Advanced Computer Networks cs538, Spring 2016 @ UIUC

Klara Nahrstedt

Lecture 2

Based on

B. M. Leiner et al, “Brief History of the Internet”, Internet Society 2014

C. Partidge, “Forty Data Communications Research Questions”, CCR, 2011

Prior 2010-2013, lecture material by Brighten Godfrey and Matt Caesar

Announcements

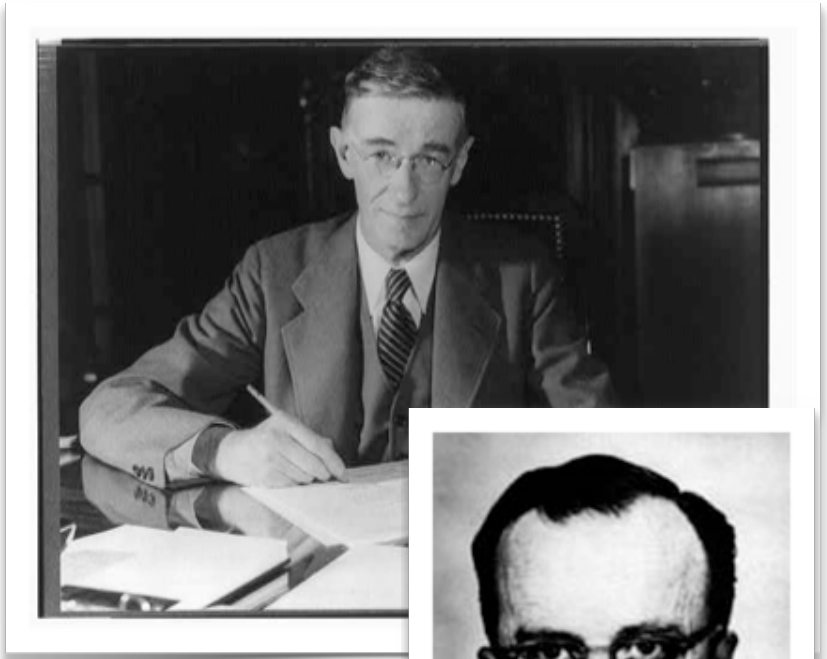
- Select reviews by January 28
- Form groups and select lecture as a group by January 28
- Read papers for January 28 lecture
  - A protocol for packet network intercommunication (Cerf and Kahn, 1974)
  - The Design Philosophy of the DARPA Internet Protocols (Clark, 1988)

Outline

- History of Internet
- Review of basic concepts
- Grand challenges – few examples

Visions

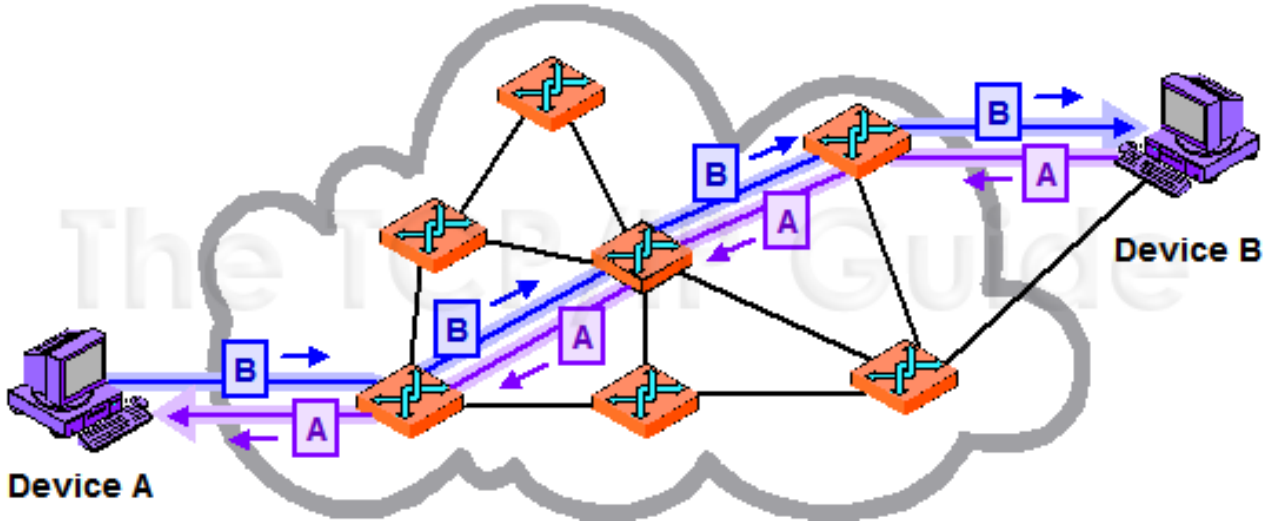
- Vannevar Bush, “As we may think” (1945): memex
- J. C. R. Licklider (1962): “Galactic Network”
  - Concept of a global network of computers connecting people with data and programs
  - First head of DARPA computer research, October 1962



