is received by every adapter on the local network

Network Concepts: LAN Address



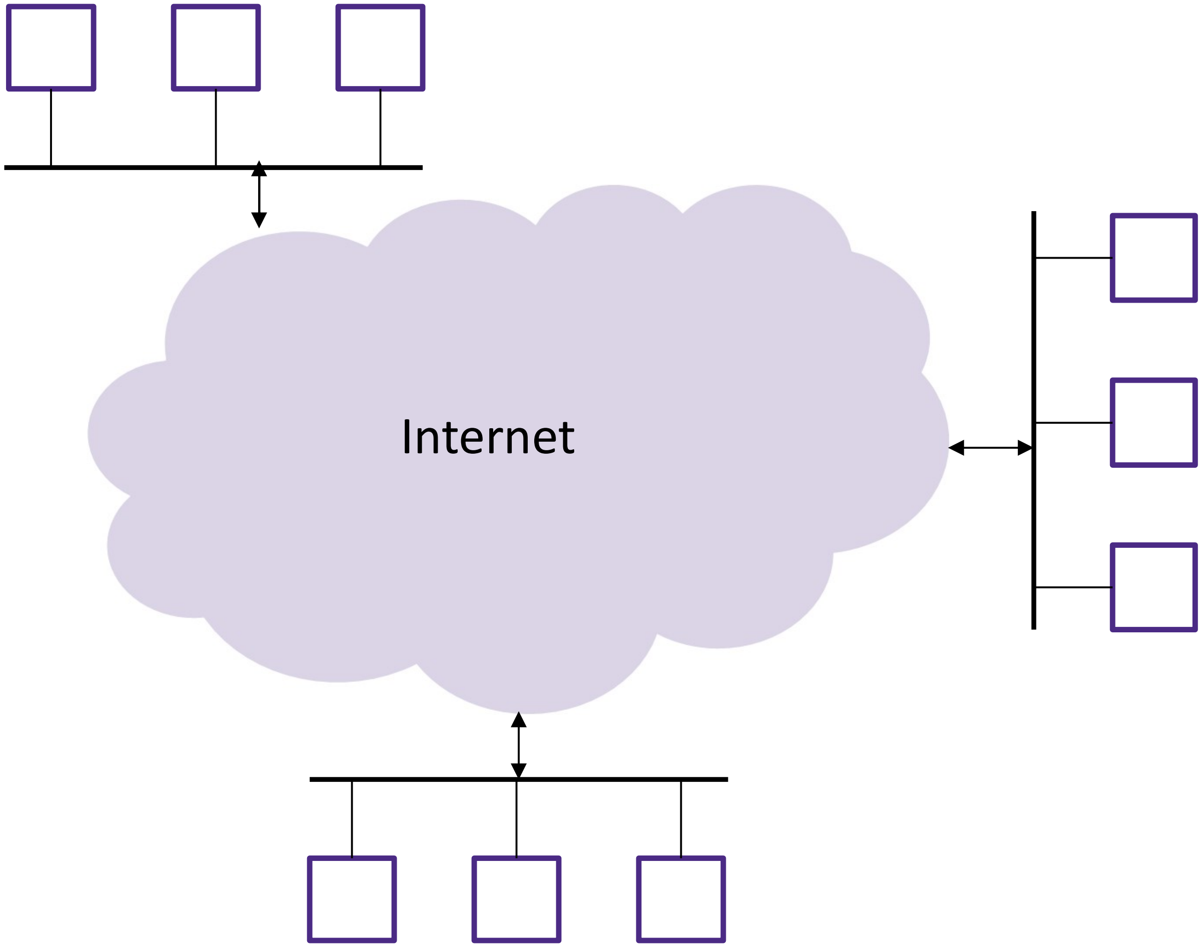
- Suppose one host wants to tell another host to power down
  - All the hosts have previously agreed that if they hear the bit pattern 0101010101010101 it represents a request to power down
- How can the green host ask only the orange host to power down?
- The bits of the message are preceded by bits representing the name of the intended recipient
  - Orange 0101010101010101
  - If you're name isn't orange, you ignore the message

Network Concepts: A Network



A LAN is sometimes referred to as "a network."

