CS 168
Introduction to the Internet: Architecture and Protocols

Fall 2014
Sylvia Ratnasamy
http://inst.eecs.berkeley.edu/~cs168/fa14/
Today

- Introductions
- What is (this course on) networking about?

5 minute break

- Class policies, administrivvia and roadmap
Introductions
Teaching Assistants

- Peter Gao
- Sangjin Han (co-head TA)
- Anurag Khandelwal
- Chang Lan
- Murphy McCauley
- Akshay Narayan
- Radhika Mittal (co-head TA)
- Shoumik Palkar
- Qifan Pu

See the course website for TA office hours and sections
Peter Xiang Gao

- 2nd year PhD student
- Research focus
  - fault-tolerant network devices
Sangjin Han

- Co-Head TA
- 4th year PhD student
- Research focus:
  - high performance network software
Anurag Khandelwal

- 2nd year PhD student
- Research focus
  - cloud computing
Chang Lan

- 2nd year PhD student
- Research focus
  - programmable routers
Murphy McCauley

- 2nd year PhD student
- Research focus
  - Software-Defined Networking
Radhika Mittal

- Co-Head TA
- 3rd year PhD student
- Research focus:
  - network congestion control
  - and queue management
Akshay Narayan

- Senior
- Research focus
  - Congestion control in datacenters
Shoumik Palkar

- Senior
- Research focus
  - Programmable routers
Qifan Pu

• 2nd year PhD student
• Research focus
  • Distributed systems
Instructor: Sylvia Ratnasamy

- Ph.D. in Computer Science from UCB in 2002
- Worked at Intel between 2002-2011; back at UCB since 2011
- Networking has been my research focus throughout

- My teaching style
  - I talk too fast
  - The more bored you look, the faster I talk
  - So, stop me with questions!!

- Office hours: 4:30-5:30pm Thursday in 413 Soda Hall
  - Always happy to chat if you have a problem (send email)
What is networking about?
while (...) {
  message = ...
  send (message, ...)
}

while (...) {
  message = receive(...)
}
Alice

hello

give me http://cs.berkeley.edu

hello

here: ...
Hello

Give me http://...

Give me http://...

Give me http://...

Give me http://...

Give me http://...

Give me http://...

Give me http://...
Why study the Internet?
The Internet is transforming everything

- The way we do business
- E-commerce, advertising, cloud computing

- The way we have relationships
- Facebook friends, email, IM, virtual worlds

- The way we learn
- Wikipedia, MOOCs, search engines

- The way we govern and view law
- E-voting, censorship, copyright

- The way we cure disease
- Digital health, remote diagnostics
The Internet is big business

- Many large and influential networking companies
  - Cisco, Broadcom, AT&T, Verizon, Akamai, Huawei, …
  - $200B+ industry (carrier and enterprise alone)

- Networking central to most technology companies
  - Google, Facebook, Microsoft, HP, Dell, VMware, …
The Internet started as a research experiment!

4 of 10 most cited authors work in networking

Many successful companies have emerged from networking research(ers)
But why is the Internet interesting?

“What’s your formal model for the Internet?” -- theorists

“Aren’t you just writing software for networks” – OS community

“You don’t have performance benchmarks???” – hardware folks

“It’s just another communication network!” – old timers at AT&T

“What’s with all these TLA protocols?” – all

“But the Internet seems to be working…” – my parents
A few defining characteristics of the Internet
A federated system

The Internet interconnects different networks (>18,000 ISPs)

One common protocol -- the “Internet Protocol (IP) -- between users and the network and between networks
A federated system

- Interoperability is the Internet’s most important goal

- Leads to a constant tussle between business and technical factors
  - competing ISPs must cooperate to serve their customers
  - practical realities of incentives, economics and real-world trust determine physical topology and path selection
  - a common protocol is great for interoperability …
  - … but complicates innovation
Tremendous scale

