EE 122: Introduction To Communication Networks

Fall 2006 (MW 4-5:30 in Cory 247)

Vern Paxson

TAs: Dilip Anthony Joseph and Sukun Kim

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

Materials with thanks to Jennifer Rexford, Ion Stoica, and colleagues at Princeton and UC Berkeley

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Goals for Today's Class

- EE 122 overview
  - Goals of the course
  - Structure of the course
  - Instructor & TAs
  - Prereqs & assignments
  - Course grading
  - Academic policies
- What makes networking challenging
  - The fundamental issues we must grapple with to build a global Internet

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What You Learn in This Course

- Insight: key concepts in networking
  - Protocols
  - Layering
  - Resource allocation
  - Security
  - Naming
- Knowledge: how the Internet works
  - Internet architecture
  - IP protocol suite
  - Applications (Web, e-mail, P2P, …)
- Skill: network programming
  - Socket programming
  - Designing and implementing protocols

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What This Course Is and Isn't

- EE122 comes in two flavors:
  - Spring offering: taught by EE faculty
    - More emphasis on diverse link technologies, wireless & mobility, communication theory & simulation
  - Fall offering: taught by CS faculty
    - More emphasis on Internet technology, applications, practice & empiricism / hands-on
  - Differences aren't huge, though
- My particular emphasis:
  - Today's *actual* (messy) Internet
    - Not yesterday's, and not much about tomorrow's
  - Security perspectives

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Structure of the Course (1st Half)

- Start at the top
  - Protocols: how to structure communication
  - Sockets: how applications view the Internet
- Then study the "narrow waist" of IP
  - IP best-effort packet-delivery service
  - IP addressing and packet forwarding
- And how to build on top of the narrow waist
  - Transport protocols (TCP, UDP)
  - Domain Name System (DNS)
  - Applications (Web, email, file transfer)
- Looking underneath IP
  - Link technologies (Ethernet, bridges, switches)

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Structure of the Course (2nd Half)

- How to get the traffic from here to there …
  - Glue (ARP, DHCP, ICMP)
  - Routing (intradomain, interdomain)
- … in a way that's both efficient and stable
  - How much data to keep in flight (the window)
  - Without clogging the network (congestion)
  - With some assurance (quality of service) … or not
- How to control network traffic …
  - Enforcing policy
  - Defending against attacks
- … and scale it to potentially huge structures
  - Peer-to-peer & overlays

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Instructor

- Vern Paxson (vern@icsi.berkeley.edu)
  - Senior scientist at the *International Computer Science Institute* and also the *Lawrence Berkeley National Lab*
    - Research focuses on network security & network measurement
  - http://www.icir.org/vern/
  - Office hours W 2:30-3:30PM in 329 Soda
    - And by appointment at ICSI
      - http://www.icsi.berkeley.edu/where.html
      - This week only by appointment
  - Phone: 666-2882
    - Email works *much* better!
  - Hearing impaired: please be ready to repeat questions & comments!

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TAs

- Dilip Anthony Joseph (dilip@eecs.berkeley.edu)
  - Office hours F 11-12 in 311 Soda
    - And by appointment
  - Section F 10-11 in 293 Cory

- Sukun Kim (binetude@eecs.berkeley.edu)
  - Office hours T 11-12 in 410 Soda
    - And by appointment
  - Section T 10-11 in 400 Cory

- Co-teach 3rd section
  - W 12-1 in 293 Cory

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Interact!

- Inevitably, you won't understand something(s) … that's my fault, but you need to help.
- Come to office hours, request an appointment, communicate by e-mail
  - We are here to help, including general advice!
  - TAs first line for help with programming problems
- Give us suggestions/complaints/feedback as early as you can
- What's your background? Tell us at
  - **http://tinyurl.com/fbc7u**

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Course Materials

- Textbooks
  - L. L. Peterson and B. Davie, *Computer Networks: A System Approach*, 3nd Edition, Morgan Kaufman, 2003.
    - Note, we jump around in it a lot
  - W. R. Stevens, B. Fenner, A. M. Rudoff, *Unix Network Programming: The Sockets Networking API*, Vol. 1, 3rd Ed., Addison-Wesley, 2004.
  - Recommended & on reserve:
    - W. R. Stevens, *TCP/IP Illustrated, Volume 1: The Protocols, Addison-Wesley, 1993.*
- Web site: http://inst.eecs.berkeley.edu/~ee122/
  - Updated frequently, including lecture slides (generally in advance)
- Mailing list: ee122@icsi.berkeley.edu
  - Sign up: http://mailman.icsi.berkeley.edu/mailman/listinfo/ee122

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Class Workload

- Four homeworks spread over the semester
  - Strict due dates (no slip days!)
  - Deadlines are generally 3:50PM prior to lecture
- Three (mini-)projects
  - Simple "echo" server (socket programming)
  - Simple Web crawler
  - "Chat" tool
    - 1st phase: design protocol
    - 2nd phase: implement to reference protocol design
  - C (or C++) required
  - Deadlines 11PM
- Exams
  - Midterm: Monday October 16
  - Final: Saturday Dec 16
  - Closed book, open crib sheet

