CS50's Understanding Technology

OpenCourseWare

Donate (https://cs50.harvard.edu/donate)

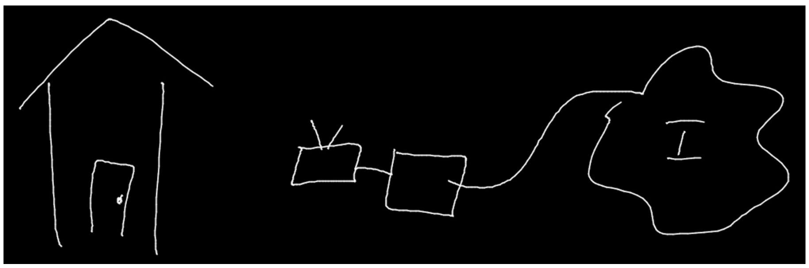
David J. Malan (https://cs.harvard.edu/malan/)
malan@harvard.edu
(https://www.clubhouse.com/@davidjmalan) (https://www.facebook.com/dmalan)
(https://github.com/dmalan) (https://www.instagram.com/davidjmalan/)
(https://www.linkedin.com/in/malan/) (https://orcid.org/0000-0001-5338-2522)
(https://www.quora.com/profile/David-J-Malan)
(https://www.reddit.com/user/davidjmalan) (https://www.tiktok.com/@davidjmalan)
(https://davidjmalan.t.me/) (https://twitter.com/davidjmalan)

Internet

by Spencer Tiberi

Introduction (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=0m10s)

- We use the internet on a daily basis and have constant access and connectivity
- Home network



        - Cable modem, DSL modem, or FIOS device
            - Connects to the internet
            - Pay monthly for an ISP (Internet Service Provider)
                - Verizon, Comcast, etc.
            - Could have built in wireless connectivity for your devices
                - May need an additional home router
                    - Devices connect to a router via cables or wifi

IP (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=2m13s)

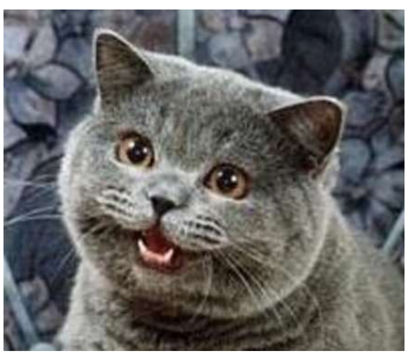
- Every computer on the internet has an IP (Internet Protocol) address
    - Of the form #.#.#.#
        - Four numbers separated by dots of the values 0-255
        - Other IP address formats exist today as well
    - Like postal addresses, they uniquely identify computers on the internet
        - Any device connected to the internet has an IP address
            - Allows other computers to talk to it
- ISPs assign a IP address to your computer (router)
    - Used to be physically configured
    - DHCP (Dynamic Host Configuration Protocol)
        - Software that ISPs provides to allow your computer to request an IP address
        - DHCP servers respond with a specific IP address for your Home
    - Multiple devices can connect to your home network
        - The home router supports DHCP and assigns IP addresses to your devices

DNS (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=6m43s)

- We access websites using domain names (Facebook.com, Google.com, etc.), but it turns out that these sites too have IP addresses
- DNS (Domain Name System) servers convert domain names into IP addresses

[Packets (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=8m21s)]

- Computers communicate by sending packets, which are like virtual envelopes sent between computers
  - Ultimately still 0s and 1s
- As an analogy, suppose we want to find a cat image on the internet
- So, we send a request to a server, say Google, like "get cat.jpg"
  - We place this request in an envelope
- On the envelope, we list out IP as the return address
- However, for the recipient of the request, we don't know the IP address for Google
  - Have to rely on DNS
  - Send a request to our ISPs DNS server for Google's IP address
    - If the ISP's DNS server doesn't know a website's IP address, it has been configured to ask another DNS server
    - There exist root servers that know where to look to for an IP address if it exists
- After sending the request off, we'll get a response ms later

  
- The cat will be sent back in one or more packets
  - If the cat image is too large for a single envelope, sending it in one packet could take up internet traffic
  - To solve this, Google will divide the cat image into smaller fragments
    - Put the fragments into different envelopes
    - Write information on the envelopes
      - Return address: Google's IP address
      - Delivery address: Our IP address
      - List the number of packets on each envelope (1 of 4, 2 of 4, etc.)

