CSE 461: Introduction

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Outline

- Administrative trivia
- Today: a brief introduction to the Internet: past and present
- Goals of the course
- How to study networks?

Administrative Details

- Everything you need is on the course web page
  - http://www.cs.washington.edu/cse461

- Your TODO list:
  - Join the mailing list cse461@cs.washington.edu

Teaching Assistants

- Stef Schoenmackers: runs the sessions
- Safeer Jiwan: Fishnet Project coordinator
- Office hours: TBA

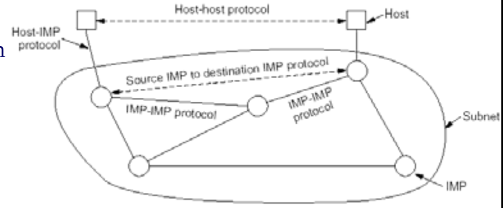
Model of a Network

- Links carry information (bits)
  - Wire, wireless, fiber optic, smoke signals …
  - May be point-to-point or broadcast
- Switches move bits between links
  - Routers, gateways,bridges, CATV headend, PABXs, …
- Hosts are the communication endpoints
  - PC, PDA, cell phone, tank, toaster, …
  - Hosts have names

- Much other terminology: channels, nodes, intermediate systems, end systems, and much more.

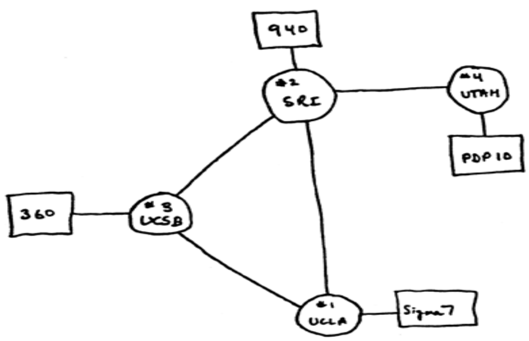
A Brief History of the Internet: Packet Switching and ARPANET

- **1957**
  - USSR launched Sputnik; US DoD formed Advanced Research Projects Agency (ARPA)
- **1961**
  - First paper by Len Kleinrock on packet switching theory
- **1964**
  - Paul Baran from RAND on design of packet switching networks
- **1965-1968**
  - ARPANET plan
  - 3 independent implementation
  - Bolt Beranek and Newman, Inc. (BBN), a small company, was awarded Packet Switch contract to build Interface Message Processors (IMPs). US Senator Edward Kennedy congratulates BBN for getting contract to build "interfaith" message processors



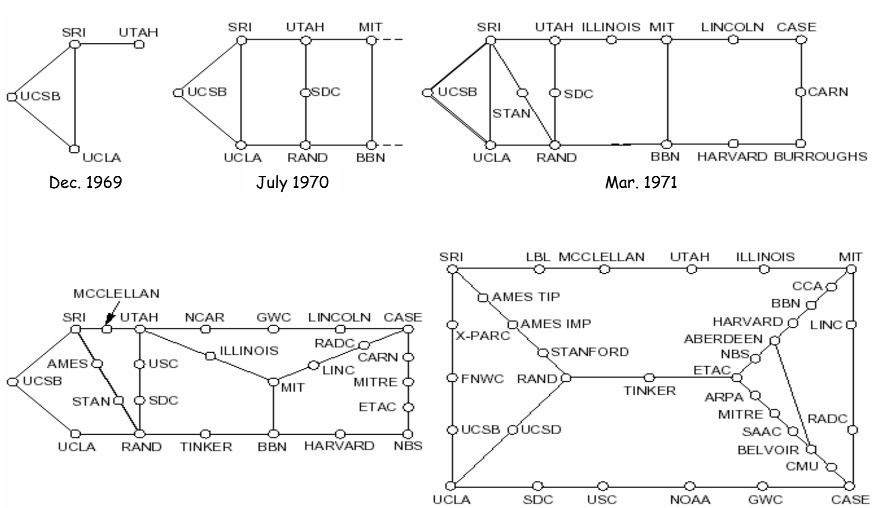
Initial ARPANET

- 1969: ARPANET commissioned: 4 nodes, 50kbps



- First packets sent by Charley Kline at UCLA as he tried logging into SRI. The first attempt resulted in the system crashing as the letter G of LOGIN was entered. (October 29)