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Prerequisites

- CS 61A, 61B
  - Programming, data structures, software engineering
  - Knowledge of C or C++
- Math 53 or 54
  - In fact, we'll be relatively light on math, though your algebra should be very solid, you should know basic probability, and you'll need to be comfortable with thinking abstractly
- Background material will ***not*** be covered in lecture. TAs will spend very little time reviewing material not specific to networking

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Grading

Homeworks	20% (5% each)
Projects	40% (10+10+20)
Midterm exam	20%
Final exam	20%

- Course graded to mean of B
  - Relatively easy to get a B, harder to get an A or a C
  - ≈ 10% A, 15% A-, 15% B+, 20% B, 15% B-, 15% C+, 10% C
  - A+ reserved for superstars (1 or 2 per class)
  - Mean can shift up for an excellent class

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No Cheating

- Cheating means not doing the assignment by yourself.
- Fine to *talk* with other students about assignments outside of class.
- No copying, no Google, etc.
- If you're unsure, then ask.
- We will do *automated similarity detection* on assignments.

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5 Minute Break

Questions Before We Proceed?

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Networking: Actually Not Boring

- How hard can it be??
- You just string a wire (or other signaling path) between two computers …
- … first one squirts bits down the link …
- … and the second one slurps them up. Right?
- Where does it get tricky?

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Why Networking Is Challenging

- Fundamental challenge: the **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

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Fundamental Challenge: Speed of Light

- Question: how long does it take an Internet "packet" to travel from Berkeley to New York?
- Answer:
  - For sure >= 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 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:
    - >= 40 msec

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Fundamental Challenge: Speed of Light

- 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 cyles/sec * 0.08 sec = 240,000,000 cycles

= An Eon

- Communication **feedback** is always *dated*
- Communication fundamentally asynchronous

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Fundamental Challenge: Speed of Light

- 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

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Why Networking Is Challenging, con't

- Fundamental challenge: we are **cheapskates** who **want it all**
- **Cheapskates**: computer science is all about *cost*
  - Or, put another way: *efficiency*
  - If cost didn't matter, networking would be **oh-so-easy**!
    - E.g., string wires between each pair of computers in the world
    - Though, um, pesky speed-of-light issues remain …
- **Want it all**: goal of the Internet is to interconnect
  - A huge number of devices
  - Using all sorts of link technologies
  - Across a very wide range of conditions
- So need to be vast in scope yet affordable

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Why Networking Is Challenging, con't

- Fundamental challenge: components **fail**
  - Network communication involves a chain of interfaces, links, routers and switches …

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Examples of Network Components

Links

Fibers

Coaxial Cable

Interfaces

Ethernet card

Wireless card

Switches/routers

Large router

Telephone switch

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Why Networking Is Challenging, con't

- Fundamental challenge: **components fail**
  - Network communication involves a chain of interfaces, links, routers and switches …
  - … **all** of which must function correctly.
- Question: suppose a communication involves 50 components which work correctly (independently) 99% of the time. What's the likelihood the communication fails at a given point of time?
  - Answer: success requires that they all function, so failure probability = $1 - 0.99^{50} = 39.5\%$.
- So we have a **lot** of components (we want it all), which tend to fail (cheapskates) …
  - … and we don't find out for an eon (speed-of-light)

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Why Networking Is Challenging, con't

- Challenge: **enormous dynamic range**
  (because **we want it all**)
  - Round-trip times (latency) vary 10 μsec's to sec's (10^5)
  - Data rates (bandwidth) vary from kbps to 10 Gbps (10^7)
  - Queuing delays inside the network vary from 0 to sec's
  - Packet loss varies from 0 to 90+%
  - End system (host) capabilities vary from *cell phones* to *supercomputer clusters*
  - Application needs vary enormously: size of transfers, bidirectionality, need for reliability, tolerance of jitter
- Related challenge: very often, there is no such thing as "typical". Beware of your "mental models"!
  - Must think in terms of design *ranges*, not points
  - Mechanisms need to be adaptive

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Why Networking Is Challenging, con't

- Challenge: **different parties must work together**
- Comes about due to network's scope
  - Once larger than a single institution, you have multiple parties with *different agendas* who still must agree how to divide the task between them ("coopetition")
- Working together requires:
  - **Protocols** (defining **who** does **what**)
    - These generally need to be standardized
  - Agreements regarding how different types of activity are treated (**policy**)
- Different parties very well might try to "**game**" the network's mechanisms to their advantage

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Why Networking Is Challenging, con't

- Challenge: **incessant rapid growth**
- Internet has sustained energetic, compound growth for **more than two decades**
  - Utility of the network scales with its size
    - ⇒ Fuels exponential growth
  - Currently about half a billion hosts
- With growth comes
  - Rapid evolution & innovation …
  - … among both the networking technology and (especially) the applications it supports.
- Adds another dimension of dynamic range …
  - … and quite a number of ***ad hoc*** artifacts
    - "Success disaster"

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Why Networking Is Challenging, con't

- Challenge: **there are Bad Guys out there**
- As the network population grows in size, so does the number of
  - Vandals
  - Crazies
- What really matters, though: as network population grows, it becomes more and more attractive to
  - **Crooks**
  - (and also spies and militaries)

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controlled.