TCP/IP (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=14m15s)

- IP goes beyond addresses
  - Set of conventions computers and servers follow to allow intercommunication
- Fragmentation like in the envelope example are supported by IP
  - If missing a packet, you can logically infer which packet you're missing based on the ones received
    - However, IP doesn't tell computers what to do in this case
- TCP (Transmission Control Protocol) ensures packets can get to their destination
  - Commonly used with IP (TCP/IP)
  - Supports sequence numbers that help data get to its destination
    - When missing a packet, a computer can make a request for the missing packet
    - The computer will put packets together to get a whole file
  - Also includes conventions for requesting services (port identifiers)
    - To make sure Google knows we're requesting a webpage and not an email or other service

Ports (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=18m14s)

- Per TCP, the world has standardized numbers that represent different services
- If 5.6.7.8 is Google's IP address, 5.6.7.8;80 (port 80) lets use know that we want a webpage
  - 80 means http (hypertext transfer protocol)
    - The language that web servers speak
  - Google will send the request to their web server via http
- Many websites use secure connections with SSL or HTTPS, which uses the port 443
- Email uses port 25
- Other ports exist as well

Protocols (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?

t=19m53s)

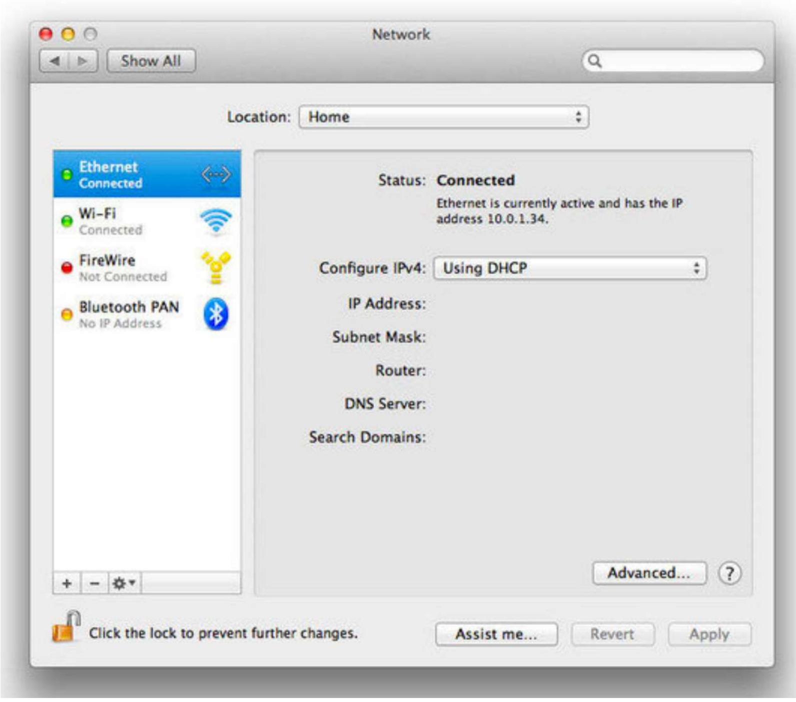
- Protocols are just sets of rules
  - Humans use these all the time, such as the protocol for meeting people: handshakes
- When a request is made to Google for an image, HTTP tells Google how to respond appropriately

UDP (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=21m12s)

