CS168: Discussion 1

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Intro to the Internet
Fall 2022

Agenda

- Introductions
- Terms
- Poking the Internet

Light discussion today

Introductions

About Me

I'm a X{th,nd,rd} year PhD student studying Networking and Systems with Scott Shenker and Sylvia Ratnasamy.

I'm from <origin>. I like <hobby1>, <hobby2>, and <hobby3>.

My office hours: Monday 10pm-11pm in Soda Hall 341B.
My email: gobears@berkeley.edu (Edstem is faster though)

About You

Show of hands survey

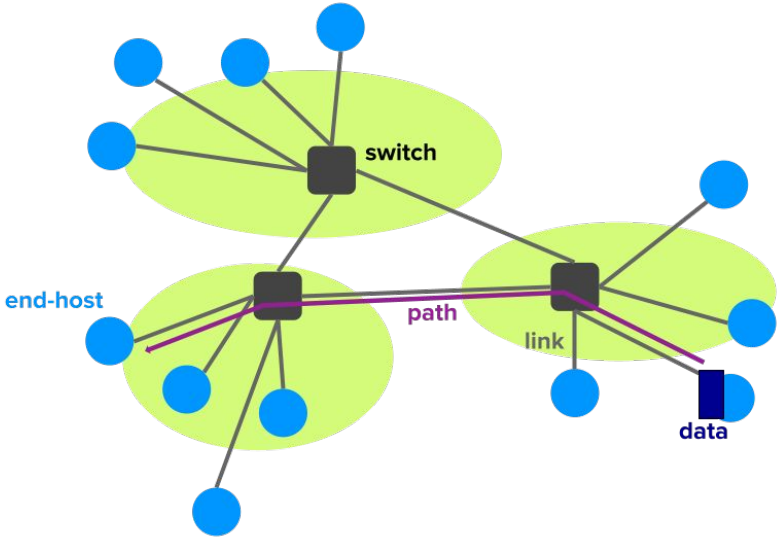
- Major?
- Year?
- Where you're from?
- Why you're taking this class?

Questions from Lecture

Terms

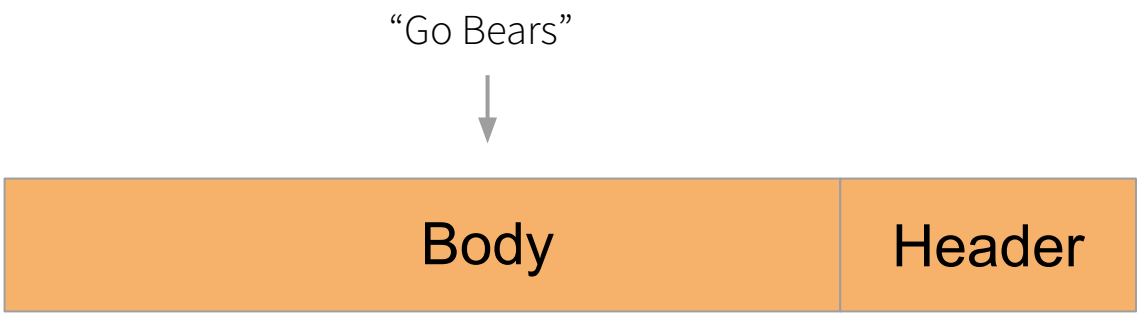
Terms

- **Routers/Switches:** Devices that forward packets arriving on one link to another link. We make no distinction between routers/switches at this point
- **End-host:** a device attached to the network that sends or receives packets.
  - Examples: mobile phone, laptop, security camera, smart fridge



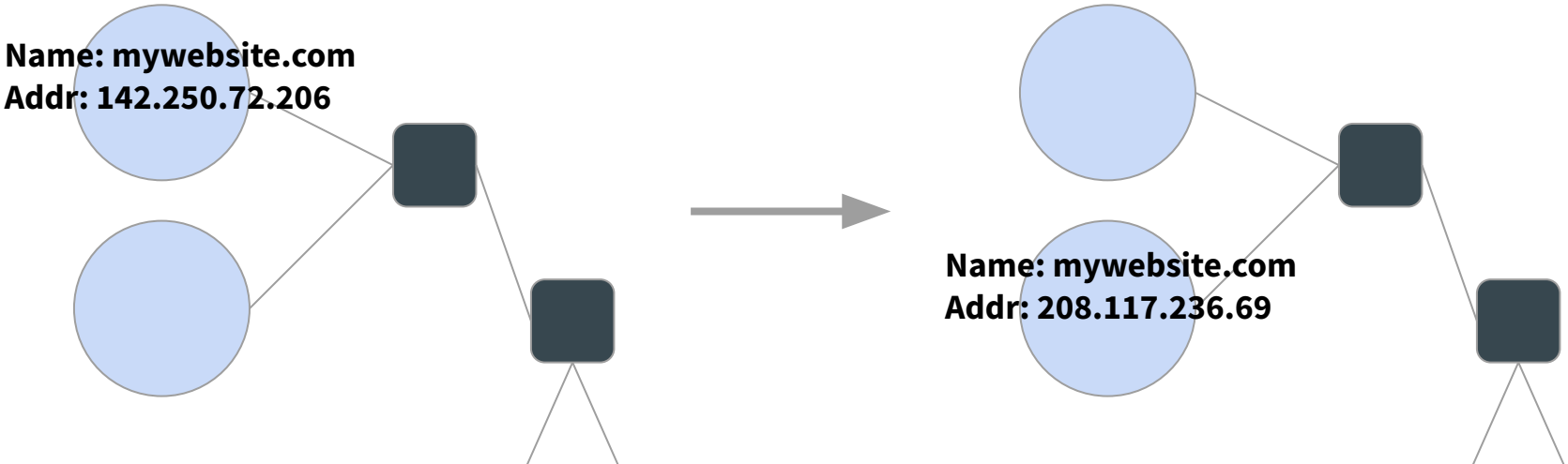
Terms

- **Packets:** A Bags of bits with a
  - *Header*-- info for network and network stack to make decisions
  - *Body*-- contains a payload. Ex. A file, image, an application header
    - The network doesn't really care about what's in the payload.



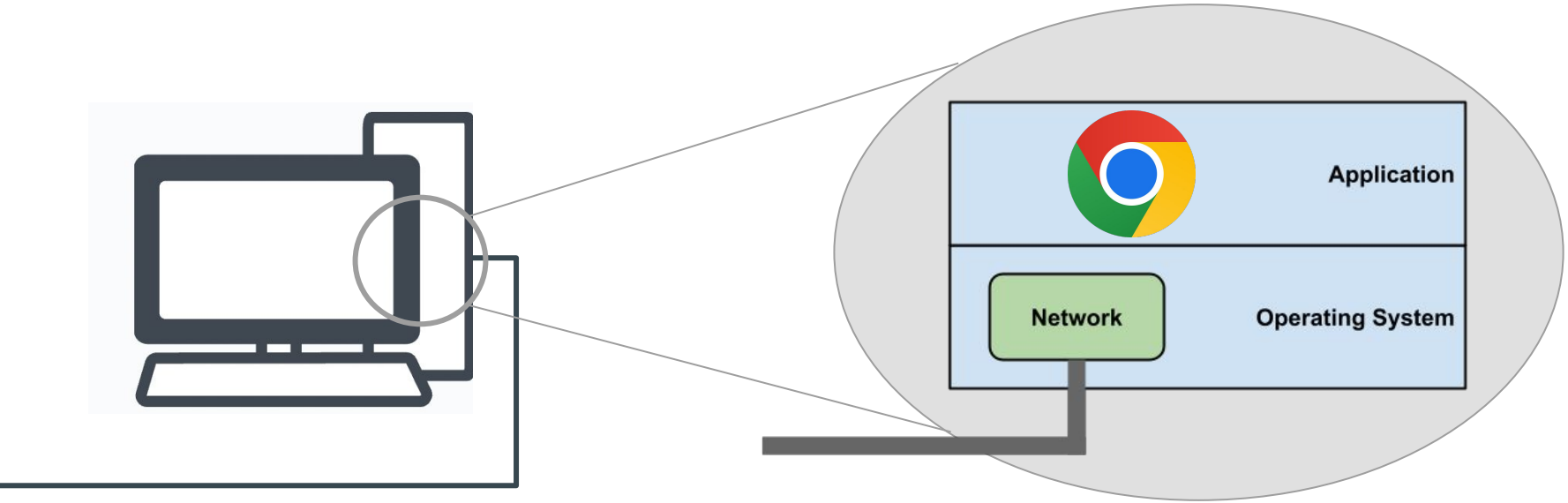
Terms

- **Naming:**
  - Network name: which host it is
  - Network address: where host is located
  - When you move a server to a new building, its name does not change but its address does



