EE 122: Introduction To Communication Networks

Fall 2011

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http://inst.eecs.berkeley.edu/~ee122/

Materials with thanks to Jennifer Rexford, Ion Stoica, Vern Paxson and other colleagues at Princeton and UC Berkeley
Why is this room so full?

• Double the normal enrollment
  – Lack of CS offerings this semester

• This is the biggest room we could find
  – We’ve changed rooms twice…..

• Good news: many of you will drop the course
  – Hopefully everyone will have a seat in steady-state
Why is this class scheduled so late?

- Initially scheduled for an earlier slot

- Students complained about clashing with 162
  - Which was especially problematic given lack of courses

- This was the only slot left with a large room
  - And even this room isn’t large enough!
Are you in the right 122 class?

- **Spring** offering: taught by EE faculty
  - More emphasis on diverse link technologies, wireless, communication theory, and mathematical analysis

- **Fall** offering: taught by CS faculty
  - More emphasis on Internet architecture and real-world practice

*Make sure class is the right one for you!*
Why does powerpoint keep crashing?

• No idea, but it went unstable earlier this week
• Will reinstall this weekend, but bear with me today
Today’s lecture will cover two topics

• Course overview
  – Material covered
  – People involved
  – Problems with course
  – Projects
  – Policies and administrivia

5 Minute Electronics Break

• Four basic questions
  – Why are networking courses so terrible?
  – Why is it important to study networking?
  – Why is this an exciting time for networking?
  – Why is networking so hard?
This class focuses on the Internet

• Many other communication networks
  – Telephone (landline) networks
  – Cellular networks
  – Supervisory control and data acquisition networks
  – Frame relay networks

  (much more money spent on non-IP equipment!)

• Internet only one that matters for computer science
  – When computers use these other networks for IP-based communication, they are part of the Internet!
  – The Internet is not a network “technology”, it is the paradigm that ties networks together! (Internet)
What topics will course cover?

• The core of the Internet “architecture”:
  – IP, DNS, BGP

• Other technologies crucial to the Internet
  – Higher-level protocols: TCP, HTTP, applications,…
  – Lower-level technologies: Ethernet, wireless…

• If a networking technology isn’t a core piece of the Internet, we won’t cover it
  – But that doesn’t mean it isn’t interesting
  – E.g., sensornets, low-level encoding, radio technology
Various perspectives on Internet

• Different levels of abstraction
  – Basic concepts versus actual protocols

• Different geographic scales:
  – LAN vs Enterprise vs WAN vs Interdomain

• Different conceptual approaches:
  – Architecture vs Protocol vs Algorithm

• Different aspects of functionality:
  – Different “layers” focus on different tasks
The Internet: an hourglass with layers
Most networking courses

• Organized around layers:
  – Top-down (K&R)
  – Bottom-up (P&D)

• Why not for this course?
  – Main distinction is not where functionality is implemented
  – It is between basic concepts and actual realization
  – If you walk through layers sequentially, do both at once

• I care most about teaching the concepts
  – Implementations needed to put these ideas into practice
  – But don’t want to lose basic concepts in sea of details
First half of course: Basics

• General overview (3 lectures)
  – Kinds of networks, basic design principles

• Idealized view of network (4 lectures)
  – Focus on fundamental conceptual questions
  – Ignore all real-world unpleasantness

• Making this vision real (5 lectures)
  – IP, TCP, DNS, Web
  – Emphasize concepts, but deal with unpleasant realities
Fundamental conceptual questions

• How can you deliver packets from source to destination?
• How do you build reliable transport on top of an unreliable network?
• How can you build applications on top of a packet delivery interface?
• How do you manage such networks?
• How can you federate a set of competing ISPs?
Second half of course: Various topics

- Congestion control
- Advanced topics in routing
- Multicast and QoS
- Security
- Ethernet
- Wireless
- Software-defined networking

Multiple Access
First lecture after midterm

• We will redesign the Internet in 90 minutes

• We will walk through the task of sending bits from one host to another
  – What do addresses look like?
  – What is network security, and how do we achieve it?
  – ....