Bush

Licklider

Circuit switching



1935

International operator, New York AT&T
Source: http://www.corp.att.com/history/nethistory/switching.html

1967

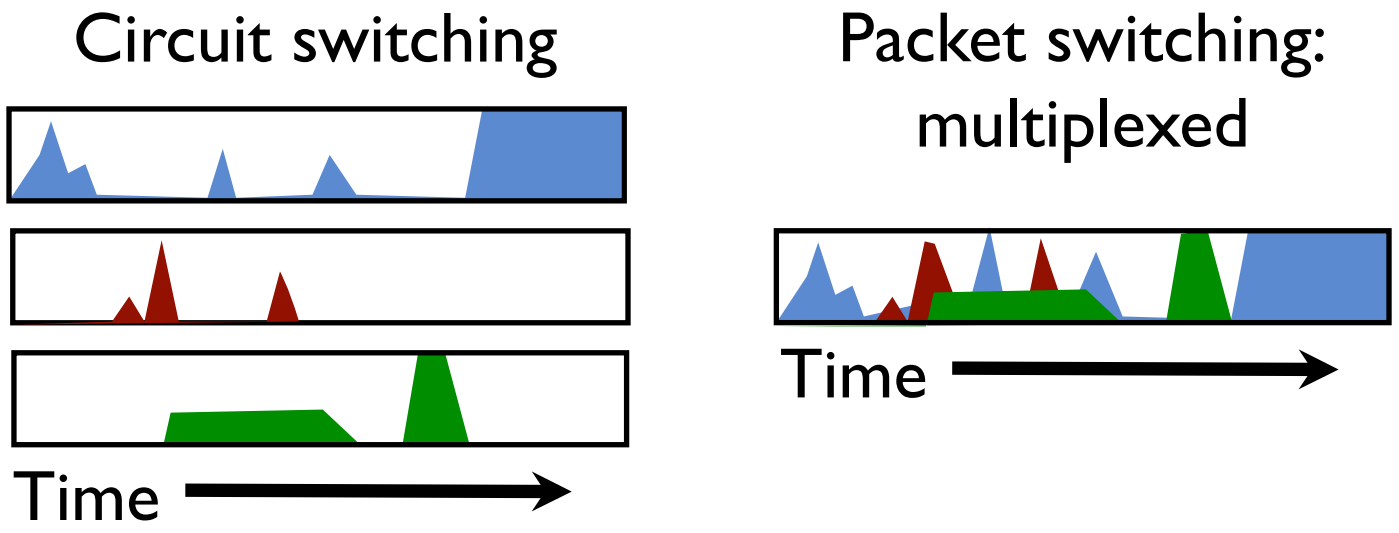
[US Air Force]

1961-64: Packet switching

Circuit Switching	Packet switching
Physical channel carrying stream of data from source to destination	Message broken into short packets, each handled separately
Three phase: setup, data transfer, tear-down	One operation: send packet
Data transfer involves no routing	Packets stored (queued) in each router, forwarded to appropriate neighbor

1961-64: Packet switching

- Key benefit: Statistical Multiplexing
  - (what else?)

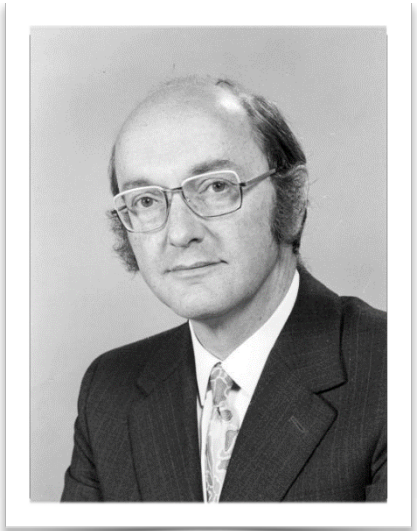


1961-64: Packet switching

- Concurrent development at three groups
  - Leonard Kleinrock (MIT): queueing-theoretic analysis of packet switching in Ph.D. thesis (1961-63) demonstrated value of statistical multiplexing
  - Paul Baran (RAND)
  - Donald Davies (National Physical Laboratories, UK)