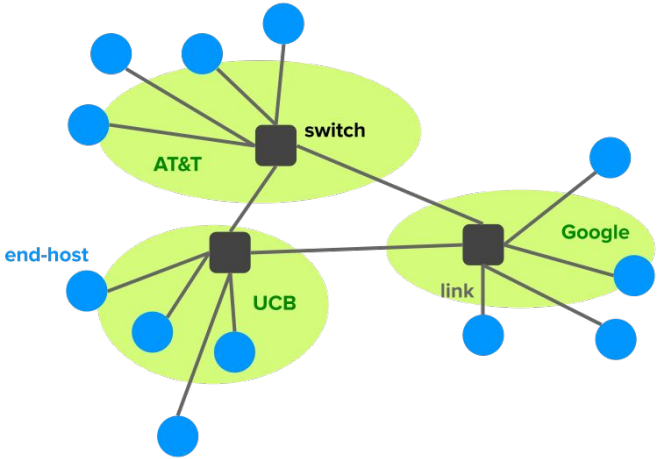
Terms

- **Network “Stack”:** Networking SW on host.
  - Replicates some router/switch functionality and adds some additional functionality before passing the body of packets to the application



Terms (cont'd)

- **ISP (Internet Service Provider):** A network of packet switches and links that provide network access (i.e. Comcast, ATT, Sonic)
- **ASes (Autonomous Systems):** Groups of routers under the same control
  - Usually each ISP has one AS, but may have multiple ASes
  - Routers within the same AS will have information about each other



Poking the Internet

Ping, Traceroute, Dig

- Internet is large and complex. Network engineers and researchers have built some handy tools to get some insight into what is going on inside and across the internet.
- We're going to play around with them a little bit

Think of this as a "tinker discussion" - you aren't expected to know any of these concepts yet. We'll learn about them throughout the semester.

Ping, Traceroute, Dig

- Simple utility that lets you “poke” a website and see if it moves (spoiler: most do!)
- You say hi and see if the server says hi back
  - This by itself is not super interesting
- Ping also tells you how long the reply took to come back
  - This is more interesting!
- Let’s try out a few websites.

Ping, Traceroute, Dig

Predictions?

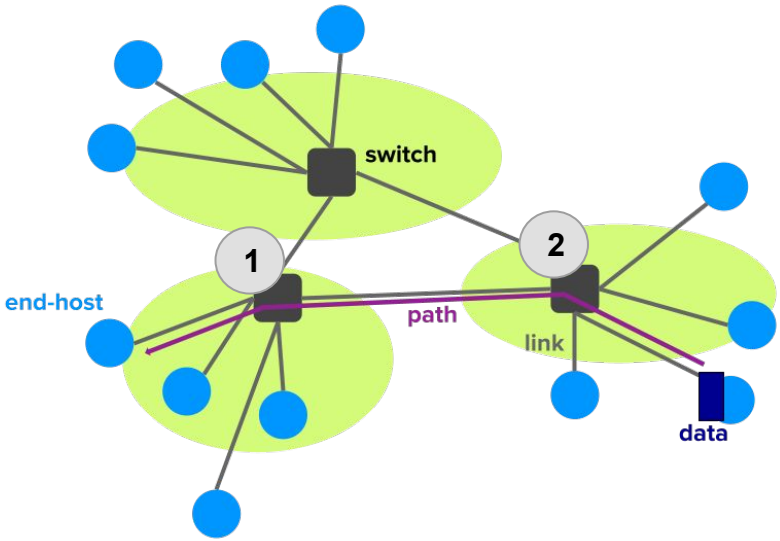
- berkeley.edu
- google.com
- ford.com (Ford, a car company headquartered in Michigan)
- csail.mit.edu (MIT's CS department)
- lmu.de (University of Munich)
- unam.edu.na (University of Namibia)

Ping: A prediction

- We've pinged a couple websites and seen pretty significant differences in *latency*.
  - **Latency** is the time between when a request is sent and when the response is heard.
- What about differences in latency for the same website, but in different regions?
- We've pinged google.com and seen its latency.
  - How many times longer will it take for a ping to google.co.uk to come back?

Ping, **Traceroute**, Dig

- Tool to *trace* the *route* that packets take from your computer to the destination.
  - Specifically lets you see the routers/switches that are forwarding your packets.



Ping, **Traceroute**, Dig

Demo, pick your favorite(s):

- berkeley.edu
- google.com
- csail.mit.edu (MIT's CS department)
- ford.com (Ford, a car company headquartered in Michigan)
- lmu.de (University of Munich)
- unam.edu.na (University of Namibia)

Now let's visualize it online at geotraceroute.com

Traceroute: Notice anything?

- Traceroute gives us a lot more interesting feedback than ping.
  - Latency to *every* step along the way.
    - Can see a breakdown of latencies!
  - Router names.
    - Often have locations in them (i.e. city name)
    - Can roughly trace packet path on a map!
  - Weird stars
    - Some routers just don't respond ¯_(ツ)_/¯

Ping, Traceroute, Dig, **Netstat**

- This shows active connections and listening ports
- Proto is the connection type (TCP/UDP), we'll return to this in a few months
- Format for Local & Foreign Addresses:
  - IP-Address : Port Number
  - We'll learn a lot more about ports/sockets in a few minutes

Ping, Traceroute, **Dig**

- When humans want to go to a website, we think in terms of names
  - i.e. google.com
- The internet does not think this way, it thinks in terms of *addresses*
  - i.e. “1.2.3.4”
- It’s like the postal service
  - You wouldn’t just write “To: Alice” on a letter
  - You would look up Alice’s address in some directory
    - Then mail the letter to her address
- Dig lets you lookup the address of a website by its name
  - Command line interface to the Domain Name Service (DNS)

Ping, Traceroute, **Dig**

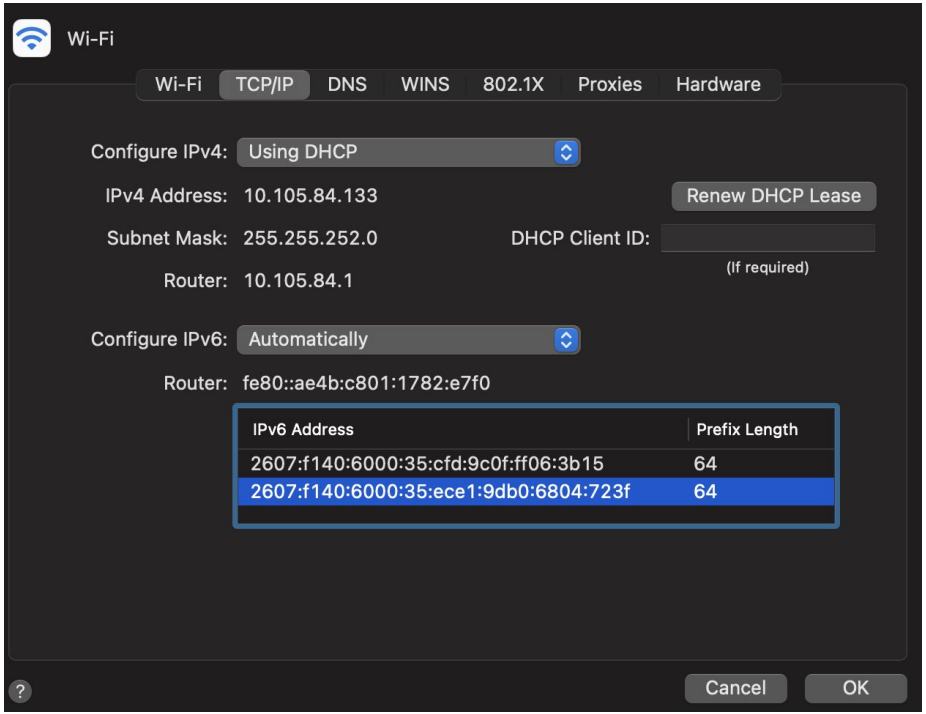
Demo

- berkeley.edu
- google.com
- csail.mit.edu (MIT's CS department)
- ford.com (Ford, a car company headquartered in Michigan)
- lmu.de (University of Munich)
- unam.edu.na (University of Namibia)

(optionally see approximate physical location at https://www.iplocation.net/)

Bonus: What's your IP Address?

