Cast

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- **How to reach us: Piazza**
  
  https://piazza.com/brown/fall2016/cs168
Overview

• **Goal: learn concepts underlying networks**
  – How do networks work? What can one do with them?
  – Gain a basic understanding of the Internet
  – Gain experience writing *protocols*
  – Tools to understand new protocols and applications

  “*From 2 communicating machines to the entire Internet*”
Prerequisites

• **CSCI-0330** (or equivalent).
  – We assume basic OS concepts (kernel/user, threads/processes, I/O, scheduling)

• **Low-level programming** or be willing to learn quickly
  – threads, locking, explicit memory management, …

• **We allow any* language**
  – No high-level networking APIs, though (unless you write them yourself)
  – You will be bit twiddling and byte packing…
Administrivia

- All assignments will be on the course page
  http://www.cs.brown.edu/courses/cs168/f16
- Texts (not required):
  - Peterson and Davie, Computer Networks - A Systems Approach, 4th or 5th editions or
  - Kurose and Ross, 'Computer Networking: A Top-Down Approach (6th or 7th editions)
- You are responsible to check the web page!
  - All announcements will be there
  - Textbook chapters corresponding to lectures: read them before class
  - Handouts, due dates, programming resources, etc…
  - Subject to change (reload before checking assignments)
Grading

• “Written” component
  – Exams: Midterm (15%) and Final (25%)
  – Homework: 3 written assignments (15%)
    • Short answer and design questions

• 4 Programming Projects (45%)
  – Snowcast: streaming music server
  – IP, as an overlay, on top of UDP
  – TCP, on top of your IP
  – Final (short, fun, to be decided)

• Must pass two components individually
Networks

• What is a network?
  – System of lines/channels that interconnect
  – *E.g.*, railroad, highway, plumbing, postal, telephone, social, computer

• Computer Network
  – Moves information
  – Nodes: general-purpose computers (most nodes)
  – Links: wires, fiber optics, EM spectrum, composite…
Why are computer networks cooler?

• Many nodes are general-purpose computers
• Very easy to innovate and develop new uses of the network: you can program the nodes
• Contrast with the ossified Telephone network:
  – Can’t program most phones
  – Intelligence in the network, control by parties vested in the status quo, …
Growth of the Internet

1969 - UCLA creates ARPANET, the beginning of the INTERNET
1982 - e-Commerce appearance (ATM and telephone banking)
1990 - Official public face of the INTERNET
1994 - e-Commerce online appearance
1995 - ICQ launching
1998 - Dot-Com companies collapse
2000 - Internet Marketing beginning
2001 - SEO beginning
2002 - PAYPAL.COM official launching
2005 - 1.1 Billion users on the network
2007

Source: Miguel Angel Todaro
During 2008, the number of things connected to the Internet exceeded the number of people on earth.

By 2020 there will be 50 billion.

These things are not just smartphones and tablets. They’re everything.

A Dutch startup, Sparked, is using wireless sensors on cattle.

Source: Cisco
Traceroute map of the Internet, ~5 million edges, circa 2003. opte.org
Why should you take this course?

• **Impact**
  – Social, economic, political, educational, …
  – Why should you care about NetNeutrality?
  – What does it mean to run out of IP addresses?
  – How could Egypt shut down the Internet internally?
  – How could Pakistan shut down Youtube *globally*?

• **Continuously changing and evolving**
  – Incredible complexity
  – Any fact you learn will be inevitably out of date
  – Learn general underlying *principles*

• **Learn to program the network**

• **Networks are cool!**
Roadmap

• **Assignments: learn by implementing**
  – Warm up: Snowcast, a networked music server
    • Get a feel for how applications use the network

• **Build knowledge from the ground up**
  – Link individual nodes
  – Local networks with multiple nodes
  – IP: Connect hosts across several networks
  – Transport: Connect processes on different hosts
  – Applications

• **A few cross-cutting issues**
  – Security, multimedia, overlay networks, P2P…
Two-minutes for stretching...

(and an opportunity to sneak out if you are shopping)
Building Blocks

• Nodes: Computers (hosts), dedicated routers, …
• Links: Coax, twisted pair, fiber, radio, …
How to connect more nodes?

Multiple wires

Shared medium
From Links to Networks

- To scale to more nodes, use *switching*
  - Nodes can connect to multiple other nodes
  - Recursively, one node can connect to multiple networks
Switching Strategies

• **Circuit Switching** – virtual link between two nodes
  – Set up circuit (e.g. dialing, signaling) – may fail: busy
  – Transfer data at known rate
  – Tear down circuit

• **Packet Switching**
  – Forward bounded-size messages.
  – Each message can have different senders/receivers
  – Focus of this course

Analogy: circuit switching reserves the highway for a cross-country trip. Packet switching interleaves everyone’s cars.
• What to do when multiple flows must share a link?
• **Synchronous time-division multiplexing**
  – Divide time into equal-sized quanta, round robin
  – Illusion of direct link for switched circuit net
  – But wastes capacity if not enough flows
  – Also doesn’t degrade gracefully when more flows than slots
FDM