Kleinrock

Baran



Davies

Baran's packet switching

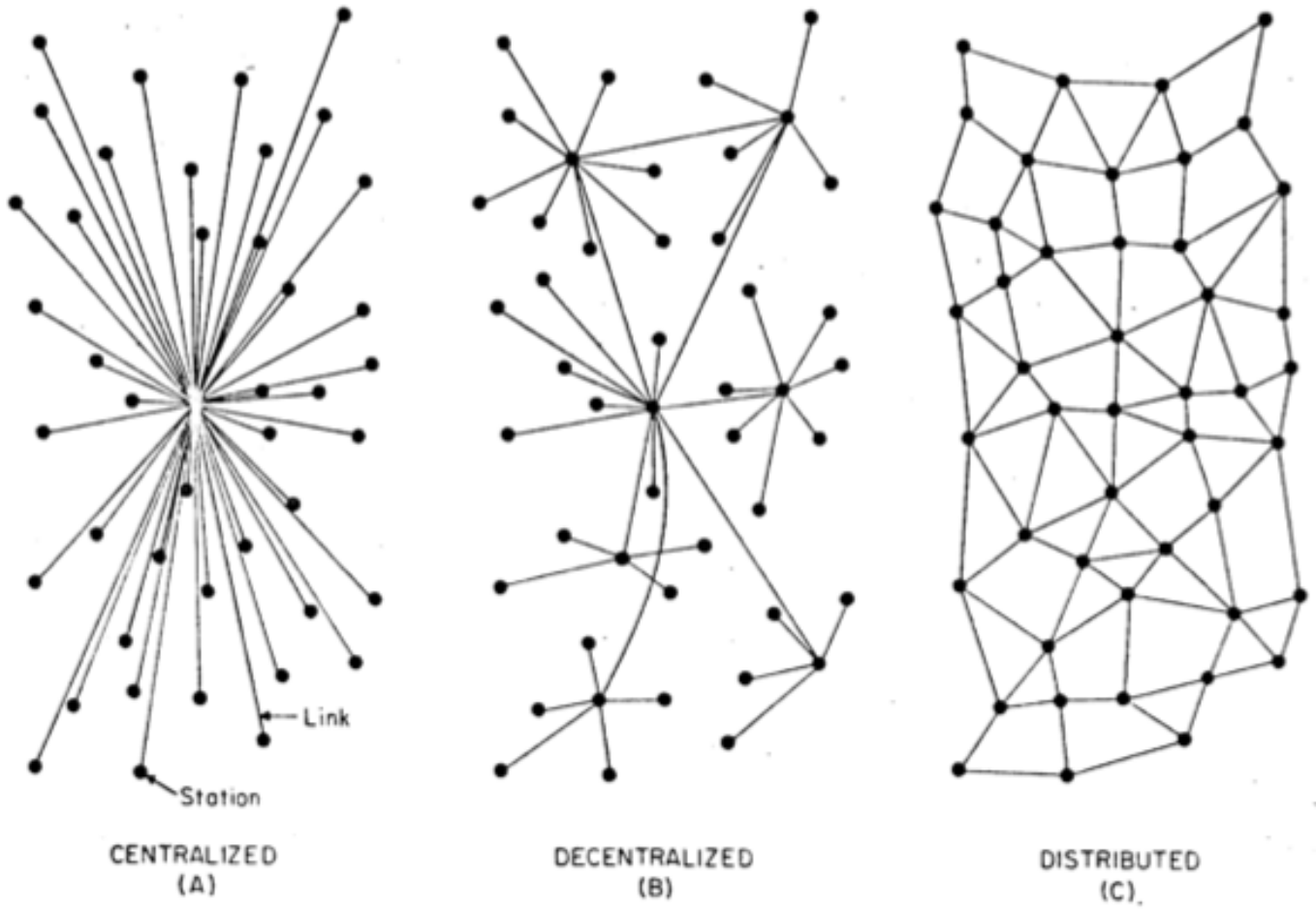


FIG. 1 – Centralized, Decentralized and Distributed Networks

Paul Baran, "On distributed communications networks", Sept. 1962

Baran's packet switching

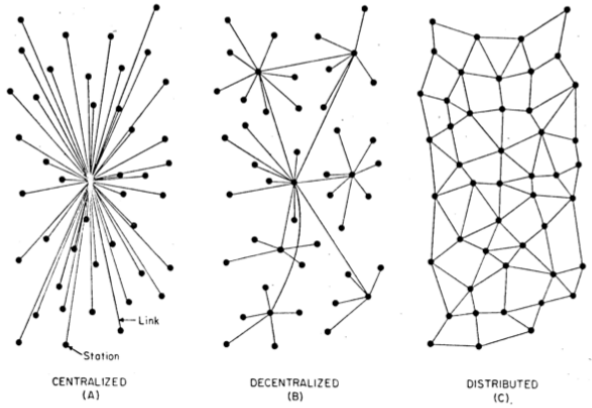


FIG. 1 – Centralized, Decentralized and Distributed Networks

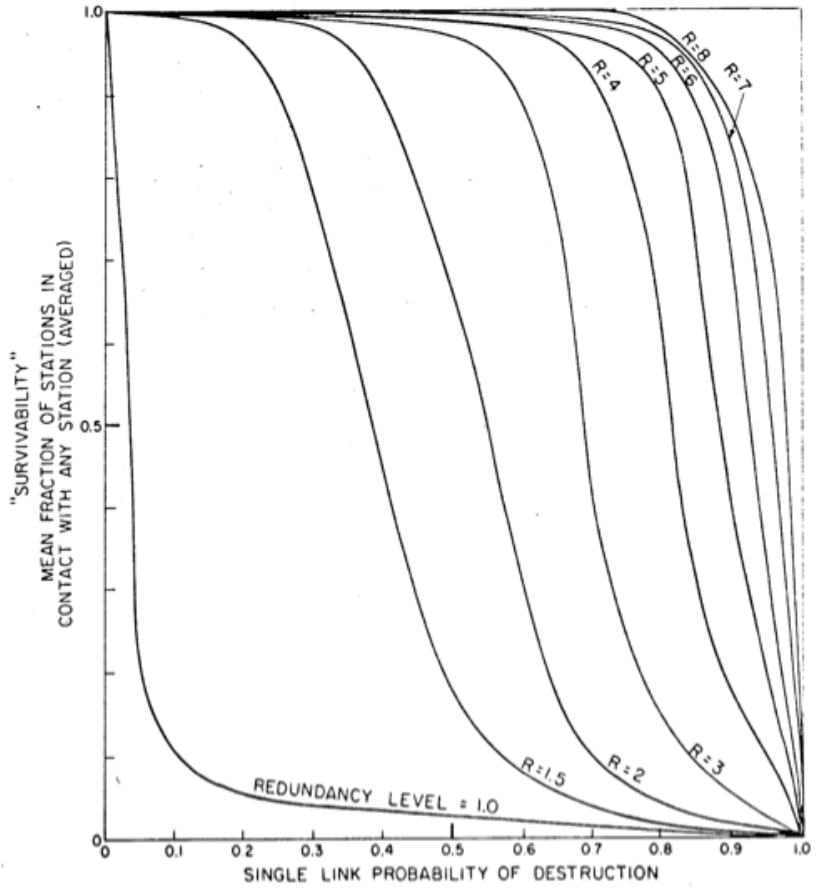


FIG. 5 – Perfect Switching in a Distributed Network – Sensitivity to Link Destruction, 100% of Nodes Operative.

Paul Baran, "On distributed communications networks", Sept. 1962

Baran's packet switching

"

There is an increasingly repeated statement made that one day we will require more capacity for data transmission than needed for voice. If this statement is correct, then it would appear prudent to broaden our planning consideration to include new concepts for future data network directions. ... New digital computer techniques using redundancy make cheap unreliable links potentially usable. ... Such a system should economically permit switching of very short blocks of data from a large number of users simultaneously with intermittent large volumes among a smaller set of points.

"

Paul Baran, "On distributed communications networks", Sept. 1962

1965: First computer network

- Lawrence Roberts and Thomas Merrill connect a TX-2 at MIT to a Q-32 in Santa Monica, CA
- ARPA-funded project
- Connected with telephone line
  - works, but it's inefficient and expensive
  - confirmed one motivation for packet switching
- Roberts utilized Davies' packet switching theory late 1960's and built into ARPANET