- 2.92 Billion users (41% of world population)
- 1 Trillion unique URLs (in 2008)
- 294 Billion emails sent per day
- 1.75 Billion smartphones
- 1.24 Billion Facebook users
- 100 hours of video uploaded to YouTube every minute
- Switches that move 300 Terabits/second ($10^{14}$)
- Links that carry 100 Gigabits/second
Enormous diversity and dynamic range

- **Communication latency**: microseconds to seconds ($10^6$)
- **Bandwidth**: 1Kbits/second to 100 Gigabits/second ($10^7$)
- **Packet loss**: 0 – 90%
- **Technology**: optical, wireless, satellite, copper
- **Endpoint devices**: sensors, cell phones, datacenters
- **Applications**: skype, live video, gaming, remote medicine,
- **Users**: the governing, governed, operators, selfish, malicious, naïve, savvy, embarrassed, paranoid, …
Constant Evolution

1970s:
- 56kilobits/second “backbone” links
- <100 computers, a handful of sites in the US
- Telnet and file transfer are the “killer” applications

Today
- 100+Gigabits/second backbone links
- 5B+ devices, all over the globe
- 20M Facebook apps installed per day
Asynchronous Operation

- Fundamental constraint: speed of light

- Consider:
  - How many cycles does your 3GHz CPU in Berkeley execute before it can possibly get a response from a message it sends to a server in NY?
    - Berkeley to New York: 4,125 km
    - Traveling at 300,000 km/s: 13.75 milliseconds
    - Then back to Berkeley: 2 x 13.75 = 27.5 milliseconds
    - $3,000,000,000$ cycles/sec * $0.0275 = 84,000,000$ cycles!

- Thus, communication feedback is always dated
Prone to Failure

- To send a message, **all** components along a path must function correctly
  - software, modem, wireless access point, firewall, links, network interface cards, switches,…
  - Including **human operators**

- Consider: 50 components, that work correctly 99% of time → 39.5% chance communication will fail

- Plus, recall
  - scale → lots of components
  - asynchrony → takes a long time to hear (bad) news
An Engineered System

- Constrained by limits of available technology
  - Link bandwidths
  - Switch port counts
  - Bit error rates
  - Cost
  - ...
Recap: The Internet is…

- A federated system
- Of enormous scale
- Dynamic range
- Diversity
- Constantly evolving
- Asynchronous in operation
- Failure prone
- Constrained by what’s practical to engineer
Recap: The Internet is...

- Too complex for theoretical models
- “Working code” needn’t mean much
- Performance benchmarks are too narrow
So, what do we need?

We still don’t really know…

- No consensus on what constitutes the “correct” or “best” network design
- No consensus on “top 10 problems”
- No consensus on the right prioritization of goals

Before you flee…
What we do know

- The early Internet pioneers came up with a solution that was successful beyond all imagining.
- Several enduring architectural principles and practices emerged from their work.
Architectural principles

- Decentralization [lectures: all]
- Packets [lecture# 2]
- Statistical multiplexing [lecture 2]
- Best effort service [lecture 3]
- The “end to end” design principle [lecture 8+]
- “Layered” decomposition [lectures: all]
- IP as “narrow waist” interface [lecture 8]
What we do know

- The early Internet pioneers came up with a solution that was successful beyond all imagining.
- Several enduring architectural principles and practices emerged from their work.
- But it is just one design.
- And numerous cracks have emerged over time:
  - want to diagnose problems but federation hides inner workings
  - want to block unwanted traffic but the network doesn’t authenticate
  - can’t optimize for different applications or customers
  - upgrading protocols is deeply painful
What we do know

- The early Internet pioneers came up with a solution that was successful beyond all imagining.
- Several enduring architectural principles and practices emerged from their work.
- But it is just one design.
- And numerous cracks have emerged over time.
- As have new requirements:
  - Mobility, reliability, data centers, sensors, …
Hence, networking today is still debating the big questions...