Initial Expansion of the ARPANET



RFC 527: ARPAWOCKY; RFC 602: The Stockings Were Hung by the Chimney with Care

The Internet Becomes a Network of Networks

- 1970: ALOHAnet, the first packet radio network, developed by Norman Abramson, Univ of Hawaii, becomes operational
- 1973: Bob Kahn poses Internet problem---how to connect ARPANET, packet radio network, and satellite network
- 1974: Vint Cerf, Bob Kahn publish initial design of Internet protocols (including TCP) to connect multiple networks
    - Christmas Day Lockup - Harvard IMP hardware problem leads it to broadcast zero-length hops to any ARPANET destination, causing all other IMPs to send their traffic to Harvard
- 1978: TCP (NCP) split to TCP/IP
- New applications kept the process going forward

Growth of the Internet

- 1980: ARPANET grinds to a complete halt on 27 October because of an accidentally-propagated status-message virus
- 1981: BITNET (Because It's Time NETwork) between CUNY and Yale. Store and forward network for email.
- 1983: Name server developed at Univ of Wisconsin, no longer requiring users to know the exact path to other systems
- 1986: NSF builds NSFNET as backbone, links 6 supercomputer centers, 56 kbps; this allows an explosion of connections, especially from universities
- 1987: 10,000 hosts
- 1988: NSFNET backbone upgrades to 1.5Mbps
    - Internet worm burrows through the Net, affecting 6000
- 1989: 100,000 hosts

Web and Commercialization of the Internet

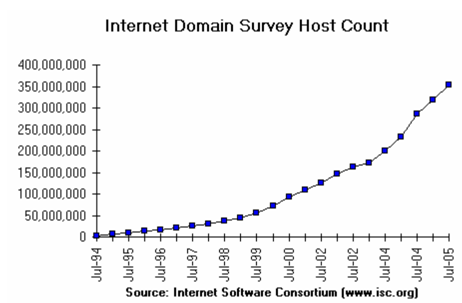
- 1990: ARPANET ceases to exist
- 1991: NSF lifts restrictions on the commercial use of the Net; Berners-Lee of European Organization for Nuclear Research (CERN) released World Wide Web
- 1992: 1 million hosts (RFC 1300: Remembrances of Things Past)
- 1994: NSF reverts back to research network (vBNS); the backbone of the Internet consists of multiple private backbones
- Today: backbones run at 10Gbps, 400s millions computers in 150 countries

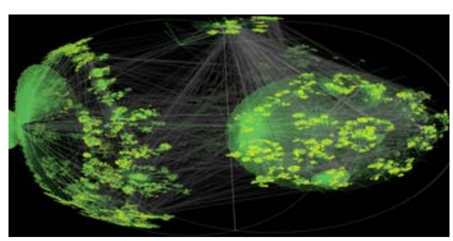
For more on Internet history, please see http://www.zakon.org/robert/internet/timeline/

Growth of the Internet in Terms of Number of Hosts

Number of Hosts on the Internet:

Aug. 1981	213
Oct. 1984	1,024
Dec. 1987	28,174
Oct. 1990	313,000
Jul. 1993	1,776,000
Jul. 1996	19,540,000
Jul. 1999	56,218,000
Jul. 2004	285,139,000
Jan. 2005	317,646,000
Jul. 2005	353,284,000

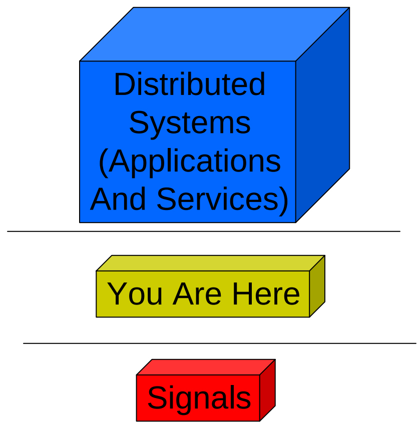




CAIDA router level view

Goal of this Course

- You will understand how to design and build *large, distributed computer* networks.
  - Fundamental problems in building networks
  - Design principles of proven value
  - Common implementation technologies
- This is a systems course, not queuing theory, signals, or hardware design.
- We focus on networks, rather than applications or services that run on top of them (distributed systems).



The networks we study

- We are interested in networks that are:
  - Large scale
  - Intrinisically Unreliable
  - Distributed
  - Heterogeneous

Intrinsic Unreliability

- Information sent from a first place to a second
  - May not arrive
  - May arrive more than once
  - May arrive in garbled fashion
  - May arrive out of order
  - May be read by others
  - May be modified by others
- Why build intrinsically unreliable networks?

Distributed

"A distributed system is a system in which I can't do my work because some computer has failed that I've never even heard of." – Lamport

- (Hopefully) independent failure modes
- Exposed and hidden dependencies
- Independent administrative controls
- Leads to…

Heterogeneous Networks

- Heterogeneous: Made up of different kinds of stuff
- Homogeneous: Made up of the same kind of stuff
- Principles
  - Homogeneous networks are easier to deal with
  - Heterogeneous networks lead to greater innovation and scale
  - Consider telephone network vs. Internet

How to study networks?