• We will discuss possible alternatives and come up with a design

• Question: Do you think we’ll come up with better design than the current Internet?
People: Teaching Assistants

• Ganesh Ananthanarayanan
• Justine Sherry
• Kristin Stephens
• Shaddi Hasan
• Tathagata Das ("TD")
• Yahel Ben-David
Instructor: Scott Shenker

• Trained as a physicist (phase transitions, chaos)

• Research: physics, economics, operating systems, security, distributed systems, datacenter design…
  – Diversity reflects my learning and teaching style

• For last 25 years, main focus has been networking and Internet architecture

• Office hours Thursday 9:30-10:30 in 415 Soda Hall
  – Always ping me by email before heading over
  – And by appointment (arrange by email)
  – On campus M, W, Th; on email 24 hours/day
  – Available after class
This course has many problems

• My teaching style:
  – Not for everyone

• Structure of course
  – Textbook
  – Projects

• Nature of networking
  – Covered in 2nd half of lecture
I don’t think visually

• “Uses blackboard terribly. Very poor diagrams when using it. and not legible also.”

• “For the love of god, use more pictures and diagrams.”

• I’m not going to turn into a blackboard virtuoso or animation wizard

• Ask TAs for pictures

• Will try to use other visual means
  – Watch for our re-enactment of reliable transport…..
When you look bored, I speed up

• “Pace gets faster if no one asks questions.”

• If you are bored, feel free to sleep (at your peril)

• If you are lost, ask me a question!
  – Or just yell “HELP!”
I hate details

• “Moves very quickly during difficult topics and slowly during basic topics.”
• Will try to go over examples in more depth
• Sections will go over these topics in even more depth
Can’t always engage class

• “He asks questions but no one answers”

• Will experiment with “participatory learning”
  – Using index cards
  – Used by Patterson & Katz in 61c

• Will look for other ways to get class engaged

• But, I don’t ask questions to get answers.....
I ask questions so you can think!

• The pause after I ask a question is the only time you get to think
  – When I ask a question, I don’t care if you answer it
  – But please, *think about the question*!

• The best way to understand networking is to *first* try to solve the design issues yourself
  – Then the current solution will make a lot more sense

• Designs not principled, just opportunistic
  – Can’t “follow the logic”, have to try designing it yourself
I won’t remember your name

• Prosopagnosia (as described by Oliver Sacks)
• In my case, it isn’t recognizing faces, but attaching names to faces

• Don’t take it personally….  
  – Can’t attach names to faces for over 50% of the faculty
Textbook is not useful

• “Book is worthless and not used.”

• For reasons I will discuss later, networking is a very hard area to teach. The textbook isn’t great, but it is about as good as they come.

• Use only as reference, and source of examples
  – Those details I like to ignore? Go read about them.

• You will not be tested on material I didn’t cover
Projects unrelated to material

- “project boring, unrelated to course”
- “relate project to lectures”

- Have reworked projects entirely.
  - Less focus on systems programming
  - More focus on the protocols being implemented
  - Related to the content of the course

- All programming in Python
  - You should be able to pick it up on-the-fly
  - Programs will have limited complexity
Three projects

• Project 1: Reliable transport (in simple simulator)

• Project 2: Routing (in simple simulator)

• Project 3: Adding functionality to a home router
  – Larger project, still in design phase
  – Will implement on your own Plug computer
  – Donated by Marvell

• TAs will handle all project-related questions!
Administrivia: Textbook


• 4th Edition ok, but translate the reading assignments
Class communications

• Web site: http://inst.eecs.berkeley.edu/~ee122/
  – Assignments, lecture slides (not always before lecture)
  – If you are following the slides during lecture, please don’t use them to answer questions I ask

• Use bspace to hand in homework, send announcements

• Use Piazza for all other intraclass communication
  – You should all be signed up now

• Fill out questionnaire
  – Go to announcements on class web page
  – http://tinyurl.com/4x6uo8r
Class workload

• Three projects (covered earlier)

• Four homeworks
  – Strict due dates (no slip days!)
  – Deadlines are generally 5:00PM prior to lecture
  – Deadly boring, but designed to prepare you for exams

