Lecture 1 – Introduction
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www.cs.cmu.edu/~prs/15-441-F14

Today’s Lecture
• Administrivia
• Why are networks important?
  • What is a network?
  • What is the Internet
  • Internet design
• A whirlwind tour of the course

Teaching Staff
• Instructors.
  • Peter Steenkiste
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• Teaching assistants.
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• staff-441@cs.cmu.edu → course staff
  • Please use this instead of emailing just one of us!
• Office hours and contact information on the web site.

Course Goals
• Become familiar with the principles and practice of data networking
  • Routing, transport protocols, naming, ...
  • Design of networks and services
• Learn how to write applications that use the network
  • A web server
  • Optimizing application performance
• Get some understanding about network internals in a hands-on way
  • TCP-style reliable congestion control
Course Format

- ~28 lectures
  - Cover the “principles and practice”
  - Complete readings before lecture
- 4 homework assignments
  - “Paper”: Do you understand and can you apply the material?
  - “Lab”: Illustrate networking concepts
  - Teach networking concepts/tools
  - Preparation for midterm and final
- 3 programming projects
  - How to use and build networks / networked applications
  - Application-layer programming; include key ideas from kernel
  - Larger, open-ended group projects. **Start early!**
- Midterm and final
  - Emphasis on understanding of course material

Recitation Sections

- Key 441 objective: system programming - C
- Different from what you’ve done before!
  - Often designed to run indefinitely. Handle all errors!
  - Must be secure
  - Interfaces specified by documented protocols
  - Concurrency involved (inter and intra-machine)
  - Must have good test methods
- Recitations address this
  - “A system hackers’ view of software engineering”
  - Help develop practical needed in projects (and beyond)
- Recitations are only one hour long!

Projects

- 3 projects: implementing application and network level functionality
  - Web server - solo
  - Congestion control with Bittorrent - team
  - Video streaming infrastructure - team
- Plan to use piazza for communication
  - See web site for details
- Must use version control – git:
  - Creating andrew directories for everyone
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Sounds Great!

How Do I Get In?

- Currently about 50 people are enrolled
  - If you do not plan to take the course, please drop it ASAP
  - While nobody is waiting for your slot, it helps in preparing projects, handouts, ...
- We will be able to clear the waiting list
  - About 30 people on the waiting list
- But only if you have enough credits!
  - If you are maxed out on courses, please drop one so we can move you
Administrative Stuff

• Watch the course web page
  • http://www.cs.cmu.edu/~prs/15-441-F14/
  • Handouts, readings, …
  • Always check here first

• Office hours posted on web page
  • Make an appointment if you have a conflict

• Course secretary
  • Kathy McNiff, Gates 9213
  • Pick up graded assignments, …

Grading

• Roughly equal weight in projects and testing
  • 45% for Projects I, II and III
  • 15% for Midterm exam
  • 25% for Final exam
  • 15% for Homework

• You MUST demonstrate competence in both projects and tests to pass the course
  • Fail either and you fail the class!

Policy on Collaboration

• Working together is important
  • Discuss course material in general terms
  • Work together on program debugging, …
  • Final submission must be your own work
    • Homeworks, midterm, final

• Projects: Solo (P1) + Teams of two (P2,P3)
  • Collaboration, group project skills
  • Both students should understand the entire project

• Web page has details, e.g., university policy, etc.

• Things we don’t want to have to say: We run projects through cheat-checkers against all previously and concurrently handed in versions…

Late Work and Rereading

• Late work will receive a 15% penalty/day
  • No assignment can be more than 2 days late
  • Only exceptions are documented illness and family emergencies

• Requests for rereading must be submitted in writing to course secretary within 2 weeks.
  • Do not contact us by e-mail
  • Office hours are fine for discussion but not for regrading
  • Rereading of assignment will be done by original grader

• No assignments with a “short fuse”
  • Homeworks: ~1-2 weeks - Projects: ~4 weeks
  • Start on time!
  • Every year some students discover that a 4 week project cannot be completed in a week
The Slides

• The slides are a resource that is shared by the many instructors of 15-441
  • Also some sharing with 18-345

• They include contributions from Peter Steenkiste, Srini Seshan, Dave Andersen, Hui Zhang, Eric Anderson, and others

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What is a Network?