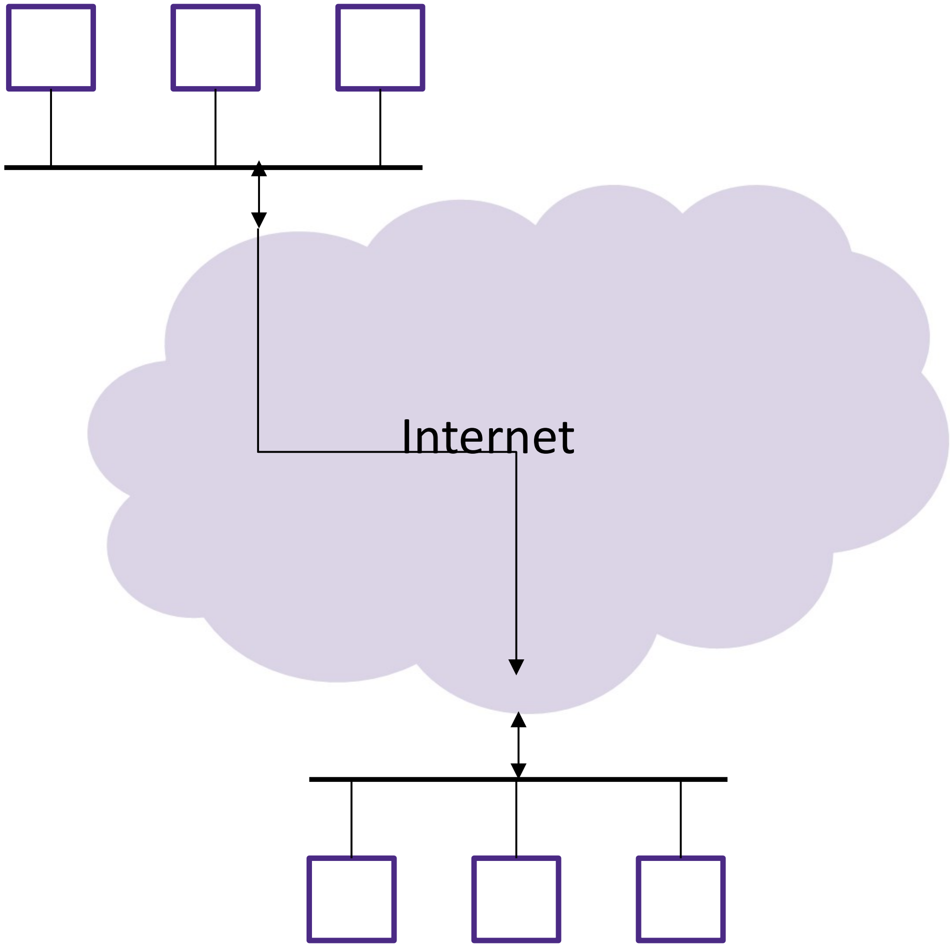
Network Concepts: Internet



Internet Data Delivery

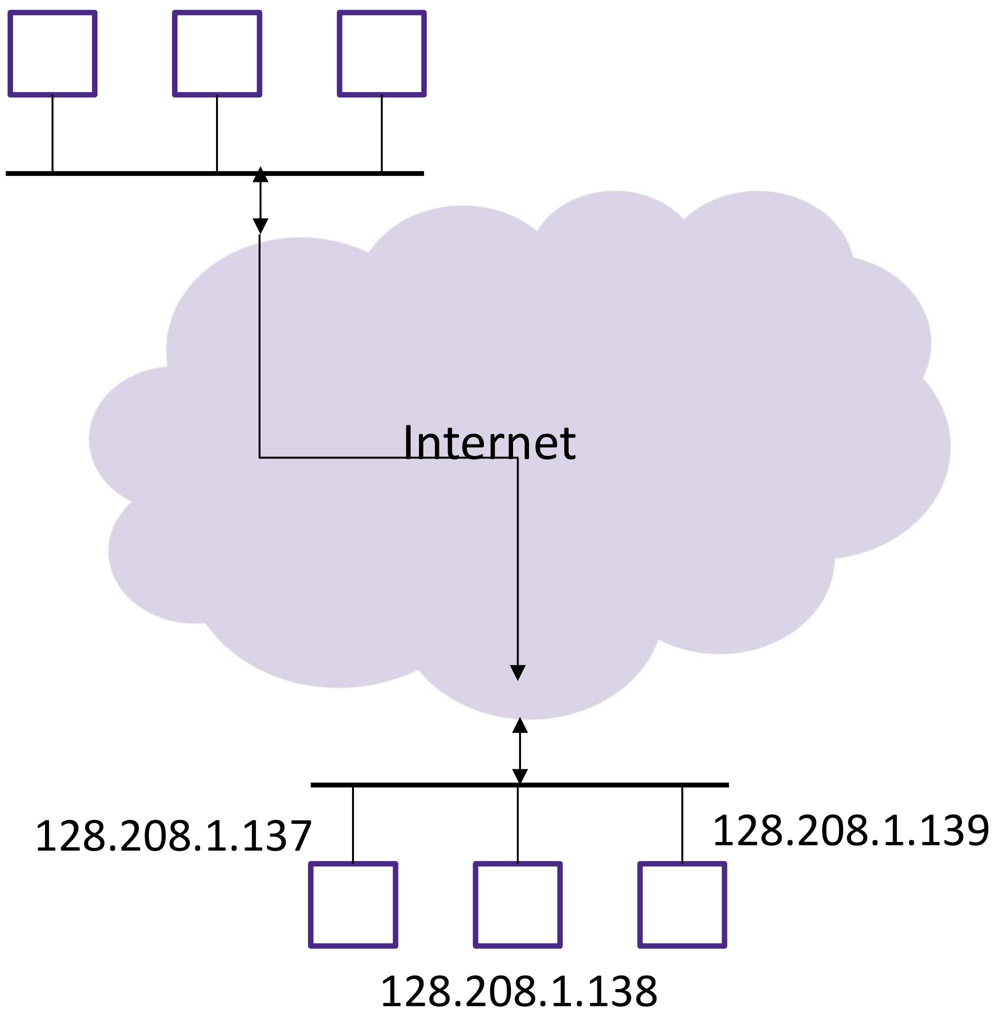
- When the sender of some data puts that data on its LAN, the receiver won’t hear it (unless it’s on the same LAN)
- The Internet is responsible for *routing* the bits from the source network to the destination network
  - From the source LAN to the LAN the receiver is on
- Two possible approaches to routing:
  1. Send every message to every LAN, thus ensuring it gets on receiver’s LAN and is heard by receiver
  2. Send it to just one LAN, the receiver’s LAN, along some directed path