On a Mac, go to System Preferences -> Network -> Advanced -> TCP/IP:



Optional Slides

Emergency Screenshots

```
C:\Users>ping berkeley.edu

Pinging berkeley.edu [35.163.72.93] with 32 bytes of data:
Reply from 35.163.72.93: bytes=32 time=36ms TTL=43
Reply from 35.163.72.93: bytes=32 time=34ms TTL=43
Reply from 35.163.72.93: bytes=32 time=33ms TTL=43
Reply from 35.163.72.93: bytes=32 time=41ms TTL=43

Ping statistics for 35.163.72.93:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 33ms, Maximum = 41ms, Average = 36ms
```

```
C:\Users>ping google.com -4

Pinging google.com [216.58.194.174] with 32 bytes of data:
Reply from 216.58.194.174: bytes=32 time=15ms TTL=53
Reply from 216.58.194.174: bytes=32 time=15ms TTL=53
Reply from 216.58.194.174: bytes=32 time=16ms TTL=53
Reply from 216.58.194.174: bytes=32 time=18ms TTL=53

Ping statistics for 216.58.194.174:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 15ms, Maximum = 18ms, Average = 16ms
```

```
C:\Users>ping microsoft.com -4

Pinging microsoft.com [104.43.195.251] with 32 bytes of data:
Request timed out.
Request timed out.
Request timed out.
Request timed out.

Ping statistics for 104.43.195.251:
    Packets: Sent = 4, Received = 0, Lost = 4 (100% loss),
```

```
C:\Users>ping zu.ac.tz

Pinging zu.ac.tz [41.204.148.21] with 32 bytes of data:
Reply from 41.204.148.21: bytes=32 time=294ms TTL=40
Reply from 41.204.148.21: bytes=32 time=374ms TTL=40
Reply from 41.204.148.21: bytes=32 time=292ms TTL=40
Reply from 41.204.148.21: bytes=32 time=294ms TTL=40

Ping statistics for 41.204.148.21:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 292ms, Maximum = 374ms, Average = 313ms
```

```
Pinging google.co.uk [216.58.194.163] with 32 bytes of data:
Reply from 216.58.194.163: bytes=32 time=16ms TTL=53
Reply from 216.58.194.163: bytes=32 time=14ms TTL=53
Reply from 216.58.194.163: bytes=32 time=32ms TTL=53
Reply from 216.58.194.163: bytes=32 time=23ms TTL=53

Ping statistics for 216.58.194.163:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 14ms, Maximum = 32ms, Average = 21ms
```

```
Tracing route to berkeley.edu [35.163.72.93]
over a maximum of 30 hops:

  1    24 ms    23 ms    21 ms  vlan715.inr-340-mulcev.berkeley.edu [136.152.208.1]
  2    63 ms    20 ms    19 ms  128.32.0.108
  3    46 ms    17 ms    17 ms  xe-0-2-0.inr-001-sut.berkeley.edu [128.32.0.64]
  4    16 ms    18 ms    16 ms  xe-4-0-0.inr-002-reccev.berkeley.edu [128.32.0.69]
  5    34 ms    18 ms    18 ms  oak-agg4--ucb-10g.cenic.net [137.164.50.30]
  6    30 ms   101 ms    25 ms  52.95.217.222
  7    28 ms    27 ms    21 ms  54.240.243.150
  8    17 ms    17 ms    18 ms  54.240.243.157
  9     *        *        *     Request timed out.
 10   151 ms    43 ms    37 ms  205.251.232.116
 11     *        *        *     Request timed out.
 12    59 ms    87 ms    48 ms  52.93.12.152
 13    43 ms    50 ms    43 ms  52.93.12.147
 14   103 ms   149 ms    66 ms  52.93.12.218
 15   175 ms    37 ms    40 ms  52.93.12.243
 16    43 ms    53 ms    45 ms  52.93.240.21
 17     *        *        *     Request timed out.
 18     *        *        *     Request timed out.
 19     *        *        *     Request timed out.
 20     *        *        *     Request timed out.
 21     *        *        *     Request timed out.
 22    40 ms    38 ms    40 ms  ec2-35-163-72-93.us-west-2.compute.amazonaws.com [35.163.72.93]

Trace complete.
```

```
C:\Users>tracert eecs.berkeley.edu

Tracing route to eecs.berkeley.edu [23.185.0.1]
over a maximum of 30 hops:

  1    21 ms    18 ms    16 ms  vlan715.inr-340-mulcev.berkeley.edu [136.152.208.1]
  2    94 ms    22 ms    16 ms  128.32.0.108
  3   120 ms    97 ms    16 ms  xe-0-2-0.inr-001-sut.berkeley.edu [128.32.0.64]
  4    31 ms    20 ms    19 ms  xe-4-0-0.inr-002-reccev.berkeley.edu [128.32.0.69]
  5    24 ms    16 ms    17 ms  oak-agg4--ucb-10g.cenic.net [137.164.50.30]
  6    17 ms    20 ms    22 ms  dc-paix-px1--oak-agg4-10ge.cenic.net [137.164.47.174]
  7    26 ms    17 ms    17 ms  eqix-sv8.fastly.com [198.32.176.230]
  8    19 ms    93 ms   115 ms  23.185.0.1

Trace complete.
```

```
C:\Users>tracert zu.ac.tz

Tracing route to zu.ac.tz [41.204.148.21]
over a maximum of 30 hops:

  1    93 ms    21 ms    88 ms  vlan715.inr-340-mulcev.berkeley.edu [136.152.208.1]
  2    25 ms    24 ms   108 ms  128.32.0.108
  3    44 ms    42 ms    15 ms  xe-0-2-0.inr-001-sut.berkeley.edu [128.32.0.64]
  4    17 ms    27 ms    19 ms  xe-4-0-0.inr-002-reccev.berkeley.edu [128.32.0.69]
  5    18 ms    22 ms    21 ms  oak-agg4--ucb-10g.cenic.net [137.164.50.30]
  6    28 ms    18 ms    17 ms  svl-agg4--oak-agg4-100ge-#2.cenic.net [137.164.46.166]
  7   151 ms    28 ms    20 ms  dc-svl-agg8--svl-agg4-100ge-#1.cenic.net [137.164.11.29]
  8    62 ms    29 ms    25 ms  dc-lax-agg8--svl-agg8--100ge--#2.cenic.net [137.164.11.20]
  9    64 ms    26 ms    30 ms  dc-lax-agg6--lax-agg8-100ge-#1.cenic.net [137.164.11.26]
 10    89 ms   101 ms    88 ms  198.32.251.86
 11   114 ms    95 ms   129 ms  100ge12-1.core1.ash1.he.net [184.105.80.201]
 12    87 ms    82 ms    84 ms  100ge5-1.core2.ash1.he.net [72.52.92.226]
 13   121 ms   161 ms    87 ms  100ge8-1.core1.nyc5.he.net [184.105.81.149]
 14   101 ms    90 ms   148 ms  100ge4-2.core1.nyc4.he.net [184.105.213.217]
 15   208 ms   152 ms   159 ms  100ge16-2.core1.lon2.he.net [72.52.92.165]
 16   156 ms   248 ms   275 ms  100ge4-1.core1.lon3.he.net [184.105.64.238]
 17   218 ms   151 ms   186 ms  wiocc-as37662.10gigabitethernet5-3.core1.lon3.he.net [216.66.85.46]
 18   293 ms   322 ms   286 ms  154.66.246.5
 19   303 ms   317 ms   285 ms  41.204.128.210
 20   348 ms     *      364 ms  41.204.148.5
 21   302 ms   301 ms   310 ms  41.204.148.21

Trace complete.
```

```
C:\Users>tracert microsoft.com

Tracing route to microsoft.com [23.100.122.175]
over a maximum of 30 hops:

  1    17 ms    21 ms    16 ms  vlan715.inr-340-mulcev.berkeley.edu [136.152.208.1]
  2    19 ms    16 ms    24 ms  128.32.0.108
  3    18 ms    19 ms    17 ms  xe-0-2-0.inr-001-sut.berkeley.edu [128.32.0.64]
  4    81 ms    16 ms    22 ms  xe-4-0-0.inr-002-reccev.berkeley.edu [128.32.0.69]
  5    31 ms    31 ms    22 ms  oak-agg4--ucb-10g.cenic.net [137.164.50.30]
  6    20 ms    30 ms    27 ms  ae11-0.pao-96cbe-1a.ntwk.msn.net [207.46.219.69]
  7    54 ms   112 ms    54 ms  be-89-0.ibr01.by2.ntwk.msn.net [104.44.9.195]
  8   112 ms    55 ms    51 ms  be-4-0.ibr01.lax03.ntwk.msn.net [104.44.4.2]
  9    54 ms    53 ms    55 ms  be-1-0.ibr02.lax03.ntwk.msn.net [104.44.4.1]
 10    56 ms    59 ms    51 ms  be-3-0.ibr01.sn4.ntwk.msn.net [104.44.4.5]
 11    81 ms    50 ms    53 ms  ae61-0.sn4-96cbe-1a.ntwk.msn.net [104.44.9.69]
 12     *        *        *     Request timed out.
 13     *        *        *     Request timed out.
 14     *        *        *     Request timed out.
 15     *        *        *     Request timed out.
 16     *        *        *     Request timed out.
 17     *        *        *     Request timed out.
 18     *        *        *     Request timed out.
 19     *        *        *     Request timed out.
 20     *        *        *     Request timed out.
 21     *        *        *     Request timed out.
 22     *        *        *     Request timed out.
 23     *        *        *     Request timed out.
 24     *        *        *     Request timed out.
 25     *        *        *     Request timed out.
 26     *        *        *     Request timed out.
 27     *        *        *     Request timed out.
 28     *        *        *     Request timed out.
 29     *        *        *     Request timed out.
 30     *        *        *     Request timed out.

Trace complete.
```

```
C:\Users>tracert google.com

Tracing route to google.com [172.217.164.110]
over a maximum of 30 hops:

  1    16 ms    15 ms    22 ms  vlan715.inr-340-mulcev.berkeley.edu [136.152.208.1]
  2   248 ms   102 ms    16 ms  128.32.0.110
  3    37 ms    23 ms    16 ms  xe-5-2-0.inr-001-sut.berkeley.edu [128.32.0.66]
  4    21 ms    17 ms    16 ms  xe-4-0-0.inr-002-reccev.berkeley.edu [128.32.0.69]
  5    18 ms    17 ms    23 ms  oak-agg4--ucb-10g.cenic.net [137.164.50.30]
  6    73 ms    19 ms    20 ms  74.125.48.172
  7    22 ms    24 ms    26 ms  108.170.243.1
  8    37 ms    18 ms    96 ms  209.85.252.251
  9    74 ms    27 ms    19 ms  sfo03s18-in-f14.1e100.net [172.217.164.110]

Trace complete.
```