• An infrastructure that allows (distributed) “users” to communicate with each other
  • People, devices, …
  • By means of voice, video, text, …
  • Focus on electrical/optical/RF/… (not trucks)

• It is assumed that the infrastructure shared by many users
  • Point to point link is not very interesting
  • Value increases with the number of users!

Basic Building Block: Links

• Simplest example: 2 nodes
  • Sender changes voltage, frequency, …
  • Or maybe it is optical or wireless?

• But receiver must “understand” sender – protocols
  • More on this later

• Okay… what about more nodes?

• How about a million?
Scaling the Network

(N^2) Wires for everybody!

Or one wire

But First a bit of History

Telegraphs & Long-Distance Message Communications

- Courier: physical transport of the message
  - Messenger pigeons, pony express, FedEx
- Telegraph: message is transmitted across a network using signals – much faster!
  - Drums, beacons, mirrors, smoke, flags,
  - Light, electricity

Electric Telegraph Networks

- Electric telegraph networks exploded
  - Message switching & Store-and-Forward operation
  - Key elements: Addressing, Routing, Forwarding
- Optical telegraph networks disappeared

Bell’s Telephone

- Alexander Graham Bell (1875) working on harmonic telegraph to multiplex telegraph signals
- Discovered voice signals can be transmitted directly
  - Microphone converts voice pressure variation (sound) into analogous electrical signal
  - Loudspeaker converts electrical signal back into sound
- Telephone patent granted in 1876
- Bell Telephone Company founded in 1877

Signal for “ae” as in cat

sound Electrical signal sound
Circuit Switching

- Source first establishes a connection (circuit) to the destination
  - Each switch along the way stores info about connection (and possibly allocates resources)
- Source sends the data over the circuit
  - No need to include the destination address with the data since the switches know the path
- The connection is explicitly torn down
- Example: telephone network (analog)

Three Phases of a Connection

1. Pick up phone
2. Dial tone.
3. Dial number
4. Network selects route; Sets up connection; Called party alerted
5. Exchange voice signals
6. Hang up.

Links and Switches in Early Telephone Networks

Circuit Switching Discussion

- Circuits have some very attractive properties.
  - Fast and simple data transfer, once the circuit has been established
  - Predictable performance since the circuit provides isolation from other users
  - E.g. guaranteed bandwidth
- But it also has some shortcomings.
  - How about bursty traffic
    - Do you need a permanent circuit to Facebook?
    - Circuit will be idle for significant periods of time
  - How about users with different bandwidth needs
Contrast this with Message (Packet) Switching (our emphasis)

- Source sends information as self-contained messages that have an address.
  - Source may have to break up single message in multiple packets
- Each packet travels independently to the destination host.
  - Switches use the address in the packet to determine how to forward the packets
  - Store and forward
- Analogy: a letter in surface mail.

And Some More Examples …

- Television network
  - Over the air
  - Cable TV
  - Satellite
- Radio broadcast
- Various private networks
  - E.g., for first responders, military, ..

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What about the Internet

  - Networks are connected using routers and other devices, e.g., for security, accounting, ...
  - Networks can use diverse technologies
  - Typically managed by different organization
- The Internet: the interconnected set of networks of the Internet Service Providers (ISPs)
  - About ~23,000 “transit” ISPs make up the Internet
  - Many more “edge” networks
What is the Objective of the Internet?

- Enable communication between diverse applications on diverse devices (“computers”)
  - Web, peer-to-peer, video streaming, distributed processing, video and audio conferencing, …
- Over very diverse infrastructures
  - The “Internet”, WiFi and cellular, data center networks, corporate networks, dedicated private networks, …
- In contrast: previous networks were special purpose and fairly homogeneous in terms of technology
- Must understand application needs/demands (Thursday)
  - Traffic data rate and loss sensitivity
  - Traffic pattern (bursty or constant bit rate)
  - Traffic target (multipoint or single destination, mobile or fixed)

Packet Switching – Statistical Multiplexing

- Switches arbitrate between inputs
- Can send from any input that’s ready
  - Links are never idle when there is traffic to send
  - (Efficiency!)