• Exams
  – Midterm: Monday October 17 in class
  – Final: Thursday Dec 15 location TBD, 11:30AM-2:30PM
  – Closed book, open crib sheet
# Grading

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homeworks</td>
<td>20% (5% each)</td>
</tr>
<tr>
<td>Projects</td>
<td>40% (10+10+20)</td>
</tr>
<tr>
<td>Midterm exam</td>
<td>15%</td>
</tr>
<tr>
<td>Final exam</td>
<td>25%</td>
</tr>
</tbody>
</table>

- Course graded to mean of B
No Cheating

• Fine to *talk* with other students about assignments
  – But only general concepts, not specifics

• General rule: no copying of specifics
  – If you’re unsure, then ask.

• Will use automated similarity detection

• *Don’t be an idiot*....
Don’t read your @#$%^!$ email

• We will have a 5 minute e-break in middle of class

• But if you want to spend class-time staring at your screen, please stay home
5 Minute E-Break
*(fill out questionnaire!)*

Questions Before We Proceed?
Four Questions

• Why are networking courses so terrible?
• Why is it important to study networking?
• Why is this an exciting time for networking?
• Why is networking so hard?
1: Why are networking courses so bad?

- **Reason 1**: The basic Internet architecture has not changed since its invention over 35 years ago
  - Even IPv6 is very similar to IP

- Can’t test an Internet architecture in lab or testbed
  - So we only understand what we currently have

- **We are teaching history, not principles**
  - You will learn “first tries” not “fundamental answers”
  - As if we taught MS-DOS in an operating system course
Bad networking courses, continued….

• **Reason 2:** No intellectual framework for networking

  • Internet inventors defined a brilliant paradigm
    – Since then, community has focused on protocols to realize this paradigm

  • Research community has failed to provide a general framework for understanding protocols

• We therefore just teach a big bag of protocols
  – And let you try to make sense of it yourself
Reason 3: Quote from John Day

There is a tendency in our field to believe that everything we currently use is a paragon of engineering, rather than a snapshot of our understanding at the time. We build great myths of spin about how what we have done is the only way to do it to the point that our universities now teach the flaws to students (and professors and textbook authors) who don’t know better.
I will try to overcome these problems

• Focus when possible on “fundamental questions”
  – And will present alternative designs in a few lectures

• You will have to learn the current design
  – But I will point out where it falls short

• You will end up with a mixture of the “big picture” and “current design details”
2: Why important to study networking?

- Huge impact
- New paradigm
- Unresolved challenges
Internet has had tremendous impact

• Internet changed the way we gather information
  – Web, search engines

• Internet changed the way we relate to each other
  – Email, facebook, twitter

• Which would you choose?
  – Computers without the Internet (standalone PCs)
  – Internet without modern computers
The Internet introduced new paradigm

• Completely different from the phone network

• Inventors had to overcome strong technical and commercial resistance to realize their dreams

• A true success story of “thinking differently”
  – Their strong vision kept the design on track
  – Brilliant in conception, sometimes weak in execution

• While mired in details, *leave room for awe*
Many challenges remain unsolved

• **Security**
  – Security of infrastructure
  – Security of users

• **Availability**
  – Internet is very resilient
  – But availability is not sufficient for critical infrastructures

• **Evolution**
  – It is too hard to change the Internet architecture
3: Why an exciting time in networking?

- The “architecture” won’t change
  - But how we build and manage networks will

- Industry has been closed, stagnant, and feudal

- **But we are on the verge of a revolution!**
  - Commodity hardware making inroads
  - Developing intellectual (and practical) framework of applying systems principles of abstraction and modularity

- Full disclosure: I have a startup in this area
  - But approach endorsed by almost everyone else
4: Why is Networking Hard?