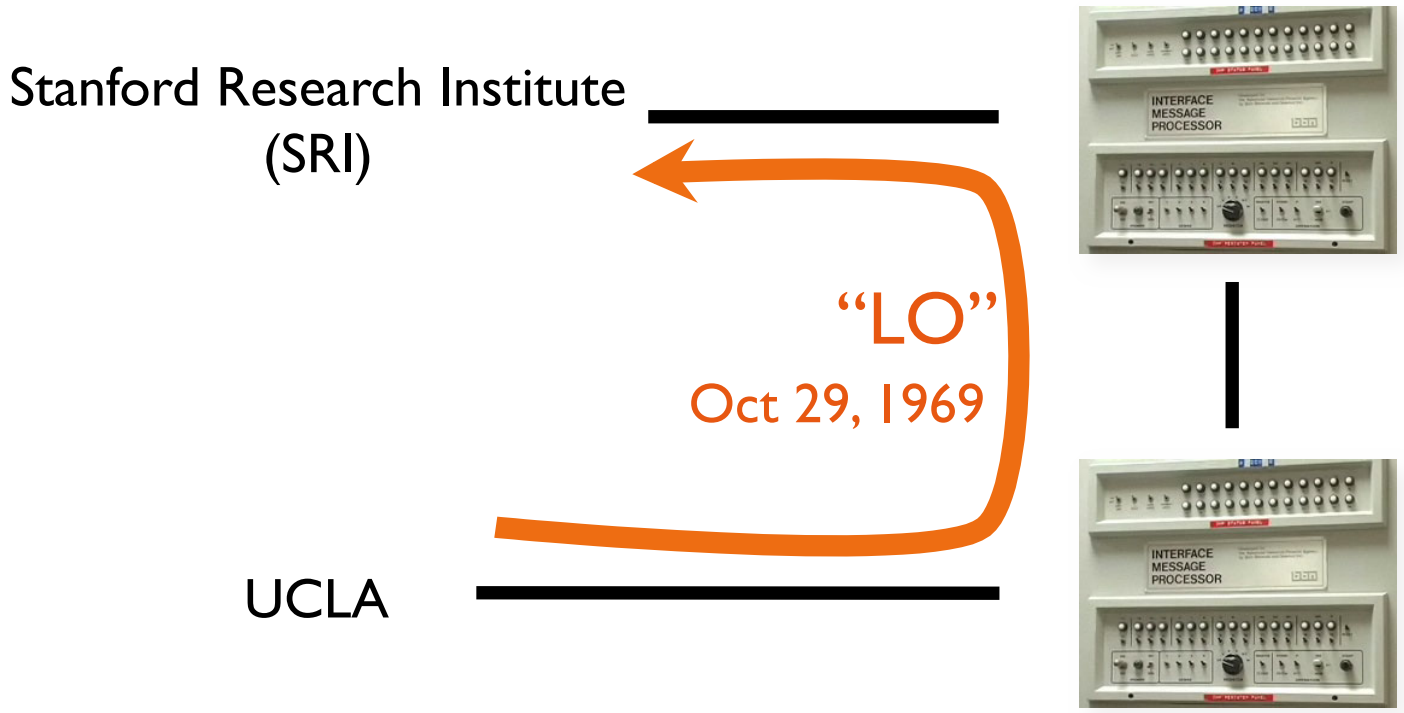
Roberts

The ARPANET begins

- Roberts joins DARPA (1966), publishes plan for the ARPANET computer network (1967)
- December 1968: Bolt, Beranek, and Newman (BBN) win bid to build packet switch, the Interface Message Processor (IMP)
  - First generation of gateways
- September 1969: BBN delivers first IMP to Kleinrock's lab at UCLA