Multiplexing

- Need to share network resources

- How? Switched network
  - Party “A” gets resources sometimes
  - Party “B” gets them sometimes
  - Interior nodes act as “Switches”
- Many challenges: fairness, efficiency, …

Internet Design

- In order to inter-operate, all participating networks must follow a common set of rules
- Example: requirements for packets:
  - Address format, header information, packet size limit, …
- But also: routing, error reporting, billing, …
- Also: what is the “service model”, i.e., the commitment made to applications
  - Internet: best-effort – packets can get lost, etc.
  - But some applications need reliable data delivery, a minimal bandwidth guarantee, low latency, …
Networks Juggle Many Goals

- Support rich set of applications
- Efficiency – resource use; cost
- The “ilities”:
  - Evolvability
  - Managability
  - Security (securability, if you must)
- Ease of:
  - Deployment
  - Management
  - Creating useful applications
- Scalability

Must also Deal with “Real World”

- Economics and public policy play a big role in the design of the Internet
  - ISPs are competing for customers but they must also work together
  - They must make money – no ISPs, no Internet
- Public policy looks after user interests and tries to promote competition and innovation
- Users will only use the network if they get value out of it
  - Concerns such as privacy can stifle use

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Whirlwind Tour of the Course

- Infrastructure: hardware (or close to it)
- Core networking protocols: IP, dealing with errors and congestion, routing, …
- Optimizing performance: QoS techniques, caching, CDNs, peer-peer, …
- Making it work well: security, management, …
- IP everywhere: the Internet, last mile, wireless, mobility, data center, video, IP-TV, skype, …
- Focus is on today’s Internet but also trends
  - What will the Internet look like in 10, 20, 30 years?
Infrastructure

- Why do we have different types of “wires”?
  - And why do I care?
- Ethernet is very old, so why is it so fast?
  - Can’t they find something better?
- What are the limits of some of the technologies?
  - Both physical and protocol limits

Core Networking Protocols

Think: traffic on the roads

- How do I found a path to my destination
- How do I specify addresses
- What if my car breaks down?
- How do I deal with traffic jams
  - …

Optimizing Performance

- Intuitively: lots of bandwidth!
- But there is more to it:
  - Latency is often more critical!
  - How voice and video – can I offer guarantees?
  - Can I beat the speed of light?
    - Hint: this can make you reach
  - Why did we use peer to peer networks?
  - And why did they (mostly) go away?

Making the Network Work Well

- Good technology is only a small part of the puzzle – deployment and management issues are equally (or more) critical
  - Involves many people, high cost
  - How do I secure my network?
    - Lots of bad guys: DOS, compromised hosts, privacy leaks, botnets, …
  - How I manage resources, reduce operator errors, deal with failures, …
    - And how does it differ in LAN, WAN, wireless, …
IP Everywhere

- Using IP technology has become attractive
  - Cheap commodity hardware, lots of tools, people trained in the technology, end-to-end support, …
- The (public) Internet: our focus
  - How do you optimize “the web”: CDNs, caching, …
- Data centers: very special requirements
  - Map-reduce, 3-tier business apps, load balancing, …
- IP TV, voice/video conferencing:
  - Very high QoE expectations
- Wireless and mobile apps
  - For many users, primary way of accessing Internet
- Residential networking

Next Lecture

- Applications and their requirements
- How to determine split of functionality
  - Across protocol layers (more in a few minutes)
  - Across network nodes
- Read two papers on the motivations for the Internet architecture (web site):
  - “The design philosophy of the DARPA Internet Protocols”, Dave Clark, SIGCOMM 88
  - “End-to-end arguments in system design”, Saltzer, Reed, and Clark, ACM Transactions on Computer Systems, November 1984