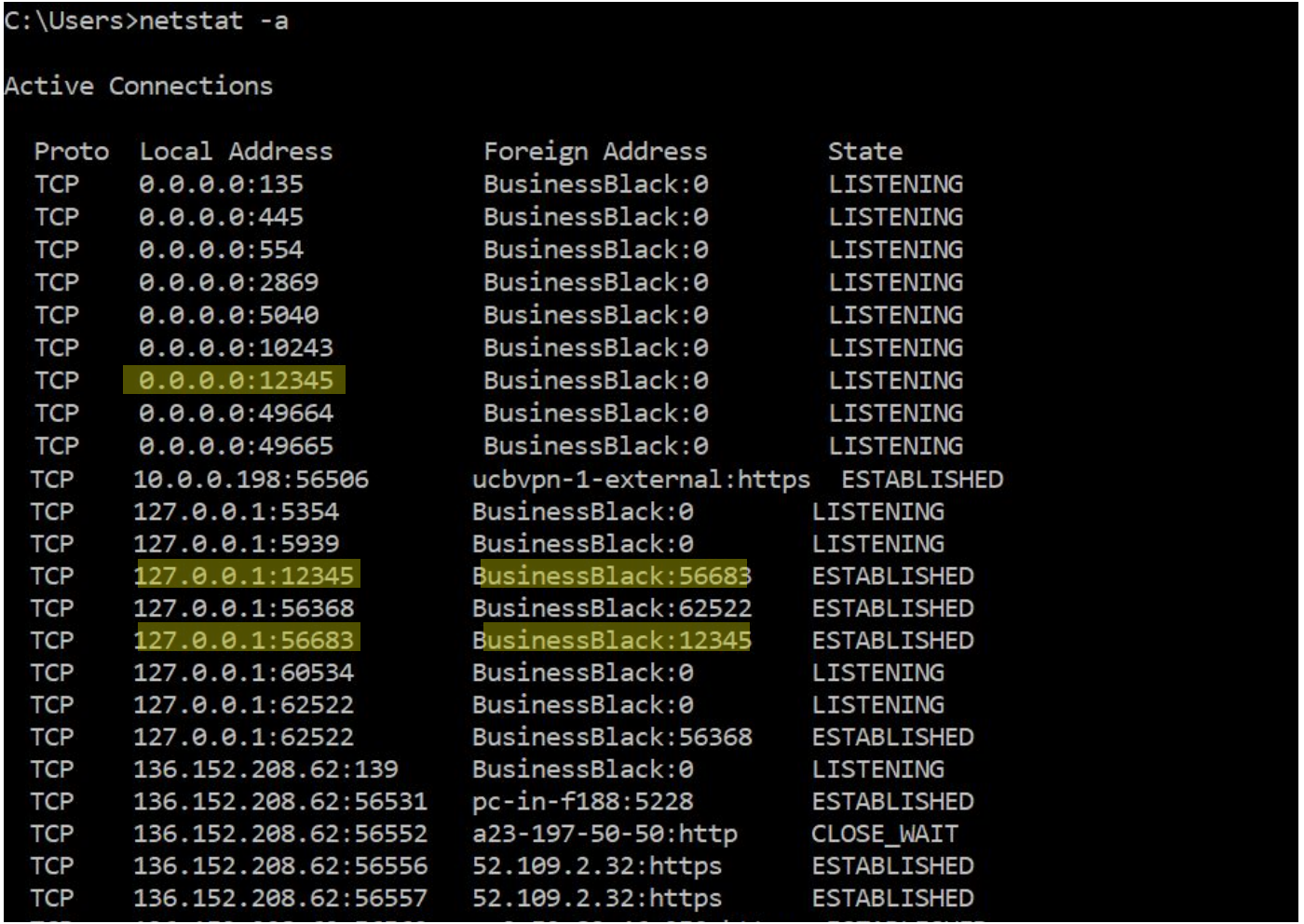
```
C:\Users>tracert google.co.uk

Tracing route to google.co.uk [172.217.164.99]
over a maximum of 30 hops:

  1    37 ms    21 ms    17 ms  vlan715.inr-340-mulcev.berkeley.edu [136.152.208.1]
  2    19 ms    80 ms    17 ms  128.32.0.108
  3    18 ms    16 ms    20 ms  xe-0-2-0.inr-001-sut.berkeley.edu [128.32.0.64]
  4    20 ms    16 ms    17 ms  xe-4-0-0.inr-002-reccev.berkeley.edu [128.32.0.69]
  5   273 ms    18 ms    21 ms  oak-agg4--ucb-10g.cenic.net [137.164.50.30]
  6    21 ms   102 ms    21 ms  74.125.48.172
  7   205 ms    17 ms    19 ms  108.170.242.225
  8    20 ms    21 ms    19 ms  74.125.252.151
  9    21 ms    18 ms    37 ms  sfo03s18-in-f3.1e100.net [172.217.164.99]

Trace complete.
```

```
; <<>> DiG 9.9.5-3ubuntu0.16-Ubuntu <<>> google.com
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 17378
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 4, ADDITIONAL: 9

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;google.com.                    IN      A

;; ANSWER SECTION:
google.com.             126     IN      A       216.58.192.14

;; AUTHORITY SECTION:
google.com.             16056   IN      NS      ns4.google.com.
google.com.             16056   IN      NS      ns1.google.com.
google.com.             16056   IN      NS      ns3.google.com.
google.com.             16056   IN      NS      ns2.google.com.

;; ADDITIONAL SECTION:
ns4.google.com.         199577  IN      A       216.239.38.10
ns4.google.com.         273833  IN      AAAA    2001:4860:4802:38::a
ns3.google.com.         199577  IN      A       216.239.36.10
ns3.google.com.         201786  IN      AAAA    2001:4860:4802:36::a
ns2.google.com.         199577  IN      A       216.239.34.10
ns2.google.com.         215263  IN      AAAA    2001:4860:4802:34::a
ns1.google.com.         199577  IN      A       216.239.32.10
ns1.google.com.         213855  IN      AAAA    2001:4860:4802:32::a

;; Query time: 58 msec
;; SERVER: 128.32.136.12#53(128.32.136.12)
;; WHEN: Tue Aug 28 21:49:22 DST 2018
;; MSG SIZE  rcvd: 303
```

```
; <<>> DiG 9.9.5-3ubuntu0.16-Ubuntu <<>> microsoft.com
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 18711
;; flags: qr rd ra; QUERY: 1, ANSWER: 5, AUTHORITY: 4, ADDITIONAL: 9

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;microsoft.com.                 IN      A

;; ANSWER SECTION:
microsoft.com.          2276    IN      A       23.96.52.53
microsoft.com.          2276    IN      A       191.239.213.197
microsoft.com.          2276    IN      A       104.40.211.35
microsoft.com.          2276    IN      A       104.43.195.251
microsoft.com.          2276    IN      A       23.100.122.175

;; AUTHORITY SECTION:
microsoft.com.          16812   IN      NS      ns1.msft.net.
microsoft.com.          16812   IN      NS      ns3.msft.net.
microsoft.com.          16812   IN      NS      ns2.msft.net.
microsoft.com.          16812   IN      NS      ns4.msft.net.

;; ADDITIONAL SECTION:
ns4.msft.net.           39908   IN      A       208.76.45.53
ns4.msft.net.           63957   IN      AAAA    2620:0:37::53
ns1.msft.net.           172015  IN      A       208.84.0.53
ns1.msft.net.           172015  IN      AAAA    2620:0:30::53
ns2.msft.net.           38763   IN      A       208.84.2.53
ns2.msft.net.           63945   IN      AAAA    2620:0:32::53
ns3.msft.net.           172015  IN      A       193.221.113.53
ns3.msft.net.           44      IN      AAAA    2620:0:34::53

;; Query time: 53 msec
;; SERVER: 128.32.136.12#53(128.32.136.12)
;; WHEN: Tue Aug 28 21:50:13 DST 2018
;; MSG SIZE  rcvd: 378
```

```
ian@BusinessBlack:/mnt/c/Users$ dig zu.ac.tz

; <<>> DiG 9.9.5-3ubuntu0.16-Ubuntu <<>> zu.ac.tz
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 61357
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;zu.ac.tz.                      IN      A

;; ANSWER SECTION:
zu.ac.tz.               13630   IN      A       41.204.148.21

;; AUTHORITY SECTION:
zu.ac.tz.               17229   IN      NS      ns45.zanzibarconnect.info.
zu.ac.tz.               17229   IN      NS      ns46.zanzibarconnect.info.
zu.ac.tz.               17229   IN      NS      41.204.132.8.ac.tz.

;; ADDITIONAL SECTION:
ns45.zanzibarconnect.info. 55360 IN     A       208.109.52.149
ns46.zanzibarconnect.info. 55360 IN     A       208.109.255.1

;; Query time: 26 msec
;; SERVER: 128.32.136.12#53(128.32.136.12)
;; WHEN: Tue Aug 28 21:51:03 DST 2018
;; MSG SIZE  rcvd: 170
```

```
ian@BusinessBlack:/mnt/c/Users$ dig berkeley.edu

; <<>> DiG 9.9.5-3ubuntu0.16-Ubuntu <<>> berkeley.edu
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 28837
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 7

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;berkeley.edu.                  IN      A

;; ANSWER SECTION:
berkeley.edu.           295     IN      A       35.163.72.93

;; AUTHORITY SECTION:
berkeley.edu.           9617    IN      NS      adns3.berkeley.edu.
berkeley.edu.           9617    IN      NS      adns2.berkeley.edu.
berkeley.edu.           9617    IN      NS      adns1.berkeley.edu.

;; ADDITIONAL SECTION:
adns2.berkeley.edu.     219     IN      A       128.32.136.14
adns2.berkeley.edu.     9606    IN      AAAA    2607:f140:ffff:fffe::e
adns1.berkeley.edu.     219     IN      A       128.32.136.3
adns1.berkeley.edu.     2025    IN      AAAA    2607:f140:ffff:fffe::3
adns3.berkeley.edu.     219     IN      A       192.107.102.142
adns3.berkeley.edu.     2343    IN      AAAA    2607:f140:a000:d::abc

;; Query time: 19 msec
;; SERVER: 128.32.136.12#53(128.32.136.12)
;; WHEN: Tue Aug 28 21:51:23 DST 2018
;; MSG SIZE  rcvd: 249
```