• There are many challenges that make designing the Internet harder than just passing bits on a wire

• Which of these apply to the phone network?
## World Internet Usage and Population Statistics

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>1,013,779,050</td>
<td>4,514,400</td>
<td>110,931,700</td>
<td>10.9 %</td>
<td>2,357.3 %</td>
<td>5.6 %</td>
</tr>
<tr>
<td>Asia</td>
<td>3,834,792,852</td>
<td>114,304,000</td>
<td>825,094,396</td>
<td>21.5 %</td>
<td>621.8 %</td>
<td>42.0 %</td>
</tr>
<tr>
<td>Europe</td>
<td>813,319,511</td>
<td>105,096,093</td>
<td>475,069,448</td>
<td>58.4 %</td>
<td>352.0 %</td>
<td>24.2 %</td>
</tr>
<tr>
<td>Middle East</td>
<td>212,336,924</td>
<td>3,284,800</td>
<td>63,240,946</td>
<td>29.8 %</td>
<td>1,825.3 %</td>
<td>3.2 %</td>
</tr>
<tr>
<td>North America</td>
<td>344,124,450</td>
<td>108,096,800</td>
<td>266,224,500</td>
<td>77.4 %</td>
<td>146.3 %</td>
<td>13.5 %</td>
</tr>
<tr>
<td>Latin America/Caribbean</td>
<td>592,556,972</td>
<td>18,068,919</td>
<td>204,689,836</td>
<td>34.5 %</td>
<td>1,032.8 %</td>
<td>10.4 %</td>
</tr>
<tr>
<td>Oceania / Australia</td>
<td>34,700,201</td>
<td>7,620,480</td>
<td>21,263,990</td>
<td>61.3 %</td>
<td>179.0 %</td>
<td>1.1 %</td>
</tr>
<tr>
<td>WORLD TOTAL</td>
<td>6,845,609,960</td>
<td>360,985,492</td>
<td>1,966,514,816</td>
<td>28.7 %</td>
<td>444.8 %</td>
<td>100.0 %</td>
</tr>
</tbody>
</table>

Two Billion Internet Users
Dynamic Range

• Round-trip times (latency) from 10μsecs to secs
  – 5 orders of magnitude

• Data rates (bandwidth) from kbps to 100 Gbps
  – 8 orders of magnitude

• Queuing delays in the network vary from 0 to secs

• Packet loss varies from 0 to 90+%
Diversity of end systems

- Cell phones
- Supercomputer clusters
- Tablets
- Televisions
- Gaming consoles
- Web cams
- Automobiles
- Sensing devices
- Picture frames
- Security systems
- Power grid
- ....
## Diversity of application requirements

- Size of transfers
- Bidirectionality (or not)
- Latency sensitive (or not)
- Tolerance of jitter (or not)
- Tolerance of packet drop (or not)
- Need for reliability (or not)
- Multipoint (or not)
- .....

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Ad hoc deployment

• Can’t assume carefully managed deployment
  – Network must work without planning
Networks contain many components

**Links**
- Fibers
- Coaxial Cable

**Interfaces**
- Ethernet card
- Wireless card

**Switches/routers**
- Large router
- Telephone switch
They can all fail....

- Consider communication that uses 50 components
  - Assume each work correctly 99% of the time
  - What is likelihood communication fails?

- Answer: success requires that they all function, so failure probability \( = 1 - (.99)^{50} \approx 39.5\% \)

- Even if nodes are 99.9% reliable, failure probability is still close to 5%

- **Must design the system to expect failure!**

- Joke: Why is the Internet like a 12-step program?
Greed

• There are greedy people out there who want to:
  – Steal your financial information (bank, credit card, etc.)
  – Use your computer for attacks

• There is a thriving underground economy for compromised computers and financial information
71. ANCHETA would develop a worm which would cause infected computers, unbeknownst to the users of the infected computers, to:
   a. report to the IRC channel he controlled;
   b. scan for other computers vulnerable to similar infection; and
   c. succumb to future unauthorized accesses, including for use as proxies for spamming.

His worm caused 1,000 to 10,000 new bots to join his botnet over the course of only three days.

73. ANCHETA would then advertise the sale of bots for the purpose of launching DDOS attacks or using the bots as proxies to send spam.

74. ANCHETA would sell up to 10,000 bots or proxies at a time.

75. ANCHETA would discuss with purchasers the nature and extent of the DDOS or proxy spamming they were interested in
79. ANCHETA would accept payments through Paypal.