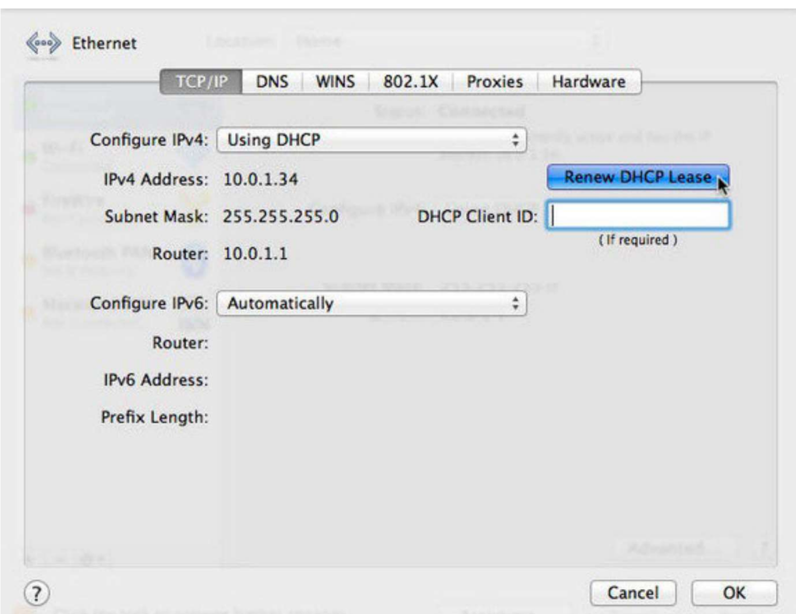
- User Datagram Protocol
  - Doesn't guarantee delivery
  - Used for video conferencing such as FaceTime
    - Packets can be dropped for the sake of keeping the conversation flowing
  - Used anytime you want to keep data coming without waiting for a buffer to fill

IPs in More Detail (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=23m28s)

- IP addresses are limited
  - In the format #.#.#.#, each number is 8 bits, so 32 bits total
    - This yields 2^{32} or about 4 billion possible addresses
      - We're running out of addresses for all computers
  - Current version of addresses is IPv4
  - Moving towards IPv6
    - Uses 128 bits, yielding 2^{128} possible addresses
- How do you find your IP address?
- On a Mac, go to system preferences an poke around a bit

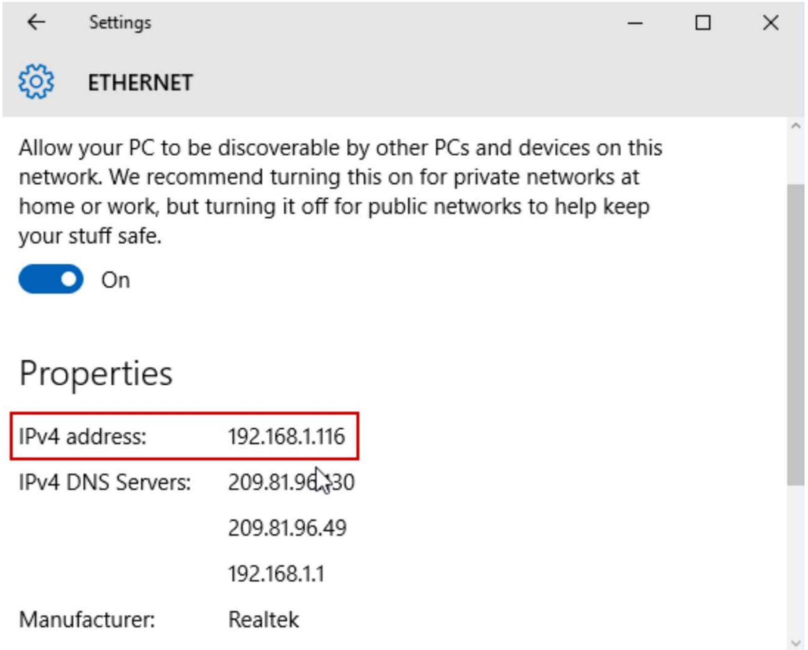


- Private addresses exist
    - 10.#.#.#, 192.168.#.#, or 172.16.#.#
    - Only with special configuration can someone talk to your computer
    - Your personal device is not a server, so people should not need to access them directly
        - Your device needs to request data from servers
    - Even email is stored on a server such as Gmail and your device makes a request to that server to access that email
- Looking at advanced settings...