C:\Users>netstat -a
Active Connections
Proto Local Address Foreign Address State
TCP 0.0.0.0:135 BusinessBlack:0 LISTENING
TCP 0.0.0.0:445 BusinessBlack:0 LISTENING
TCP 0.0.0.0:554 BusinessBlack:0 LISTENING
TCP 0.0.0.0:2869 BusinessBlack:0 LISTENING
TCP 0.0.0.0:5040 BusinessBlack:0 LISTENING
TCP 0.0.0.0:10243 BusinessBlack:0 LISTENING
TCP 0.0.0.0:12345 BusinessBlack:0 LISTENING
TCP 0.0.0.0:49664 BusinessBlack:0 LISTENING
TCP 0.0.0.0:49665 BusinessBlack:0 LISTENING
TCP 10.0.0.198:56506 ucbvpn-1-external:https ESTABLISHED
TCP 127.0.0.1:5354 BusinessBlack:0 LISTENING
TCP 127.0.0.1:5939 BusinessBlack:0 LISTENING
TCP 127.0.0.1:12345 BusinessBlack:56683 ESTABLISHED
TCP 127.0.0.1:56368 BusinessBlack:62522 ESTABLISHED
TCP 127.0.0.1:56683 BusinessBlack:12345 ESTABLISHED
TCP 127.0.0.1:60534 BusinessBlack:0 LISTENING
TCP 127.0.0.1:62522 BusinessBlack:0 LISTENING
TCP 127.0.0.1:62522 BusinessBlack:56368 ESTABLISHED
TCP 136.152.208.62:139 BusinessBlack:0 LISTENING
TCP 136.152.208.62:56531 pc-in-f188:5228 ESTABLISHED
TCP 136.152.208.62:56552 a23-197-50-50:http CLOSE_WAIT
TCP 136.152.208.62:56556 52.109.2.32:https ESTABLISHED
TCP 136.152.208.62:56557 52.109.2.32:https ESTABLISHED

```
TCP    136.152.208.62:56662   13.107.21.200:https    ESTABLISHED
TCP    136.152.208.62:56663   40.97.80.2:https       ESTABLISHED
TCP    136.152.208.62:56664   13.107.140.254:https   ESTABLISHED
TCP    136.152.208.62:56665   13.107.246.10:https    ESTABLISHED
TCP    136.152.208.62:56666   204.79.197.254:https   ESTABLISHED
TCP    136.152.208.62:56667   204.79.197.222:https   ESTABLISHED
TCP    136.152.208.62:56668   13.107.246.254:https   ESTABLISHED
TCP    136.152.208.62:56669   13.107.128.254:https   ESTABLISHED
TCP    136.152.208.62:56670   a184-31-160-116:https  CLOSE_WAIT
TCP    136.152.208.62:56673   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56674   a-0011:https           TIME_WAIT
TCP    136.152.208.62:56675   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56676   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56677   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56678   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56679   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56680   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56681   msnbot-157-55-109-228:https  TIME_WAIT
TCP    136.152.208.62:56682   ec2-34-200-202-18:https  ESTABLISHED
TCP    136.152.208.62:56684   52.109.2.10:https      ESTABLISHED
TCP    136.152.208.62:56685   52.109.20.5:https      ESTABLISHED
```

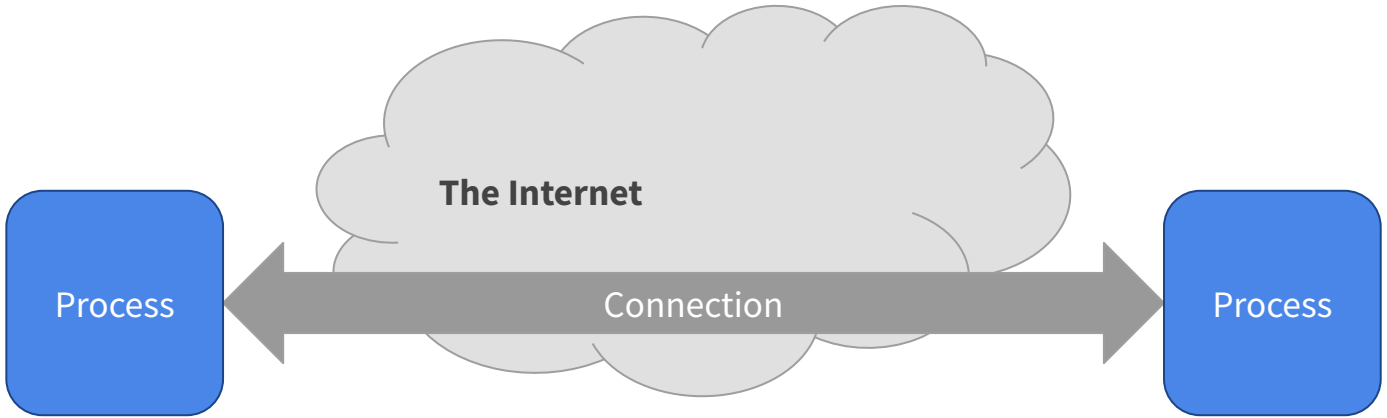
Sockets

Sockets

- The Internet's user API
- Developed here, at UC Berkeley!

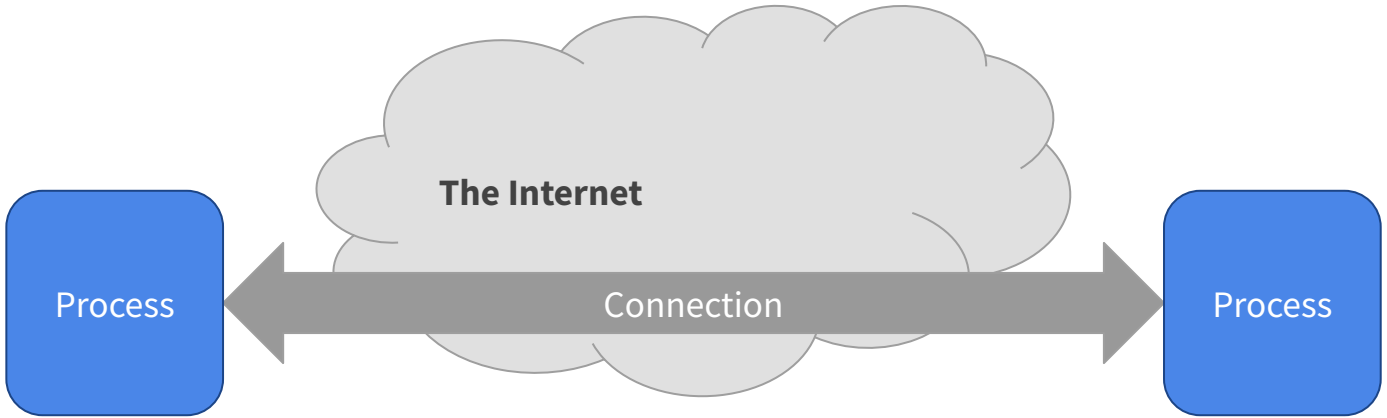
Connection (the basic abstraction)

- Think of this as a simple pipe between two processes
  - A process is just a program running on a host
- Data goes in one end, and comes out the other
- Data flows both ways!