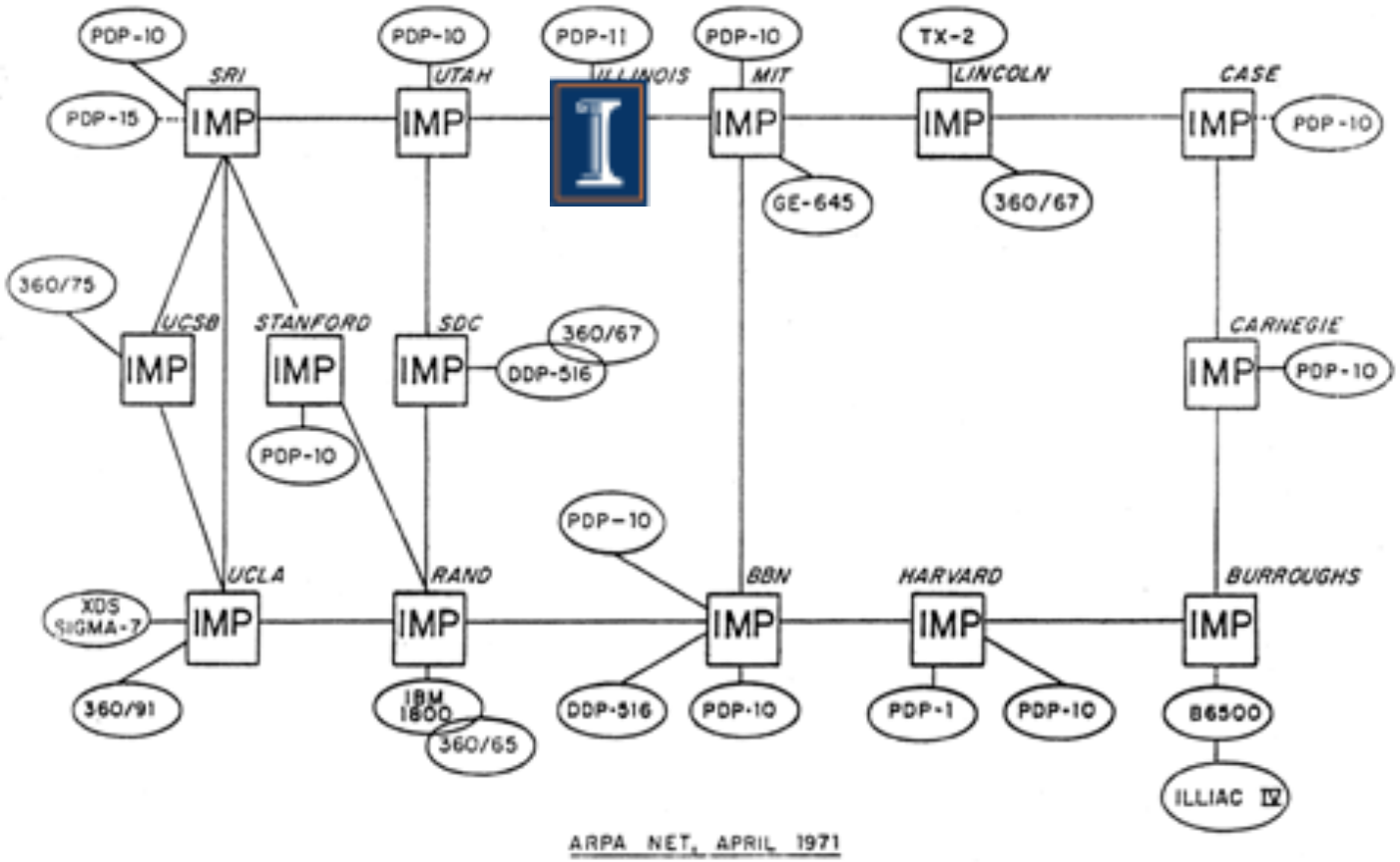
An older Kleinrock with the first IMP

ARPANET comes alive



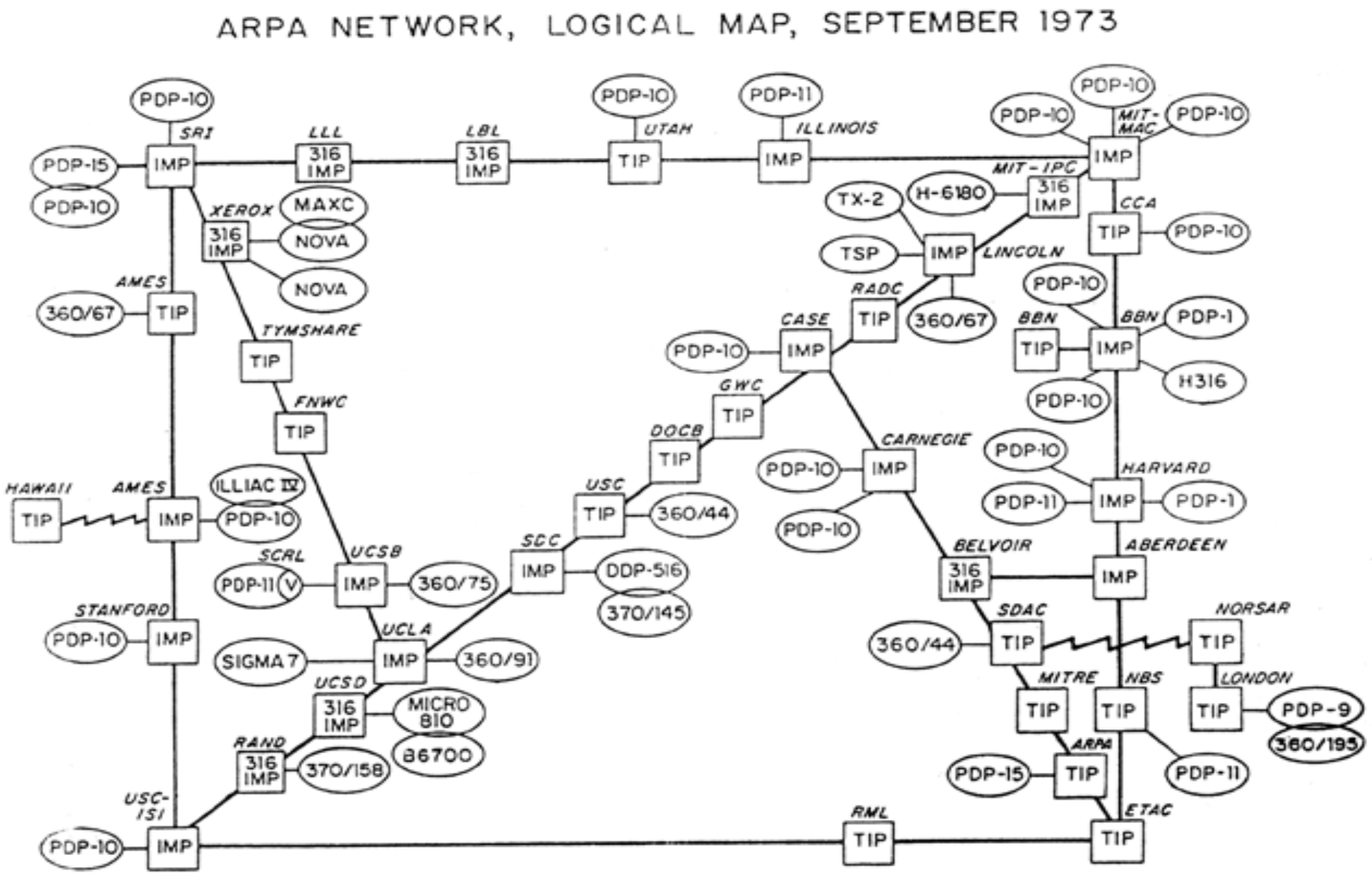
ARPANET grows

- Dec 1970: ARPANET Network Control Protocol (NCP)
- 1971: Telnet, FTP
- 1972: Email (Ray Tomlinson, BBN)
- 1979: USENET