103. In or about August 2004, ANCHETA updated his advertisement to increase the price of bots and proxies, to limit the purchase of bots to 2,000 “due to massive orders,” and to warn, adware on those computers without notice to or consent from the users of those computers, and by means of such conduct, obtained the following approximate monies from the following advertising service companies:

<table>
<thead>
<tr>
<th>COUNT</th>
<th>APPROXIMATE DATES</th>
<th>APPROXIMATE NUMBER OF PROTECTED COMPUTERS ACCESSED WITHOUT AUTHORIZATION</th>
<th>APPROXIMATE PAYMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEVEN</td>
<td>November 1, 2004 through November 19, 2004</td>
<td>26,975</td>
<td>$4,044.26 from Gammacash</td>
</tr>
<tr>
<td>EIGHT</td>
<td>November 16, 2004 through December 7, 2004</td>
<td>8,744</td>
<td>$1,306.52 from LOUDcash</td>
</tr>
<tr>
<td>NINE</td>
<td>January 15, 2005</td>
<td>19,934</td>
<td>$2,088.11</td>
</tr>
</tbody>
</table>
Malice

- There are malicious people out there who want to:
  - Bring your system down and/or steal confidential data

- When attacker is a nation-state, attacks are far harder to stop
  - Many defensive techniques involve stopping attacks that have been seen before
  - But nation-states can use new attack vectors
Speed of Light

• Question: how long does it take light to travel from Berkeley to New York?

• Answer:
  – Distance Berkeley → New York: 4,125 km (great circle)
  – Traveling 300,000 km/s: 13.75 msec
Networking Latencies

• Question: how long does it take an Internet “packet” to travel from Berkeley to New York?

• Answer:
  – For sure $\geq 13.75$ msec
  – Depends on:
    • The route the packet takes (could be circuitous!)
    • The propagation speed of the links the packet traverses
      • E.g., in optical fiber light propagates at about $\frac{2}{3} C$
    • The transmission rate (bandwidth) of the links (bits/sec)
      • and thus the size of the packet
    • Number of hops traversed (store-and-forward delay)
    • The “competition” for bandwidth the packet encounters (congestion). It may have to sit & wait in router queues.
  – In practice this boils down to:
    • $\geq 40$ msec
Implications for Networking

• Question: how many cycles does your PC execute before it can possibly get a reply to a message it sent to a New York web server?

• Answer:
  – Round trip takes ≥ 80 msec
  – PC runs at (say) 3 GHz
  – $3,000,000,000$ cycles/sec$\times 0.08$ sec = $240,000,000$ cycles

= An Eon
  – Communication feedback is always dated
  – Communication fundamentally asynchronous
Even a Problem for LANs

• Question: what about between machines directly connected (via a *local area network* or LAN)?

• Answer:

  % ping www.icir.org
  PING www.icir.org (192.150.187.11): 56 data bytes
  64 bytes from 192.150.187.11: icmp_seq=0 ttl=64 time=0.214 ms
  64 bytes from 192.150.187.11: icmp_seq=1 ttl=64 time=0.226 ms
  64 bytes from 192.150.187.11: icmp_seq=2 ttl=64 time=0.209 ms
  64 bytes from 192.150.187.11: icmp_seq=3 ttl=64 time=0.212 ms
  64 bytes from 192.150.187.11: icmp_seq=4 ttl=64 time=0.214 ms

• **200 µsec = 600,000 cycles**
  – Still a loooong time …
  – … and asynchronous
Summary

• The Internet is a large complicated system that must meet an unprecedented variety of challenges
  – Scale, dynamic range, diversity, ad hoc, failures, asynchrony, malice, and greed

• An amazing feat of engineering
  – Went against the conventional wisdom
  – Created a new networking paradigm

• In hindsight, some aspects of design are terrible
  – Will revisit when we do the clean slate design
  – But enormity of genius far outweighs the oversights
Next Lecture

• Read Sections 1.1-1.3 of the textbook
• Take the survey
• Try your hand at Python
• Pick up a form for your instructional account