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

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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:

COUNT	APPROXIMATE DATES	APPROXIMATE NUMBER OF PROTECTED COMPUTERS ACCESSED WITHOUT AUTHORIZATION	APPROXIMATE PAYMENT
SEVEN	November 1, 2004 through November 19, 2004	26,975	$4,044.26 from Gammacash
EIGHT	November 16,2004 through December 7,2004	8,744	$1,306.52 from LOUDcash
NINE	January 15, 2005	19,934	$2,988.11

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Cops smash 100,000 node botnet

Largest zombie army ever detected

Tom Sanders in California, vnunet.com 10 Oct 2005

Dutch authorities arrested three individuals last week accused of running one of the largest ever **hacker botnets** comprising over 100,000 **zombie PCs**.

The three men, aged 19,

ADVERTISEME

Botnet operation controlled 1.5m PCs

Largest zombie army ever created

Tom Sanders in California, vnunet.com 21 Oct 2005

A recently foiled **botnet operation** has turned out to be 15 times larger that police initially thought.

On further investigation,

ADVERTISEMENT

IBM eServer x100

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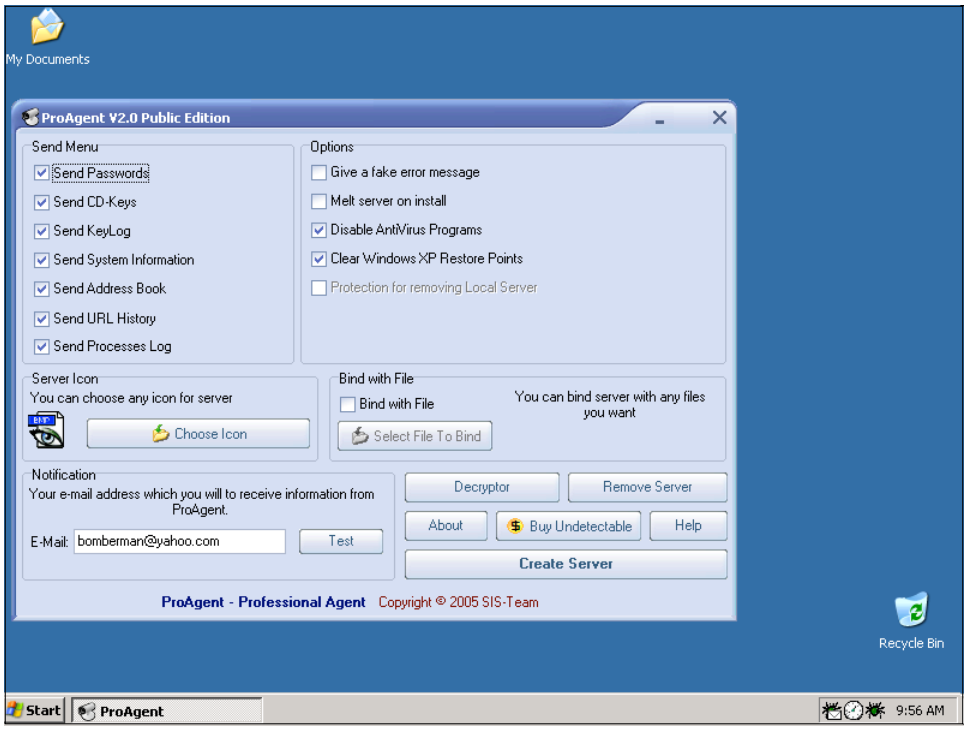

Why Crooks Matter for Networking

- They (and other attackers) seek ways to misuse the network towards their gain
  - Carefully crafted "bogus" traffic to manipulate the network's operation
    - E.g., altering Internet routing or name lookups
  - Torrents of bogus (or even legitimate) traffic to overwhelm a service (denial-of-service)
    - E.g., as an extortion threat against an ecommerce site
  - Passively recording network traffic in transit (sniffing)
    - E.g., to steal information or aid in crafting manipulative traffic
  - Exploit flaws in clients and servers using the network to trick into executing the attacker's code (compromise)
- They do all this **energetically** because there is significant $$$ to be made

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Summary

- A number of deep challenges
  - Speed-of-light
  - Desiring a pervasive global network
  - Need for it to work efficiently/cheaply
  - Failure of components
  - Enormous dynamic range (“no such thing as typical”)
  - Disparate parties must work together
  - Rapid growth/evolution
  - Crooks & other bad guys
- Next lecture: types of networks, protocols
  - Read through 1.2 of the Peterson/Davie book
  - Take the survey (**http://tinyurl.com/fbc7u)**
  - Dust off your C/C++ programming skills if need be

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