CS 268: Graduate Computer Networks – Spring 2006

- Instructor: Ion Stoica (istoica@cs.berkeley.edu, 645 Soda Hall)
- Lecture time: MW, 1:00-2:30pm
- Place: 320 Soda Hall
- Office hour: W 2:30-4pm

Overview

- Administrative trivia
  - Overview and history of the Internet
  - A Taxonomy of Communication Networks
Administrative Trivia’s

- Course Web page:
  - [http://www.cs.berkeley.edu/~istoica/cs268/06/](http://www.cs.berkeley.edu/~istoica/cs268/06/)
  - Check it periodically to get the latest information

- Deadlines
  - Unless otherwise specified, it means 10 minutes before the lecture
  - Special circumstances should be brought to my attention ahead of deadlines

Goals of this Course

- Understand
  - How does the Internet work?
  - What are the Internet’s design principles?
  - Where is the Internet heading to?

- Get familiar with current Internet research efforts

- Understand solutions in context
  - Goals
  - Assumptions
Goals of this Course (cont’d)

- Appreciate what is good research
  - Problem selection
  - Solution & research methodology
  - Presentation

- Apply what you learned in a class project

What Do You Need To Do?

- A research-oriented class project
- Two exams
- Paper reading
- One 20min paper presentation
Research Project

- Investigate new ideas and solutions in a class research project
  - Define the problem
  - Execute the research
  - Work with your partner
  - Write up and present your research

- Ideally, best projects will become conference papers (e.g., SIGCOMM, INFOCOM, MOBICOM)

Research Project: Steps

- I’ll distribute a list of projects
  - You can either choose one of these projects or come up with your own
- Pick your project, partner, and submit a one page proposal describing:
  - The problem you are solving
  - Your plan of attack with milestones and dates
  - Any special resources you may need
- A midterm presentation of your progress (8-10 minutes)
- Poster session
- Submit project papers
Paper Reviews

- Goal: synthesize main ideas and concepts in the papers
- Number: around two papers per class
- Length: no more than half page per paper
- Content
  - Main points intended by the author
  - Points you particularly liked/disliked
  - Other comments (writing, conclusions…)
- Submission:
  - Submit each review via e-mail before the class on lecture day
  - See class web page for details

Grading

<table>
<thead>
<tr>
<th>Term project</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midterm exam</td>
<td>10%</td>
</tr>
<tr>
<td>Final exam</td>
<td>15%</td>
</tr>
<tr>
<td>Class participation and presentation</td>
<td>15%</td>
</tr>
<tr>
<td>Paper reviews</td>
<td>10%</td>
</tr>
</tbody>
</table>

- This is a graduate networking class: more important is what you realize/learn than the grade
Enrollment Policy

- Graduate students get highest priority
- Among other students, priority is given to those who
  - Have backgrounds in networking, operating systems
  - Have relatively light course load
- Procedure of enrollment for undergraduate students
  - Be officially on the waiting list
  - Send me an email with URL that has pointers to
    - Your resume or cv
    - A short statement of relevant courses (textbook, university, grade) and experience
    - Other courses you are taking this semester

Send the Following Information

- Please send me (istoica@cs.berkeley.edu) an email with the subject “cs268 registration” and the following information:
  - Last and first name
  - Student ID
  - Your department
  - Preferred email address
  - URL of your home page
Overview

- Administrative trivia
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The Internet (cont’d)

- Global scale, general purpose, heterogeneous-technologies, public, computer network

- Internet Protocol
  - Open standard: Internet Engineering Task Force (IETF) as standard body (http://www.ietf.org)
  - Technical basis for other types of networks
    - Intranet: enterprise IP network

- Developed by the research community
History of the Internet

- 70’s: started as a research project, 56 kbps, < 100 computers
- 80-83: ARPANET and MILNET split,
- 85-86: NSF builds NSFNET as backbone, links 6 Supercomputer centers, 1.5 Mbps, 10,000 computers
- 87-90: link regional networks, NSI (NASA), ESNet(DOE), DARTnet, TWBNet (DARPA), 100,000 computers
- 90-92: NSFNET moves to 45 Mbps, 16 mid-level networks
- 94: NSF backbone dismantled, multiple private backbones
- Today: backbones run at >10 Gbps, >300 millions computers in 150 countries

Time Line of the Internet

• Source: Internet Society
# Growth of the Internet

**Number of Hosts on the Internet:**

<table>
<thead>
<tr>
<th>Date</th>
<th>Host Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug. 1981</td>
<td>213</td>
</tr>
<tr>
<td>Oct. 1984</td>
<td>1,024</td>
</tr>
<tr>
<td>Dec. 1987</td>
<td>28,174</td>
</tr>
<tr>
<td>Oct. 1990</td>
<td>313,000</td>
</tr>
<tr>
<td>Oct. 1993</td>
<td>2,056,000</td>
</tr>
<tr>
<td>Apr. 1995</td>
<td>5,706,000</td>
</tr>
<tr>
<td>Jan. 1997</td>
<td>16,146,000</td>
</tr>
<tr>
<td>Jan. 1999</td>
<td>56,218,000</td>
</tr>
<tr>
<td>Jan. 2001</td>
<td>109,374,000</td>
</tr>
<tr>
<td>Jan. 2003</td>
<td>171,638,297</td>
</tr>
<tr>
<td>Jul 2004</td>
<td>285,139,107</td>
</tr>
<tr>
<td>Jul 2005</td>
<td>353,284,187</td>
</tr>
</tbody>
</table>