    - Subnet mask is used to decide if another computer is on the same network
    - Router (aka Gateway) has its own address
        - Routs data in different directions

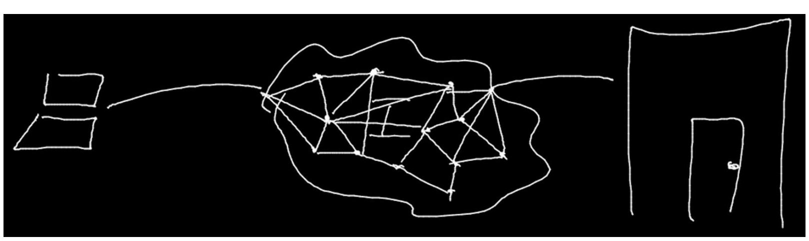
- On windows:



  - Shows DNS servers as well

[Routers (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=27m6s)](https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=27m6s)

- Routers have bunches if wires coming and going out of them
  - They have a big table with IP addresses and where data should be routed to get to that destination
    - Often, the data is routed to some next router
- Routers purpose is to send data in the direction of a destination
  - The next router will send it to another until it reaches a destination



- The internet is a network of networks (with their own routers)
  - Often multiple ways to go from A to B
    - Based in US Military logic to prevent downtime if a particular router goes down
    - When multiple packets are sent, like cat.jpg from Google, they can each take a different path, still getting to their destination eventually

- Sometimes the internet is busy and the quickest path changes

Traceroute (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=32m31s)

- How long does it take for this process of data transfer to take on the internet?
- Traceroute is a program that sends packets to each router on a path to a destination, reporting the time it takes to reach that router
- From Sanders Theatre to Google.com:

```
$ traceroute www.google.com
traceroute to www.google.com (4.53.56.109), 30 hops max, 40 byte packets
 1  10.243.16.161 (10.243.16.161)  0.572 ms
 2  10.240.144.33 (10.240.144.33)  0.890 ms
 3  coregw1-vl-415-fas.net.harvard.edu (140.247.2.61)  0.813 ms
 4  coregw1-te-3-6-core.net.harvard.edu (128.103.0.77)  1.463 ms
 5  5-1-20.bear2.Boston1.Level3.net (4.53.56.9)  3.607 ms
 6  5-1-20.bear2.Boston1.Level3.net (4.53.56.9)  3.722 ms
 7  *
 8  *
 9  *
10  *
11  *
12  *
13  *
14  *
```

  - 1-2: A few unnamed routers at Harvard
  - 3-4: More Harvard routers
  - 5-6: Level3 is a ISP
  - 7+: The routers are denying the request
- From Sanders Theatre to Berkeley.edu

```
traceroute to www.berkeley.edu (128.32.203.137), 30 hops max, 40 byte packets
 1  10.243.16.161 (10.243.16.161)  0.333 ms
 2  10.240.144.33 (10.240.144.33)  0.517 ms
 3  core-ne-gw-vl408.fas.harvard.edu (140.247.2.33)  0.676 ms
 4  bdrgw1-te-4-7-core.net.harvard.edu (128.103.0.146)  1.314 ms
 5  18.254.32.5 (18.254.32.5)  1.637 ms
 6  i2-re-nox1sumgw1.nox.org (192.5.89.18)  14.017 ms
 7  et-3-0-0.4079.sdn-sw.eqch.net.internet2.edu (162.252.70.113)  22.988 ms
 8  et-5-3-0.4079.rtsw.chic.net.internet2.edu (162.252.70.114)  23.451 ms
 9  et-5-3-0.4079.rtsw.chic.net.internet2.edu (162.252.70.114)  23.217 ms
10  et-8-0-0.4079.sdn-sw.denv.net.internet2.edu (162.252.70.10)  44.928 ms
11  et-8-0-0.4079.sdn-sw.denv.net.internet2.edu (162.252.70.10)  44.836 ms
12  et-7-0-0.4079.sdn-sw.lasv.net.internet2.edu (162.252.70.30)  61.950 ms
13  et-7-0-0.4079.sdn-sw.lasv.net.internet2.edu (162.252.70.30)  61.859 ms
14  et-4-1-0.4079.rtsw.losa.net.internet2.edu (162.252.70.29)  66.695 ms
15  hpr-svl-hpr3--lax-hpr3-100ge.cenic.net (137.164.25.74)  78.135 ms
16  hpr-ucb--svl-hpr-10g.cenic.net (137.164.27.133)  80.391 ms
17  t1-3.inr-201-sut.berkeley.edu (128.32.0.65)  79.948 ms
18  e3-48.inr-310-ewdc.berkeley.edu (128.32.0.97)  80.265 ms
19  calweb-farm-prod.ist.berkeley.edu (128.32.203.137)  80.162 ms
```