- Networks in general, and Internet in particular, are complex beasts
- Question: how do we begin to understand Internet's workings?

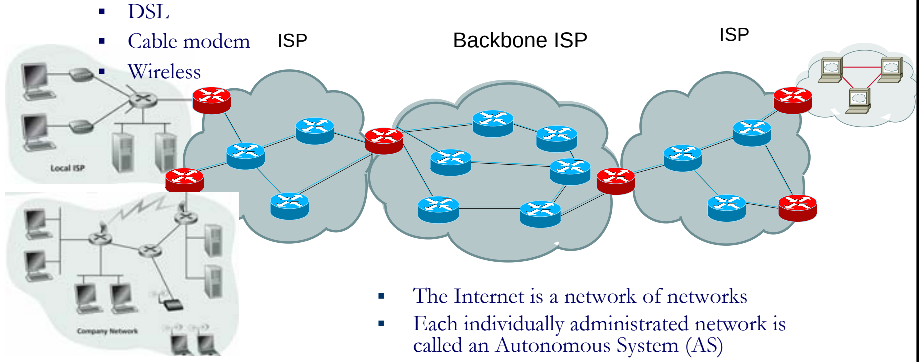
Explore, read, tinker, break, build …

- Internet's connectivity
- Protocol layering
- Fundamental algorithms

Internet Physical Infrastructure

Residential access

- Modem
- DSL
- Cable modem
- Wireless



Campus access

- Ethernet
- FDDI
- Wireless

- The Internet is a network of networks
- Each individually administrated network is called an Autonomous System (AS)
- We can roughly divide the networks into access networks and transit networks

A Connectivity Exploration Tool

- Traceroute:
  - Run traceroute host-name on unix machines
  - tracert host-name on windows
- Sends three probes to each intermediate node on the path to the final destination (more details later)
- Reports the IP address, a more readable name, and the round-trip latencies for the probes

Traceroute to an East Coast College

```
-bash-3.1$ traceroute planetx.scs.cs.nyu.edu
traceroute to planetx.scs.cs.nyu.edu (216.165.109.79), 30 hops max, 40 byte packets
 1  acar-hsh-01-vlan75.cac.washington.edu (128.208.2.100)  0.362 ms  0.353 ms  0.396 ms
 2  uwcr-hsh-01-vlan3904.cac.washington.edu (205.175.110.17)  0.407 ms  0.444 ms  0.478 ms
 3  uwcr-hsh-01-vlan1901.cac.washington.edu (205.175.103.5)  0.592 ms  0.665 ms  0.687 ms
 4  uwbr-ads-01-vlan1902.cac.washington.edu (205.175.103.10)  50.060 ms  50.120 ms  50.130 ms
 5  hnsp2-wes-ge-0-0-0-0.pnw-gigapop.net (209.124.176.12)  0.703 ms  0.729 ms  0.760 ms
 6  abilene-pnw.pnw-gigapop.net (209.124.179.2)  0.544 ms  0.561 ms  0.588 ms
 7  dnvrng-sttlng.abilene.ucaid.edu (198.32.8.50)  46.984 ms  46.969 ms  47.009 ms
 8  kscyng-dnvrng.abilene.ucaid.edu (198.32.8.14)  63.746 ms  62.699 ms  62.709 ms
 9  iplsng-kscyng.abilene.ucaid.edu (198.32.8.80)  57.320 ms  57.305 ms  57.344 ms
10  chinng-iplsng.abilene.ucaid.edu (198.32.8.76)  70.506 ms  71.011 ms  70.985 ms
11  buf-7600-abilene-chin.nysernet.net (199.109.2.1)  73.003 ms  72.942 ms  72.946 ms
12  nyc-gsr-buf-7600.nysernet.net (199.109.7.14)  81.995 ms  81.966 ms  81.936 ms
13  nyu-nyc-gsr.nysernet.net (199.109.4.22)  82.179 ms  82.249 ms  82.314 ms
14  WWLABGW.NYU.NET (192.76.177.75)  82.350 ms  82.188 ms  82.200 ms
15  delancy.scs.cs.nyu.edu (216.165.108.191)  82.307 ms  82.662 ms  82.558 ms
16  planetx.scs.cs.nyu.edu (216.165.109.79)  82.629 ms  82.493 ms  82.592 ms
```