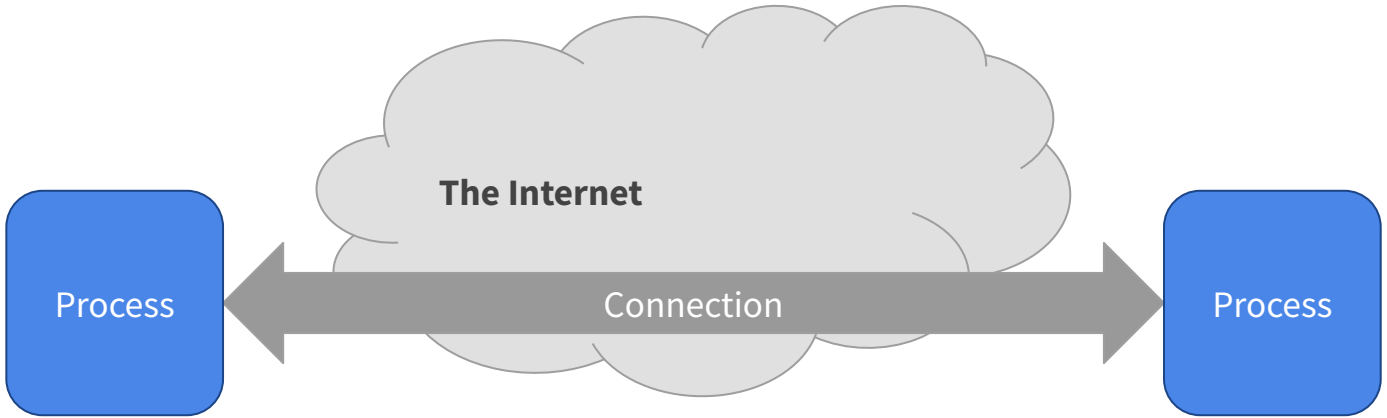
Connection (the basic abstraction)

- Data is sent simply as a stream of bits
- Reconstruction of what the bits mean done entirely at the endpoints
- Means the Internet knows nothing about what it's transmitting!



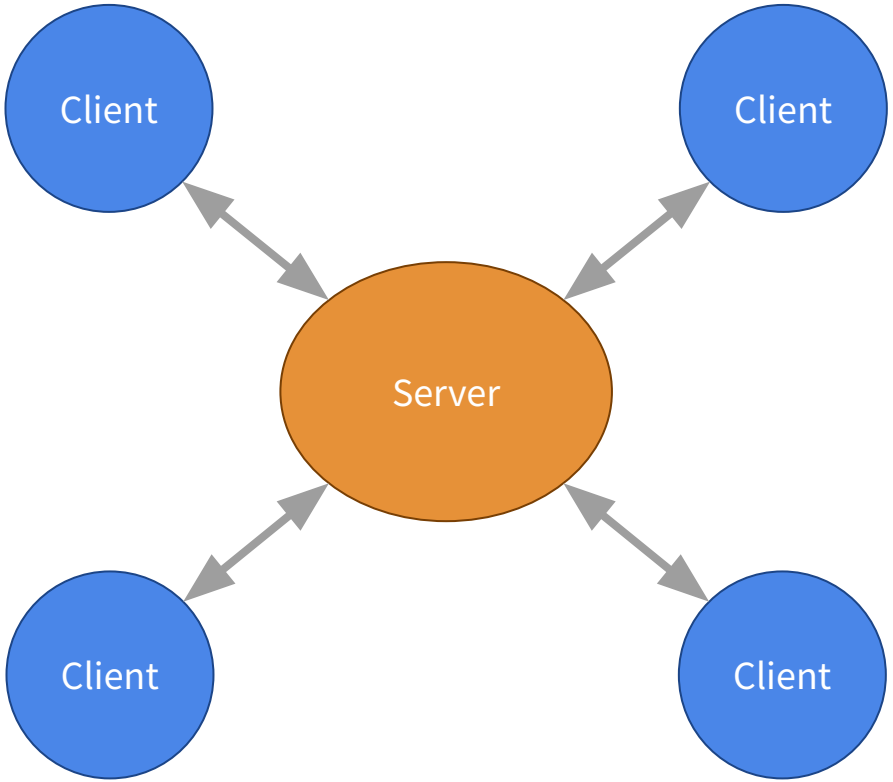
Socket API

- Establish Connection
- Sending
- Receiving



Connections

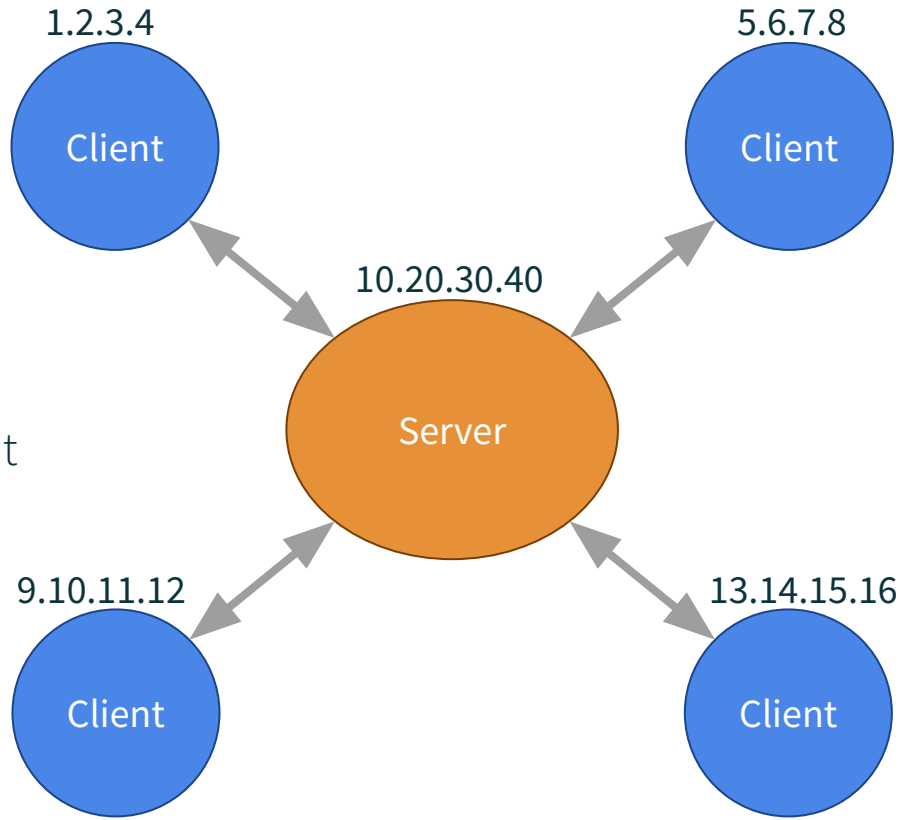
- Two types of sockets
  - Server and Client
- Servers *listen* for clients to connect to them
  - Wait until a connection is attempted
    - Accept and dispatch connection
  - Usually serving many clients at once
- Clients *initiate* new connections to servers
- Example
  - Server: berkeley.edu
  - Client: Your internet browser