  - 6: Northern Crossroads
  - 7-14: A fast connection
    - 8-9: Chicago
    - 10-11: Denver

        - 12-13: Las Vegas
        - 14: Los Angeles
    - 19 is where it arrives at Berkeley in 80 ms!
- From Sanders Theatre to MIT.edu

```
$ traceroute www.mit.edu
traceroute to www.mit.edu (104.91.71.143), 30 hops max, 40 byte packets
 1  10.243.16.161 (10.243.16.161)  0.413 ms
 2  10.240.144.33 (10.240.144.33)  9.888 ms
 3  coregw1-vl-415-fas.net.harvard.edu (140.247.2.61)  0.666 ms
 4  bdrgw1-te-4-2-core.net.harvard.edu (128.103.0.18)  1.565 ms
 5  bdrgw2-te-4-4-core.net.harvard.edu (192.5.66.17)  1.498 ms
 6  nyc2-edge-01.inet.qwest.net (205.171.134.34)  6.364 ms
 7  nyc2-edge-01.inet.qwest.net (205.171.134.34)  6.272 ms
 8  a104-91-71-143.deploy.static.akamaitechnologies.com (104.91.71.143)  6.321 ms
```

    - 6-7: Goes to New York connectivity
    - 8: MIT's website is outsourced to Akamai's NYC servers
- From Sanders Theatre to CNN.jp

```
$ traceroute www.cnn.co.jp
traceroute to www.cnn.co.jp (27.121.48.200), 30 hops max, 40 byte packets
 1  10.243.16.161 (10.243.16.161)  0.504 ms
 2  10.240.144.33 (10.240.144.33)  0.806 ms
 3  coregw1-vl-415-fas.net.harvard.edu (140.247.2.61)  0.978 ms
 4  bdrgw2-te-4-2-core.net.harvard.edu (128.103.0.2)  1.376 ms
 5  18.254.48.5 (18.254.48.5)  1.798 ms
 6  et-10-0-0.122.rtr.eqch.net.internet2.edu (198.71.47.61)  23.029 ms
 7  *
 8  sea001bb00.IIJ.Net (58.138.81.210)  85.044 ms
 9  sea001bb00.IIJ.Net (58.138.81.210)  106.799 ms
10  osk004bb00.IIJ.Net (58.138.88.193)  193.943 ms
11  osk004ip57.IIJ.Net (58.138.107.206)  213.306 ms
12  p078.net061211176.broadline.ne.jp (61.211.176.78)  191.566 ms
13  p070.net061211176.broadline.ne.jp (61.211.176.70)  194.730 ms
14  p246.net061200097.broadline.ne.jp (61.200.97.246)  193.614 ms
15  27.121.48.200 (27.121.48.200)  213.724 ms
16  *
```

    - 9-10 jumps from Seattle to Osaka past an ocean!
        - Using undersea cabling

Undersea Cabling (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=40m56s)

- David shows a video about undersea cables

Cable Modem Demo (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=43m5s)

- David examines a home cable modem, focusing on its ports
    - Coaxial cable to plug into the wall

- Phone jacks (RJ11) as many services are bundled together these days
- Four jacks for ethernet cables (RJ45)
  - Devices can plug into these for internet connectivity
- This modem has wifi support built in

Network Switch Demo (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=46m27s)

- David examines a network switch
  - A device that you can plug into your router to allow more connections for all your other devices

Home Router Demo (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=47m48s)

- David examines a home router
- Home routers can have wifi, firewall, and switching capabilities

Network Cable Demo (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=48m54s)

- David cuts open a network ethernet cable to examine its inner workings
- Inside a network cable are 8 wires of different colors
  - Some are for transmitting data, others for receiving data
  - Others still are for insulation and cancellation of interference

Closing Thoughts and Homework (https://video.cs50.net/cscie1a/2017/fall/lectures/internet?t=50m24s)

- For homework, find a device that looks like a modem or router and take a look at the connectors on the back of it
    - If brave, play around with unplugging cables
        - Note: Your internet may go down in the process, but can be easily restarted with the cables properly reconnected!
    - If you have a spare ethernet cable, take a look inside yourself
        - These are a bit harder to put back together!