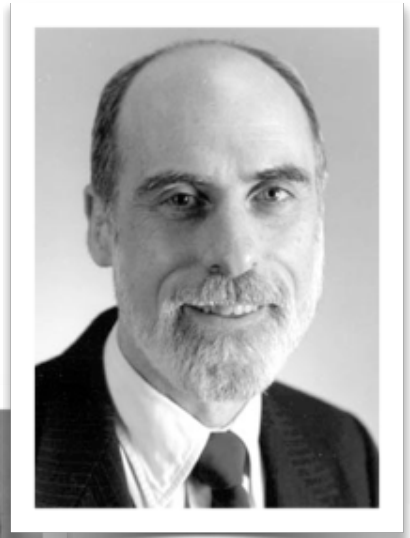
ARPANET, April 1971

ARPANET grows



ARPANET to Internet

- Meanwhile, other networks such as PRnet, SATNET developed
- May 1973: Vinton G. Cerf and Robert E. Kahn present first paper on interconnecting networks
- Concept of connecting diverse networks, unreliable datagrams, global addressing, ...
- Became TCP/IP



Cerf

Kahn

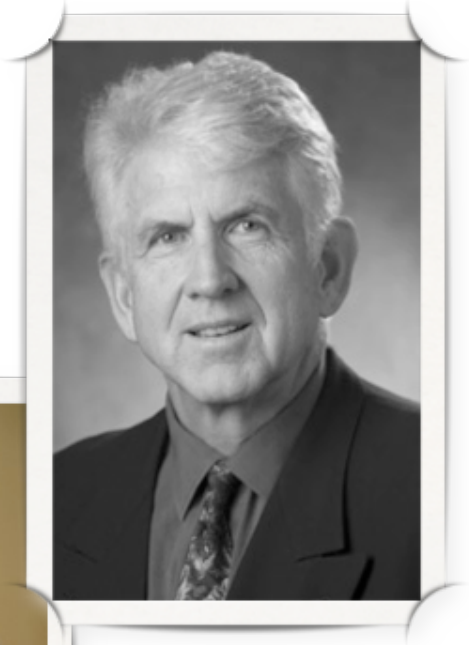
TCP/IP deployment

- TCP/IP implemented on mainframes by groups at Stanford, BBN, UCL
- David Clark guides architecture, implements it on Xerox Alto and IBM PC
- 1982: International Organization for Standards (ISO) releases Open Systems Interconnection (OSI) reference model
    - Design by committee didn't win
- January 1, 1983: "Flag Day" NCP to TCP/IP transition on ARPANET

OSI Reference Model's layers

Growth from Ethernet

- Ethernet: R. Metcalfe and D. Boggs, July 1976
- Spanning Tree protocol: Radia Perlman, 1985
- Made local area networking easy

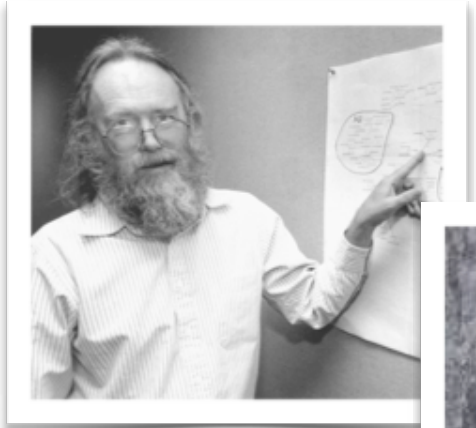


Metcalfe

Perlman

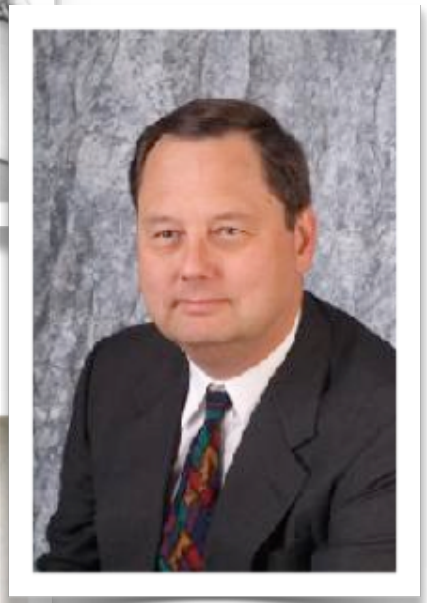
Growth spurs organic change

- Early 1980s: Many new networks: CSNET, BITNET, MFENet, SPAN (NASA), ...
- Nov 1983: DNS developed by Jon Postel, Paul Mockapetris (USC/ISI), Craig Partridge (BBN)
- 1984: Hierarchical routing: EGP and IGP (later to become eBGP and iBGP)