Connections

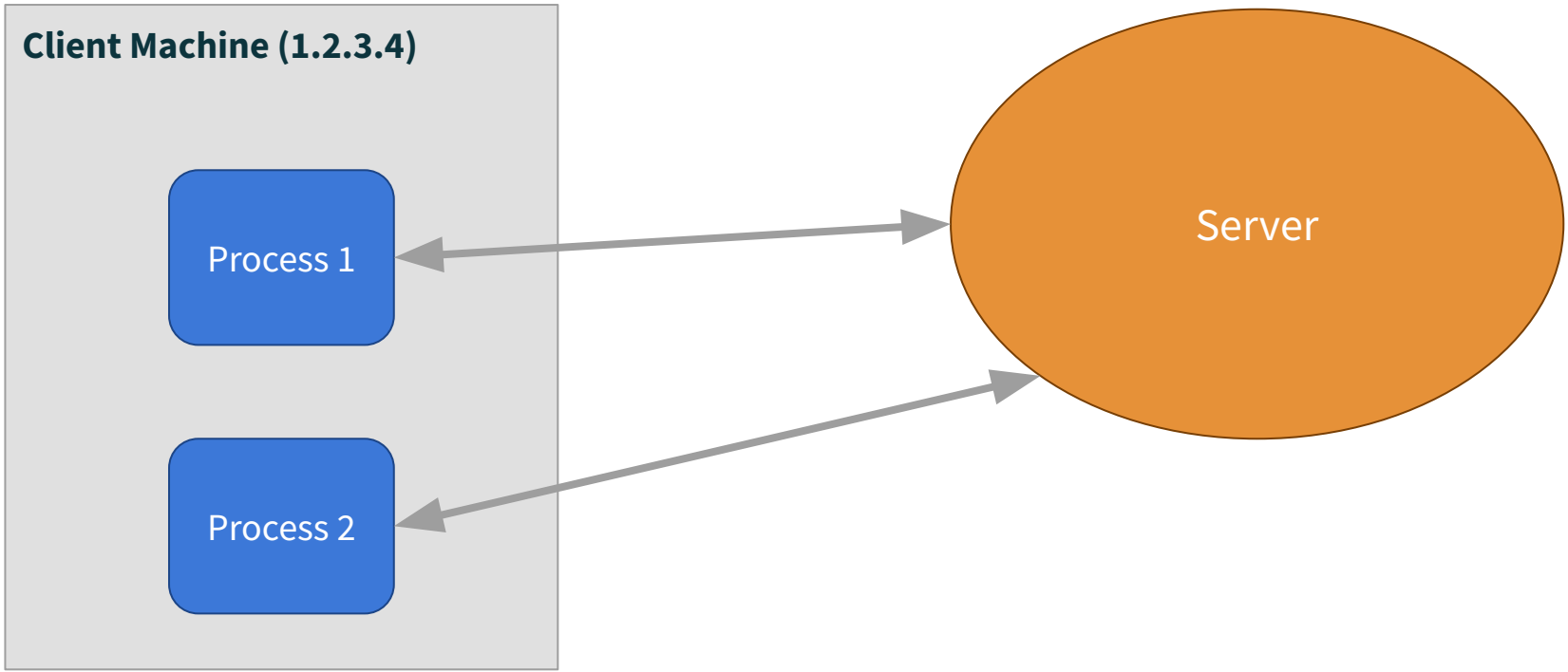
- Hosts have addresses
  - Unique identifier (just like a street address)
- Clients (different users) find servers with their addresses
  - Servers send data back with the client address
- Example addresses ➔

Are addresses enough to make this work?



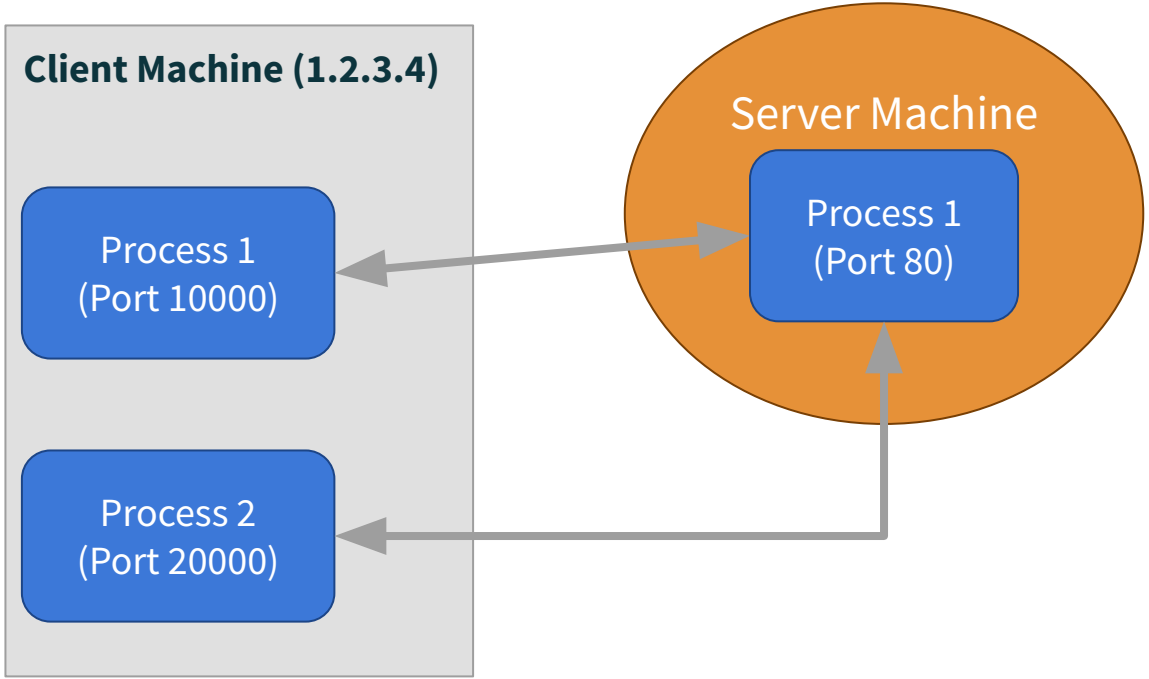
Address aren't enough

How does the client computer know which process (i.e. web browser) to deliver data to?



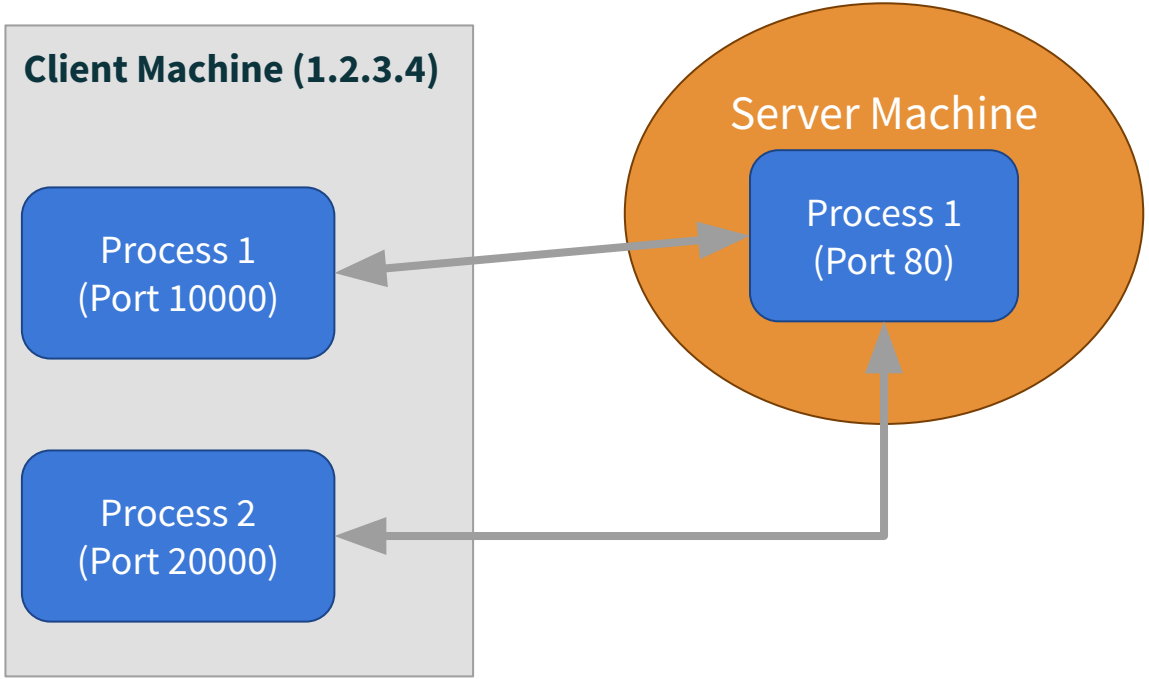
Ports

- Sockets are identified by unique IP:port pairs
- A port is a number that the OS associates with a process when it is created
  - Used in the address to tell which port socket is listening on
  - i.e. sending to address “1.2.3.4:10000” would send data to the socket owned by Process 1