Network Concepts: Internet



- Sender needs to name receiver
- MAC addresses aren’t very helpful because they’re essentially random
- Create a new namespace with the property that “similar names are in the same place”
- IP addresses

IP Addresses



- IP addresses are (usually) global in scope
- They name adapters, which means they name hosts

- IPv4 addresses are 32 bits
    - 4G names
- IPv6 addresses are 128 bits
    - ∞ names

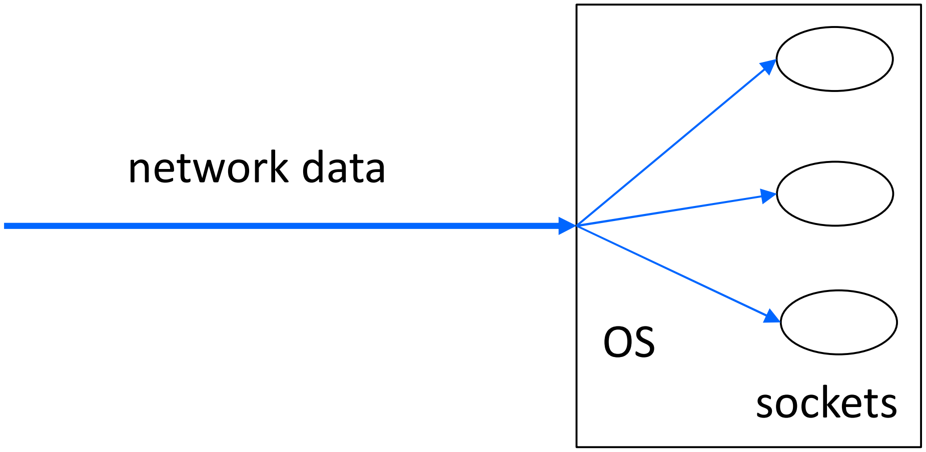
Network Connections

- IP addresses name hosts, but we want to communicate from one host to another
  - We want to communicate from an application running on one host to an application running on another host

- Ports / Sockets
  - Internet messages carry an IP address: host identifier
  - They also carry a port number (a small int)
  - The operating system maintains a map from port numbers at its IP address and running applications on its system
    - Sockets

Connections and Demultiplexing

- Demultiplexing is taking data arriving from one source and moving it forward to one of several next steps



- TCP demultiplexes using
  (TCP, source IP, source port, dest IP, dest port)
  as the key

A Bit of Context Without Context: SO_REUSEADDR

- When a TCP socket is closed, it goes into a TIMED_WAIT state
  - It is still there for a little while related to how long undelivered packets might still be "in flight"
  - By being there, it prevents a new socket from being created and binding to the same address:port
  - That prevents confusion where data sent to the now closed connection arrives late and is demultiplexed to the new socket's incoming buffer
- This can mean that when you terminate your server and then "immediately" restart it, it fails
  - It fails because it tries to acquire the same IP:port as it just had, and that address is being kept busy exactly so you can't acquire it again for a while 😠

A Bit of Context Without Context: SO_REUSEADDR

```
/* Set a socket option to enable re-use of the port number as
   soon as the server exits. ("man setsockopt“ and “man 7 socket”) */

int optval = 1;
if ( setsockopt(listen_sock_fd_, SOL_SOCKET, SO_REUSEADDR, &optval, sizeof(optval))
{
   perror(“setsockpt(SO_REUSEADDR) failed”);
   exit(1);
}
```

Next…

- What's wrong with this pseudo-code?

  -
    ```
    server_sock = createServerSock();
    while(1)
    {
        client_sock = server_sock.accept();
        while (  request = read_request(client_sock) )
         {
             process_request(request);
          }
    }
    ```