- Frequency-division multiplexing: allocates a frequency band for each flow
  - Same TV channels and radio stations
- Similar drawbacks to STDM
  - Wastes bandwidth if someone not sending
  - Can run out of spectrum
Statistical Multiplexing

- Idea: like STDM but with no pre-determined time slots (or order!)
- Maximizes link utilization
  - Link is never idle if there are packets to send
Statistical Multiplexing

• **Cons:**
  – Hard to guarantee fairness
  – Unpredictable queuing delays
  – Packets may take different paths

• **Yet...**
  – This is the main model used on the Internet
Traceroute map of the Internet, ~5 million edges, circa 2003. opte.org
Managing Complexity

• Very large number of computers
• Incredible variety of technologies
  – Each with very different constraints
• No single administrative entity
• Evolving demands, protocols, applications
  – Each with very different requirements!

• How do we make sense of all this?
Layering

- **Separation of concerns**
  - Break problem into separate parts
  - Solve each one independently
  - Tie together through common interfaces: abstraction
  - Encapsulate data from the layer above inside data from the layer below
  - Allow independent evolution

- **Example**
  - A *network layer* packet from A to D is put in *link layer* frames A to B, B to C, C to D
Single Link Communication

• **Physical Layer: Several questions:**
  – Encoding: voltage, frequency, phase,…
  – Medium: copper, fiber, radio, light,…

• **Link Layer: how to send data?**
  – When to talk
  – What to say (format, “language”)

• **Examples: Ethernet, USB**
  Stay tuned for lectures 3 and 4…
Layers

- **Application** – what the users sees, *e.g.*, HTTP
- **Presentation** – crypto, conversion between representations
- **Session** – can tie together multiple streams (*e.g.*, audio & video)
- **Transport** – demultiplexes, provides reliability, flow and congestion control
- **Network** – sends *packets*, using *routing*
- **Data Link** – sends *frames*, handles media access
- **Physical** – sends individual bits
Protocols

• What do you need to communicate?
  – Definition of message formats
  – Definition of the semantics of messages
  – Definition of valid sequences of messages
    • Including valid timings
Addressing

• Each node typically has a unique* name
  – When that name also tells you how to get to the node, it is called an address
• Each layer can have its own naming/addressing
• *Routing is the process of finding a path to the destination*
  – In packet switched networks, each packet must have a destination address
  – For circuit switched, use address to set up circuit
• Special addresses can exist for broadcast/multicast/anycast

* or thinks it does, in case there is a shortage
Network Layer: Internet Protocol (IP)

- **Used by most computer networks today**
  - Runs *over* a variety of physical networks, can connect Ethernet, wireless, modem lines, etc.

- **Every host has a unique* 4-byte IP address (IPv4)**
  - *E.g.*, www.cs.brown.edu → 128.148.32.110
  - The *network* knows how to route a packet to any address

- **Need more to build something like the Web**
  - Need naming (DNS)
  - Interface for browser and server software (next lecture)
  - Need demultiplexing within a host: which packets are for web browser, Skype, or the mail program?

* NATs make this story more complicated, we’ll talk about this more
Inter-process Communication

- Talking from host to host is great, but we want abstraction of inter-process communication
- Solution: *encapsulate* another protocol within IP
Transport: UDP and TCP

• **UDP and TCP most popular protocols on IP**
  – Both use 16-bit *port* number & 32-bit IP address
  – Applications *bind* a port & receive traffic on that port

• **UDP – User (unreliable) Datagram Protocol**
  – Exposes packet-switched nature of Internet
  – Sent packets may be dropped, reordered, even duplicated (but there is corruption protection)

• **TCP – Transmission Control Protocol**
  – Provides illusion of reliable ‘pipe’ or ‘stream’ between two processes anywhere on the network
  – Handles congestion and flow control
Uses of TCP

• **Most applications use TCP**
  – Easier to program (reliability is convenient)
  – Automatically avoids congestion (don’t need to worry about taking down the network)

• **Servers typically listen on well-known ports:**
  – SSH: 22
  – SMTP (email): 25
  – Finger: 79
  – HTTP (web): 80
Strict layering not required
- TCP/UDP “cheat” to detect certain errors in IP-level information like address
- Overall, allows evolution, experimentation
IP as the Narrow Waist

- Many applications protocols on top of UDP & TCP
- IP works over many types of networks
- This is the “Hourglass” architecture of the Internet.
  - If every network supports IP, applications run over many different networks (e.g., cellular network)
Roadmap

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Coming Up

• **Snowcast: start TODAY!**

• **Next class: how do applications use the network?**
  – Introduction to programming with Sockets
  – Peterson & Davie 1.4
  – Beej’s Guide to Network Programming (link on the course website)

• **Then…**
  – We start moving up the network stack, starting from how two computers can talk to each other.