Course Summary

What have we learned: a huge amount!

- principles
- practice

….. using Internet to motivate examples
What did we do?

Introduction
- What is the Internet, protocol?
- network edge, core, access nets
- physical media
- delay, loss, throughput
- layers, service models
- Internet structure, ISPs
- history

Application layer
- application-layer protocols
- the WWW: HTTP
- FTP
- email: SMTP, POP3, IMAP
- DNS
- P2P
- Socket programming
What did we do?

Transport Layer
- services, principles
- multiplexing, demultiplexing
- UDP
- principles of reliable of data transfer: rdt
- TCP
- principles of congestion control
- TCP congestion control

Network Layer
- service model(s)
- what’s inside a router?
- addressing, IP, DHCP
- routing algorithms: link state, DV
- hierarchical routing
- routing in the Internet: RIP, OSPF, BGP
What did we do?

Link Layer, LANs
- introduction, services
- error detection, correction
- multiple access protocols
- LAN addresses, ARP
- Ethernet
- learning switches

Wireless
- channel characteristics
- Link layer: CDMA, 802.11 (WiFi)
- mobility principles: direct, indirect routing
- mobile IP
- mobility in GSM
Whither goest networking?
(a couple of examples, and some big-picture thoughts)

- Content centric networks
- Specialized networks: e.g., smart grid
- Software-defined networking
Getting connected: a history

1 413-545-1585

+55-21-2562-8668

ftp 128.119.40.186

http://www.amazon.com

host-to-host communication
The rise of content

Cisco 2011:
- P2P, video account for more than 80% of network traffic
- **content**: what, not where

"I want to watch Madmen"

**host-to-content communication**
Today’s content search/delivery

Content distribution networks (CDN):

“I want to watch Madmen”

Akamai CDN

Limelight CDN

Akamai CDN
Today’s content search/delivery

Content distribution networks (CDN):

- separate
- disconnected
- application layer, at network’s edge

“I want to watch Madmen”

hulu
A content centric network vision

Figure: [Jacobson 2009]
Caching in content-centric networking

**Traditional Networking**
- Content bound to location
- Network protocols support locating hosts in network

**Content-Centric Networking**
- Network protocols support locating content by name

Future Internet architecture proposals, including *CCN* [Jacobson 2009], *NetInf* [Ahlgren 2008] and *DONA* [Koponen 2007], utilize *caching*
The electric grid: structure

power sources

Interconnected regional transmission operators (RTOs)

edge (distribution) networks

transmission network (backbone)

distribution network (edge)
What can the smart grid learn from 40 years of computer networking research?
The smart grid: *control* plane needed

- large-scale electricity generators
- regional transmission network operator(s)
- distribution network operator(s)

*equivalent to “data” plane.*
The smart grid: *control* plane loops

- large-scale electricity generators
- regional transmission operator(s)
- distribution network operator(s)

Monitoring:
- transmission network (backbone)
- regional transmission operator(s)
- distribution network operator(s)

Monitoring demand/response, distributed generation, smart scheduling, distributed network (edge)
Current control plane: highly centralized

- **SCADA**: simple centralized polling
  - hard to scale as # data producers, consumers increase
- control plane architectural opportunities in edge networks
  - distributed generation
  - intermittent sources
  - microgrids
  - smart homes
Control plane data dissemination

publish-subscribe architecture?

- many distributed sources, sinks of data, with interests in subsets of data
- quasi-centralization via brokers consistent with Internet trend
  - separating control from data switching
  - centralization (RCP, 4D)
- challenges: reliability, manageability, security, privacy
Openflow: open network control plane
Openflow: open smart grid control plane

Network OS

Smart grid protocol

Custom Hardware

Custom Hardware

Custom Hardware

Custom Hardware
Q: Whither goest networking?

A: nobody knows! General tends:

- **ubiquity** of communications
  - IP dialtone, IP: like electricity: it’s everywhere!
  - network-capable appliances (e.g., smart homes)
  - issues of scale important: 100's of millions of network-connected devices

- **mobility** important:
  - people move, need to communicate

- **multimedia** important:
  - it is how people communicate

- **application-layer networking**: p2p, skype – services at the edge (at the application layer)
Q: Whither goest networking?

- **increasing link rates**, but bandwidth not free
  - increased bandwidth requirements of enabled apps (video to become 90% of backbone traffic?)
- **cyber-physical systems**: embedded networked devices “everywhere”
- **security, management, robustness**: critical concerns
- **agents**: processing “in” or “on” the network in support of end users
- **regulation, business models**
  - net neutrality
  - comcast vs level-3/netflix: a glimpse of things to come?
The future: a broader CS view

1980 - 1995

1995-2009

2009 - ?

Computing
Communications

Content, applications
Our Very Last Note Page!

- networking: will play a central role in computing, information processing

- this course:
  - specific architectures, protocols
  - fundamental issues: APIs, reliable data transfer, flow/congestion control, routing, multiple access, switching

- remember: you learned it HERE!