- Packets → “circuits”
- Statistical multiplexing → “reservations”
- Protocol layers
- A “narrow waist” at the network layer
- Best-effort service → “Quality of Service (QoS)”
- The “end to end” design principle → “middleboxes”
- Decentralization → “centralize”
Backing up a level

- The Internet offers us a lesson on how to reason through the design of a complex system
  - What are our goals and constraints?
  - What’s the right prioritization of goals?
  - How do we decompose a problem?
  - Who does what? How?
  - What are the tradeoffs between design options?

- In short: a lesson in how to architect a system
Network Architecture

- More about thinking rigorously than doing rigorous math
- More about understanding tradeoffs than running benchmarks
- More about practicality than optimality

Done right, can be a powerful thing
What (I hope) CS 168 will teach you

- How the Internet works
- Why it works the way it does
- How to reason through a complicated (networking) design problem
Let’s take a 5 minute break
Today

- Introductions
- What is (this course on) networking about?

  5 minute break

- Class policies, roadmap, administrivia
Class Workload

- Three projects
- Three homeworks
- Exams:
  - midterm: October 20 in class
  - final: December 18, 8-11am, location TBA
  - closed book, open crib sheet
- No lecture on November 26 (for Thanksgiving)
## Grading

<table>
<thead>
<tr>
<th>Course</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Homeworks</td>
<td>15% (3x 5% each)</td>
</tr>
<tr>
<td>3 Projects</td>
<td>40% (10+10+20)</td>
</tr>
<tr>
<td>Midterm exam</td>
<td>20%</td>
</tr>
<tr>
<td>Final exam</td>
<td>25%</td>
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</tbody>
</table>

- Course graded to mean of B
Topics we will cover

- Basic concepts  [Lectures 2, 3]
  - packets, circuits, delay, loss, protocols
- How the “insides” of the Internet work  [Lectures 3-8]
  - IP, DV/LS routing, BGP
- How endpoints use the network  [Lectures 9-16]
  - TCP, DNS, HTTP
- Crucial lower-level technologies  [Lectures 17-20]
  - Ethernet, wireless
- Important new(er) topics  [Lectures 21-26]
  - management, security, datacenters
Three projects

- Project 1: Routing (in simple simulator)
- Project 2: Reliable Transport (in simple simulator)
- Project 3: Build a network firewall
  - Larger project, in two phases

TAs will handle all project-related questions!

- 5th Edition ok, but translate the reading assignments

You will not be tested on material we didn’t cover in lecture or section

- Use as a reference and a source of examples
Enrollment and wait list

- Class size will not increase

- Wait-listed students will be admitted as and when registered students drop the class
  - If you’re planning to drop, please do so soon!
  - Waitlist will be processed in order; seniors get priority
Class communications

- Web site: [http://inst.eecs.berkeley.edu/~cs168/fa14/](http://inst.eecs.berkeley.edu/~cs168/fa14/)
  - Assignments, lecture slides, announcements

- Use your instructional account to hand in assignments
  - Accounts will be handed out next week

- Use Piazza for all other intra-class communication
  - You should all be signed up by now

- Copy Radhika (radhika@cs) and Sangjin (sangjin@cs) on any emails sent directly to me (sylvia@cs)
Policy on late submissions, re-grade requests, cheating

- Detailed description is on the class website

- Summary version:
  - You may submit assignments late or request re-grades but to a point, and it will cost you
  - The policy on re-grades for projects will be announced by the lead TA on the project and may vary across projects
  - Your responsibility to keep your code private!
  - When in doubt about the policy, ask us!
Class Participation

- We will post slides ~10 minutes before class
- **Ask and answer questions!!**
  - it helps you understand
  - it helps others understand
  - it helps you stay awake
  - it helps me stay awake
  - it’s just more fun for all of us
- Sit towards the front
- Limit electronic access for < 90 minutes
  - you will have a 5 minute break in the middle to get online
Next Steps

- For our next lecture
  - read 1.1 and 1.3 of K&R

- Make sure you are registered with the correct email address and on piazza

- Discussion sections will start on September 10
  - Sections on Wednesday and the following Monday will cover the same material
  - OK to swap sections unless we hit room capacity limits
Any questions?