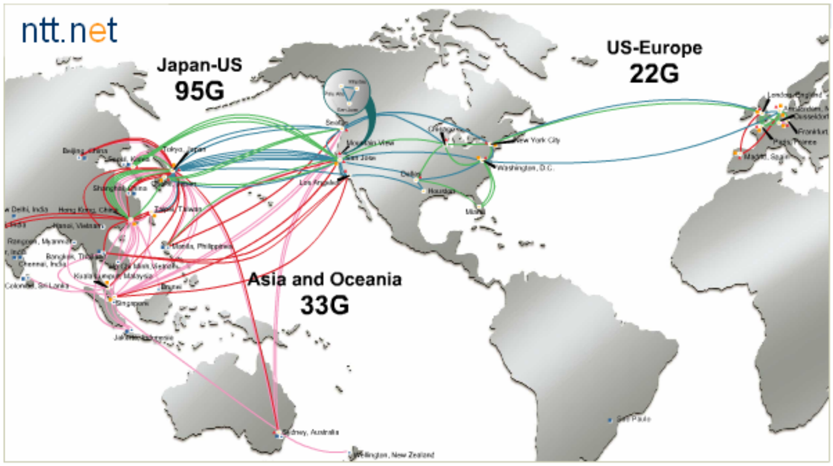
Abilene I2 Backbone

http://abilene.internet2.edu/maps-lists/

Traceroute to a commercial webserver

```
-bash-3.1$ traceroute www.nytimes.com
traceroute to www.nytimes.com (199.239.136.200), 30 hops max, 40 byte packets
 1  acar-hsh-01-vlan75.cac.washington.edu (128.208.2.100)  0.358 ms  0.357 ms  0.400 ms
 2  uwcr-hsh-01-vlan3904.cac.washington.edu (205.175.110.17)  0.426 ms  0.467 ms  0.502 ms
 3  uwcr-hsh-01-vlan1901.cac.washington.edu (205.175.103.5)  0.609 ms  0.639 ms  0.687 ms
 4  uwbr-ads-01-vlan1902.cac.washington.edu (205.175.103.10)  0.386 ms  0.428 ms  0.445 ms
 5  cnsp1-wes-ge-0-0-0-0.pnw-gigapop.net (209.124.176.8)  0.579 ms  0.643 ms  0.730 ms
 6  129.250.10.194 (129.250.10.194)  70.290 ms  66.878 ms  66.907 ms
 7  xe-1-2-0.r20.sttlwa01.us.bb.gin.ntt.net (129.250.2.206)  1.060 ms  1.063 ms  1.045 ms
 8  ae-0.r21.sttlwa01.us.bb.gin.ntt.net (129.250.2.54)  0.901 ms  0.901 ms  0.883 ms
 9  p64-2-0-0.r20.nycmny01.us.bb.gin.ntt.net (129.250.5.17)  74.106 ms  74.095 ms  74.103 ms
10  xe-4-1.r02.nycmny01.us.bb.gin.ntt.net (129.250.2.187)  141.125 ms  141.209 ms  141.305 ms
11  ge-1-1.a00.nycmny01.us.da.verio.net (129.250.30.113)  73.897 ms  73.997 ms  73.968 ms
12  * * *
13  * * *
14  * * *
```

A Commercial backbone: NTT



Traceroute to another commercial webserver

```
-bash-3.1$ traceroute www.nyse.com
traceroute to www.nyse.com (209.124.184.150), 30 hops max, 40 byte packets
 1  acar-hsh-01-vlan75.cac.washington.edu (128.208.2.100)  0.327 ms  0.353 ms  0.392 ms
 2  uwcr-hsh-01-vlan3904.cac.washington.edu (205.175.110.17)  0.374 ms  0.412 ms  0.443 ms
 3  uwcr-hsh-01-vlan1901.cac.washington.edu (205.175.103.5)  0.595 ms  0.628 ms  0.659 ms
 4  uwbr-ads-01-vlan1902.cac.washington.edu (205.175.103.10)  0.445 ms  0.472 ms  0.501 ms
 5  ccar1-ads-ge-0-0-0-0.pnw-gigapop.net (209.124.176.32)  0.679 ms  0.747 ms  0.775 ms
 6  a209.124.184.150.deploy.akamaitechnologies.com.184.124.209.in-addr.arpa
     (209.124.184.150)  0.621 ms  0.456 ms  0.419 ms
```

```
-bash-3.1$ nslookup www.nyse.com
Name:   a789.g.akamai.net
Address: 209.124.184.137
Name:   a789.g.akamai.net
Address: 209.124.184.150
```

What is going on?

Points to note

- Multi-homed
- Certain routers don't respond
- Variability in response times
- Geography not apparent
  - Geography does not dictate paths
  - Sometimes paths are horribly inflated. Why?
- Content distribution networks operate by returning a nearby cache site

- Reverse engineering is fun!