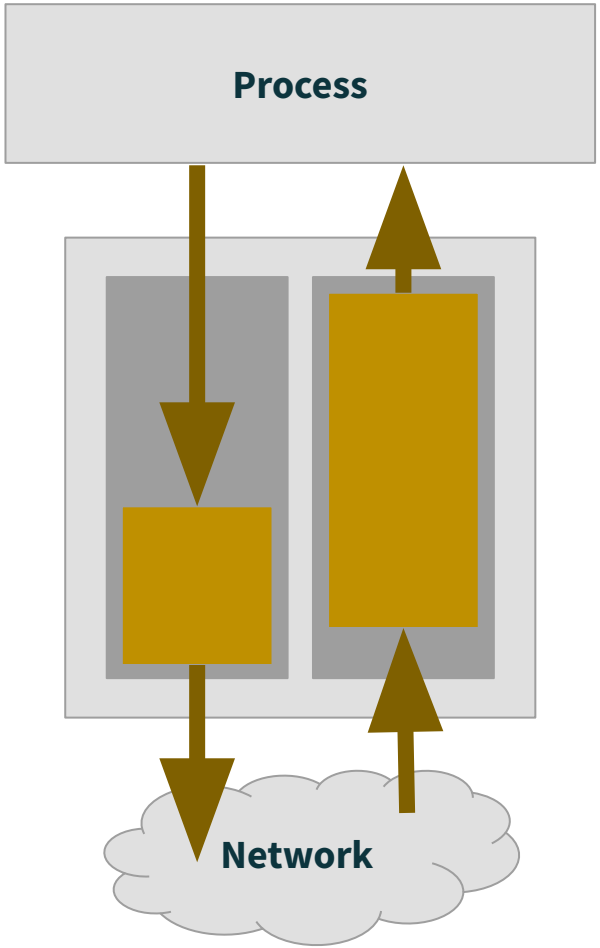
Ports

- Packets carry port number
- Servers listen on a port
  - Which one depends on application
  - HTTP: 80
  - SSH: 22
- Client process connects to well known port
- Client also has a port
  - Randomly assigned by OS
  - Used by OS to send data to correct process



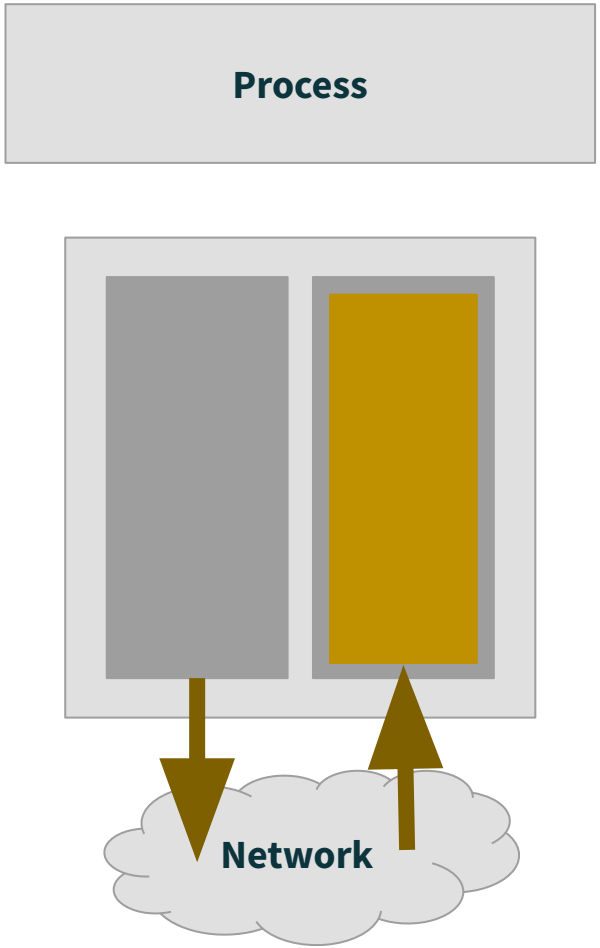
Socket Mechanics

- Send buffer
  - Filled by process
  - Drained by network
  - Bits wait to be transmitted by network
- Receive buffer
  - Filled by network
  - Drained by process
  - Bits wait to be read by process
- Why two buffers?



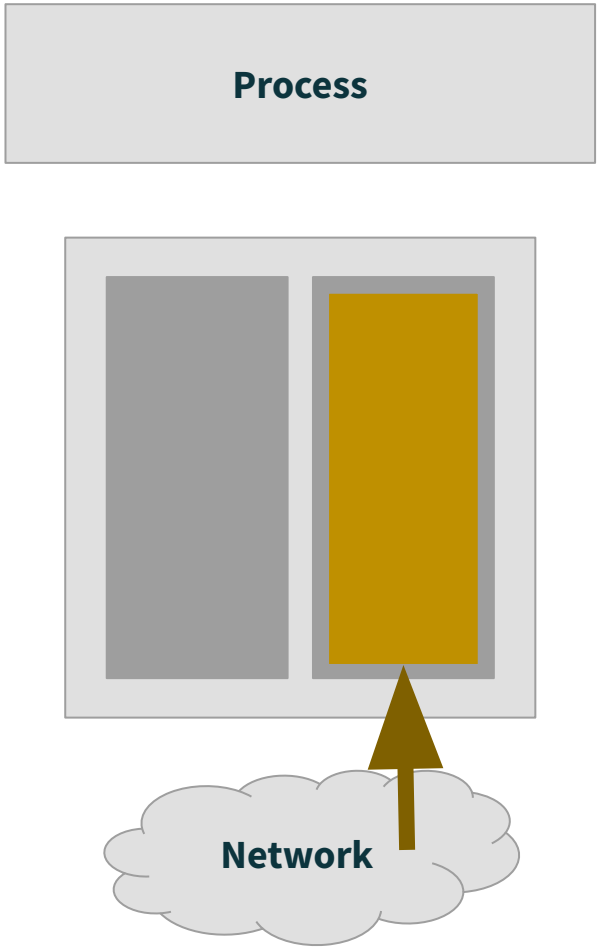
Socket Mechanics: Full or Empty

- What if you write to a full socket buffer or read from an empty one?
- Two solutions:
  - Blocking (wait)
  - Non-blocking (return error)
- We'll talk about blocking briefly.



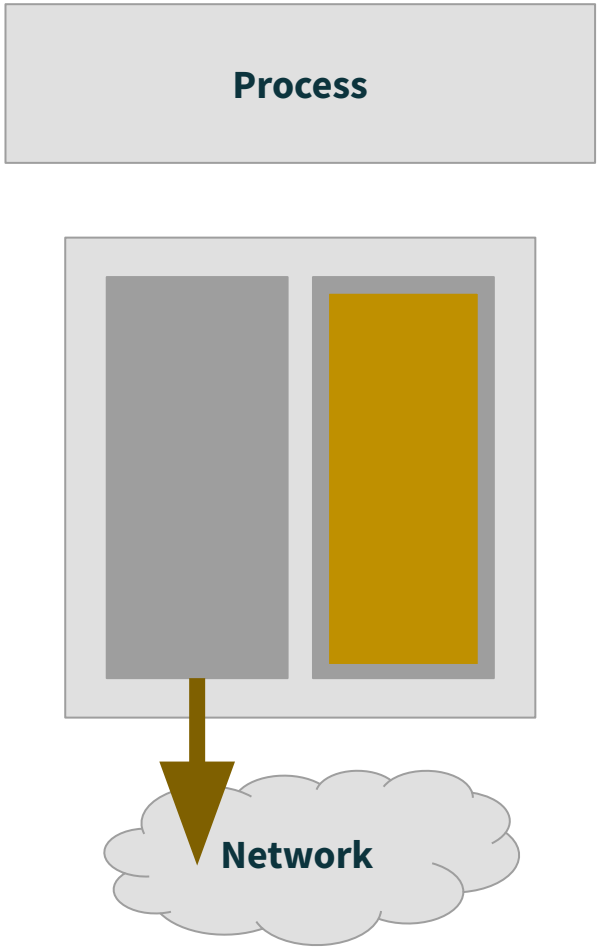
Socket Mechanics: Blocking Write

- Try to write, but buffer is full
- Block (wait) until there is enough room in the buffer
- Write the data and return



Socket Mechanics: Blocking Read

- Try to read, but buffer is empty
- Block (wait) until some bits appear in the buffer
- Read the bits and return them



Socket Mechanics: Non Blocking

- Non blocking reads and writes behave differently
- If the buffer isn’t ready for the operation
  - Just return an error
- The user must try again later

Discussion: Which is better, blocking or non-blocking?

Bonus Slides

Ping, **Traceroute**, Dig

- Traceroute gives you the path of routers and switches your packets take.
- How?
  - Takes advantage of something called a **TTL** in the packet IP header.
  - TTL denotes how many times a packet should be forwarded before it is discarded.
    - Why does this exist?
      - To stop the internet from collapsing! (We'll cover this when we get to routing)
  - Sets the TTL to 1, 2, 3, etc
  - When packets are dropped because of TTL expiring, most routers send back a message telling us.
  - Use the source of this notification to identify the routers along the packet's path.

Dig: A breakdown

- When using the +trace option, there was a lot more information
- We could see the steps that were taken when resolving the names
  - First, the ‘root’ servers were queried
  - Then, the TLD (top level domain) server was queried
  - After that, successive servers were asked until the IP was found
- More on how this works when we discuss DNS