Source: Internet Software Consortium (www.isc.org)

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**AT&T IP Backbone Network 2Q2000**

**Note:** map is not to scale.

OC1 (45 Mbps), OC2 (155 Mbps), ..., OC192 (10 Gbps)
Services Provided by the Internet

- Shared access to computing resources
  - Telnet (1970’s)
- Shared access to data/files
  - FTP, NFS, AFS (1980’s)
- Communication medium over which people interact
  - Email (1980’s), on-line chat rooms (1990’s)
  - Instant messaging, IP Telephony (2000’s)
- A medium for information dissemination
  - USENET (1980’s)
  - WWW (1990’s)
    - Replacing newspaper, magazine
  - Audio, video (2000’s): peer-to-peer systems
    - Replacing radio, telephony, TV, …

Overview

- Administrative trivia
- Overview and history of the Internet
  - A Taxonomy of Communication Networks
A Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:

  Communication Network
    ├── Switched Communication Network
    │     ├── Circuit-Switched Communication Network
    │     └── Packet-Switched Communication Network
    └── Broadcast Communication Network
        └── Datagram Network
            └── Virtual Circuit Network

Broadcast vs. Switched Communication Networks

- Broadcast communication networks
  - Information transmitted by any node is received by every other node in the network
    - E.g., LANs (Ethernet, Wavelan)
  - Problem: coordinate the access of all nodes to the shared communication medium (Multiple Access Problem)

- Switched communication networks
  - Information is transmitted to a sub-set of designated nodes
    - E.g., WANs (Telephony Network, Internet)
  - Problem: how to forward information to intended node(s)
    - Done by special nodes (e.g., routers, switches) running routing protocols
A Taxonomy of Communication Networks

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  Communication Network
  ├── Switched Communication Network
  │    └── Circuit-Switched Communication Network
  │         └── Datagram Network
  │         ├── Virtual Circuit Network
  │         └── Packet-Switched Communication Network
  └── Broadcast Communication Network

Circuit Switching

- Three phases
  1. circuit establishment
  2. data transfer
  3. circuit termination

- If circuit not available: “Busy signal”

- Examples
  - Telephone networks
  - ISDN (Integrated Services Digital Networks)
Timing in Circuit Switching

A node (switch) in a circuit switching network

- Circuit Establishment
- Data Transmission
- Circuit Termination
Circuit Switching:
Multiplexing/Demultiplexing

- Time divided in frames and frames divided in slots
- Relative slot position inside a frame determines which conversation the data belongs to
- Needs synchronization between sender and receiver
- In case of non-permanent conversations
  - Needs to dynamic bind a slot to a conversation
  - How to do this?

A Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:
Packet Switching

- At each node the entire packet is received, stored, and then forwarded to the next node (Store-and-Forward Networks)

Packet Switching: Multiplexing/Demultiplexing

- Data from any conversation can be transmitted at any given time
- How to tell them apart?
  - Use meta-data (header) to describe data
A Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:
  
  - Switched Communication Network
  - Broadcast Communication Network
  - Packet-Switched Communication Network
  - Virtual Circuit Network
  - Datagram Network

Datagram Packet Switching

- Each packet is independently switched
  - Each packet header contains destination address
- No resources are pre-allocated (reserved) in advance
- Example: IP networks
### Timing of Datagram Packet Switching

<table>
<thead>
<tr>
<th>Host 1</th>
<th>Node 1</th>
<th>Node 2</th>
<th>Host 2</th>
</tr>
</thead>
</table>

- **Transmission time of Packet 1 at Host 1**
- **Propagation delay between Host 1 and Node 2**
- **Processing delay of Packet 1 at Node 2**

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### Datagram Packet Switching

- **Host A**
- **Host B**
- **Host C**
- **Host D**
- **Host E**

- **Node 1**
- **Node 2**
- **Node 3**
- **Node 4**
- **Node 5**
- **Node 6**
- **Node 7**
A Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:

  - Switched Communication Network
  - Packet-Switched Communication Network
  - Datagram Network
  - Virtual Circuit Network

Virtual-Circuit Packet Switching

- Hybrid of circuit switching and packet switching
  - Data is transmitted as packets
  - All packets from one packet stream are sent along a pre-established path (=virtual circuit)

- Guarantees in-sequence delivery of packets

- However: Packets from different virtual circuits may be interleaved

- Example: ATM networks
Virtual-Circuit Packet Switching

- Communication with virtual circuits takes place in three phases
  1. VC establishment
  2. data transfer
  3. VC disconnect

- Note: packet headers don’t need to contain the full destination address of the packet

Timing of Datagram Packet Switching
Packet-Switching vs. Circuit-Switching

- Most important advantage of packet-switching over circuit switching: ability to exploit statistical multiplexing:
  - Efficient bandwidth usage; ratio between peak and average rate is 3:1 for audio, and 15:1 for data traffic
- However, packet-switching needs to deal with congestion:
  - More complex routers
  - Harder to provide good network services (e.g., delay and bandwidth guarantees)
- In practice they are combined:
  - IP over SONET, IP over Frame Relay

Summary

- Course administrative trivia
- Internet history and trivia
- Rest of the course a lot more technical and (hopefully) more exciting