Computer Networks
CSE 461

**Lectures:**
- MWF 12:30-01:20

**Section AA:**
- TH 01:30-02:20

**Section AB:**
- TH 02:30-03:20

**Section AC:**
- TH 03:30-04:20

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**Office Hours**

- M 01:30-02:20

**Textbooks**

- Computer Networks (6E 19), Peterson [Online Book](https://courses.cs.washington.edu/courses/cse461/20au/)
- Computer Networks (5th Edition), Andrew Tanenbaum, David Wetherall

**Class mailing list**

- The class email is cse461a_au20@u.washington.edu. It's updated nightly from the official registration list, and uses your u.wash email address.
3 Projects (10+15+15%)
  • Group of 3
  • Can be same or different

Individual assignments (20%)

Mid term (20%)

Final (20%)
The Main Point

1. To learn how the Internet works »
   - What really happens when you “browse the web”?
   - What are TCP/IP, DNS, HTTP, NAT, VPNs, 802.11 etc. anyway?

2. To learn the fundamentals of computer networks
Why learn about the Internet?

1. Curiosity »
2. Impact on our world »
3. Job prospects!
From this experimental network ...

ARPANET ~1970

Internet ~2005

- An everyday institution used at work, home, and on-the-go
- Visualization contains millions of links

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Internet – Societal Impact

• An enabler of societal change
  – Easy access to knowledge
  – Electronic commerce
  – Personal relationships
  – Discussion without censorship
Internet – Economic impact

• An engine of economic growth
  – Advertising-sponsored search
  – “Long tail” online stores
  – Online marketplaces
  – Crowdsourcing
The Main Point (2)

1. To learn how the Internet works
2. To learn the fundamentals of computer networks
   - What hard problems must they solve?
   - What design strategies have proven valuable?
Why learn the Fundamentals?

1. Apply to all computer networks
2. Intellectual interest »
3. Change / reinvention »
Fundamentals – Intellectual Interest

• Example key problem: Reliability!
  – Any part of the Internet might fail
  – Messages might be corrupted
  – So how do we provide reliability?

• Reliability solutions
  – Codes to detect/correct errors
  – Routing around failures ...
### Fundamentals – Intellectual Interest (2)

<table>
<thead>
<tr>
<th>Key problem</th>
<th>Example solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability despite failures</td>
<td>Codes for error detection/correction Routing around failures</td>
</tr>
<tr>
<td>Network growth and evolution</td>
<td>Addressing and naming Protocol layering</td>
</tr>
<tr>
<td>Allocation of resources like bandwidth</td>
<td>Multiple access Congestion control</td>
</tr>
<tr>
<td>Security against various threats</td>
<td>Confidentiality of messages Authentication of communicating parties</td>
</tr>
</tbody>
</table>
Fundamentals – Reinvention

• The Internet is constantly being re-invented!
  – Growth over time and technology trends drive upheavals in Internet design and usage »

• Today’s Internet is different from yesterday’s
  – And tomorrow’s will be different again
  – But the fundamentals remain the same
Fundamentals – Reinvention (2)

• At least a billion Internet hosts and growing …
**Fundamentals – Reinvention (3)**

- Examples of upheavals in the past 1-2 decades

<table>
<thead>
<tr>
<th>Growth / Tech Driver</th>
<th>Upheaval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergence of the web</td>
<td>Content Distribution Networks</td>
</tr>
<tr>
<td>Digital songs/videos</td>
<td>Peer-to-peer file sharing</td>
</tr>
<tr>
<td>Falling cost/bit</td>
<td>Voice-over-IP calling</td>
</tr>
<tr>
<td>Many Internet hosts</td>
<td>IPv6</td>
</tr>
<tr>
<td>Wireless advances</td>
<td>Mobile devices</td>
</tr>
</tbody>
</table>
Not a Course Goal

• To learn IT job skills
  – How to configure equipment
    • e.g., Cisco certifications
  – But course material is relevant, and we use hands-on tools
Example Uses of Networks

• Work:
  – Email, file sharing, printing, ...

• Home:
  – Movies / songs, news, calls / video / messaging, e-commerce, ...

• Mobile:
  – Calls / texts, games, videos, maps, information access ...
Example Uses of Networks

- **Work:**
  - Email, file sharing, printing, ...

- **Home:**
  - Movies / songs, news, calls / video / messaging, e-commerce, ...

- **Mobile:**
  - Calls / texts, games, videos, maps, information access ...

What do these uses tell us about why we build networks?
For User Communication

• From the telephone onwards:
  – VoIP (voice-over-IP)
  – Video conferencing
  – Instant messaging
  – Social networking

→ Enables remote communication
  – Need low latency for interactivity
For Resource Sharing

- Many users may access the same underlying resource
  - E.g., 3D printer, search index, machines in the cloud
For Computer Communication

• To let computers interact with other computers
  – E.g., e-commerce, reservations

→ Enables automated information processing across different parties
To Connect Computers to the Physical World

• For gathering sensor data, and for manipulating the world
  – E.g., webcams, location on mobile phones, door locks, ...

• This is a rich, emerging usage
Parts of a Network (3)
## Component Names

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application</strong>, or app, user</td>
<td>Uses the network</td>
<td>Skype, iTunes, Amazon</td>
</tr>
<tr>
<td><strong>Host</strong>, or end-system, edge</td>
<td>Supports apps</td>
<td>Laptop, mobile, desktop</td>
</tr>
<tr>
<td><strong>device, node, source, sink</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Router</strong>, or switch, node, hub,</td>
<td>Relays messages between links</td>
<td>Access point, cable/DSL modem</td>
</tr>
<tr>
<td><strong>intermediate system</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Link</strong>, or channel</td>
<td>Connects nodes</td>
<td>Wires, wireless</td>
</tr>
</tbody>
</table>
Types of Links

- **Full-duplex**
  - Bidirectional

- **Half-duplex**
  - Bidirectional

- **Simplex**
  - Unidirectional
Wireless Links

- Message is **broadcast**
  - Received by all nodes in range
  - Not a good fit with our model
Wireless Links (2)

- Often show logical links
  - Not all possible connectivity
A Small Network

- Connect a couple of computers

- Next, a large network ...
Example Networks (2)

- WiFi (802.11)
- Enterprise / Ethernet
- ISP (Internet Service Provider)
- Cable / DSL
- Mobile phone / cellular (2G, 3G, 4G)
- Bluetooth
- Telephone
- Satellite ...
## Network names by scale

<table>
<thead>
<tr>
<th>Scale</th>
<th>Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vicinity</td>
<td>PAN (Personal Area Network)</td>
<td>Bluetooth (e.g., headset)</td>
</tr>
<tr>
<td>Building</td>
<td>LAN (Local Area Network)</td>
<td>WiFi, Ethernet</td>
</tr>
<tr>
<td>City</td>
<td>MAN (Metropolitan Area Network)</td>
<td>Cable, DSL</td>
</tr>
<tr>
<td>Country</td>
<td>WAN (Wide Area Network)</td>
<td>Large ISP</td>
</tr>
<tr>
<td>Planet</td>
<td>The Internet (network of all networks)</td>
<td>The Internet!</td>
</tr>
</tbody>
</table>
Internetworks

• An internetwork, or internet, is what you get when you join networks together
  – Just another network

• The Internet (capital “I”) is the internet we all use
Key Interfaces

- Between (1) apps and network, and (2) network components
  - More formal treatment later on
Key Interfaces (2)

1. Network-application interfaces define how apps use the network
   - Sockets are widely used in practice

![Diagram of network setup with host, app, and network connection]
Key Interfaces (3)

2. Network-network interfaces define how nodes work together
   - Traceroute can peek in the network
Network-Application Interface

• Defines how apps use the network
  – Lets apps talk to each other via hosts; hides the details of the network

![Diagram showing network interfaces and applications communicating through hosts]
Motivating Application

• Simple client-server setup
Motivating Application (2)

• Simple client-server setup
  – Client app sends a request to server app
  – Server app returns a (longer) reply

• This is the basis for many apps!
  – File transfer: send name, get file (§6.1.4)
  – Web browsing: send URL, get page
  – Echo: send message, get it back

• Let’s see how to write this app ...
Socket API

• Simple abstraction 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

• Supports two kinds of network services
  – Streams: reliably send a stream of bytes »
  – Datagrams: unreliably send separate messages. (Ignore for now.)
Socket API (2)

- Sockets let apps attach to the local network at different ports
Network Service API Hides Details

- Apps talk to other apps with no real idea of what is inside the network
  - This is good! But you may be curious ...

![Diagram](image-url)
Traceroute

- Widely used command-line tool to let hosts peek inside the network
  - On all OSes (tracert on Windows)
  - Developed by Van Jacobson ~1987
  - Uses a network-network interface (IP) in ways we will explain later

: Credit: Wikipedia (public domain)
Traceroute (2)

- Probes successive hops to find network path
Traceroute (3)
Using Traceroute

```
Using Traceroute

Tracing route to www.washington.edu [128.95.155.134]
over a maximum of 30 hops:

1  1 ms  <1 ms  2 ms  192.168.1.1
2  8 ms  8 ms  9 ms  188.Red-80-58-67.staticIP.rima-tde.net [80.58.67.88]
3  16 ms  5 ms  11 ms  169.Red-80-58-78.staticIP.rima-tde.net [80.58.78.169]
4  12 ms  12 ms  13 ms  217.Red-80-58-87.staticIP.rima-tde.net [80.58.87.217]
5  5 ms  11 ms  6 ms  et-1-0-0-1-101-GRDBONES1.red.telefonica-wholesale.net [94.142.103.20]
6  40 ms  38 ms  38 ms  176.52.250.226
7  108 ms  106 ms  136 ms  xe-6-0-2-0-grtncpnt2.red.telefonica-wholesale.net [213.140.43.9]
8  180 ms  179 ms  182 ms  Ke9-2-0-0-grtptcpot2.red.telefonica-wholesale.net [94.142.118.178]
9  178 ms  175 ms  176 ms  te-4-2.car1.SanJose2.Level3.net [4.59.0.225]
10  190 ms  186 ms  187 ms  vlan80.csv3.SanJose1.Level3.net [4.69.152.190]
11  185 ms  185 ms  187 ms  ae-82-82.ebr2.SanJose1.Level3.net [4.69.153.25]
12  268 ms  205 ms  207 ms  ae-7-7.ebr1.Seattle1.Level3.net [4.69.132.50]
13  334 ms  202 ms  195 ms  ae-12-51.car2.Seattle1.Level3.net [4.69.147.132]
14  195 ms  196 ms  195 ms  PACIFIC-NOR.car2.SanJose1.Level3.net [4.53.146.142]
15  197 ms  195 ms  196 ms  ae0-04000.iccr-sttlva01-02.infra.pwn-gigapp.net [209.124.188.132]
16  196 ms  196 ms  195 ms  v14000.uwr-br-ads-01.infra.washington.edu [209.124.188.133]
17  *     *     *     Request timed out.
18  201 ms  194 ms  196 ms  ae4-583.uwar-ads-1.infra.washington.edu [128.95.155.131]
19  197 ms  196 ms  195 ms  www1.cac.washington.edu [128.95.155.134]
Trace complete.
```
Using Traceroute (2)

- ISP names and places are educated guesses