Postel

Mockapetris



Partridge

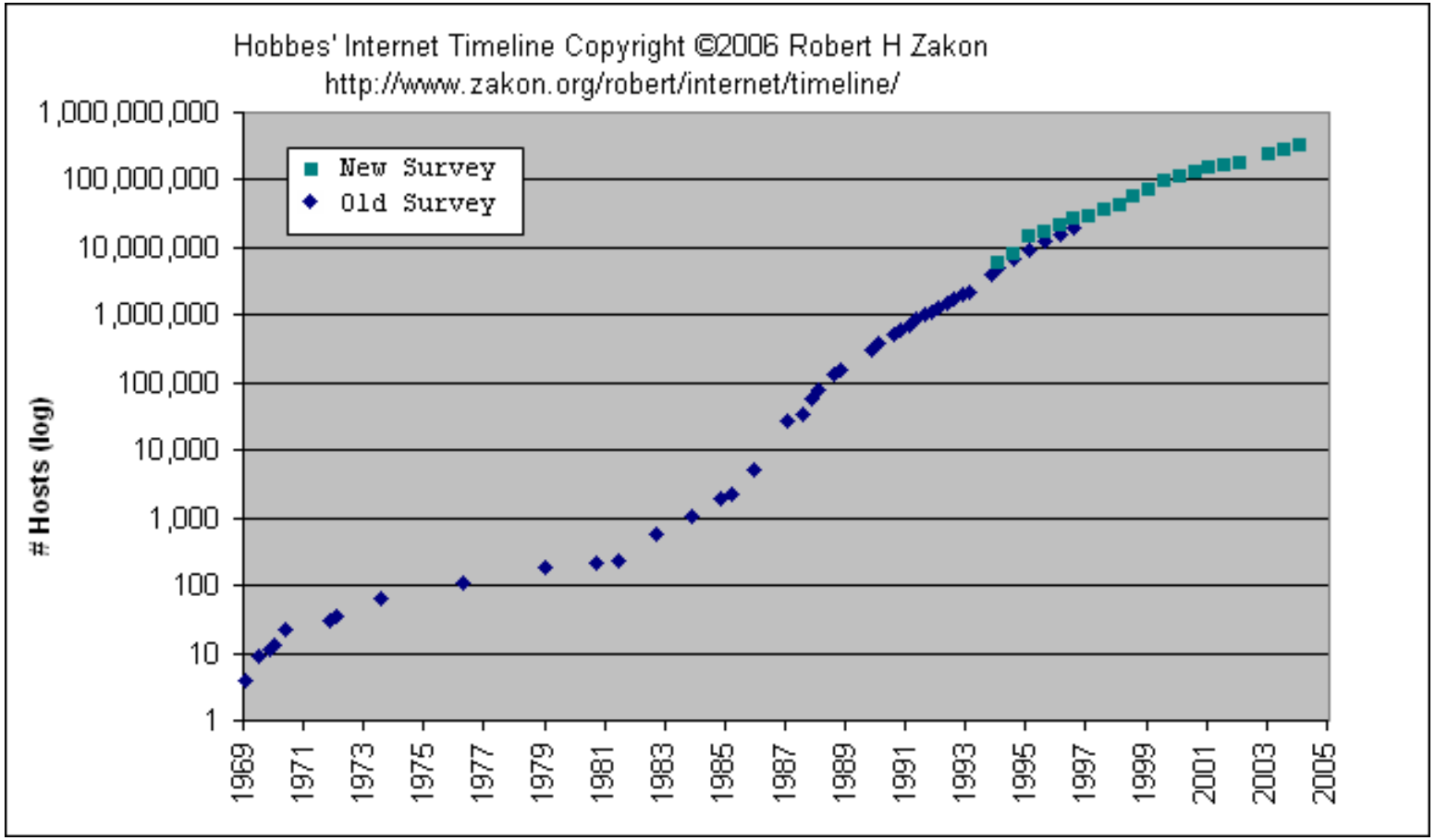
NSFNET

- 1984: NSFNET for US higher education
  - Serve many users, not just one field
  - Encourage development of private infrastructure (e.g., backbone required to be used for Research and Education)
  - Stimulated investment in commercial long-haul networks
- 1990: ARPANET ends
- 1995: NSFNET decommissioned

NSFNET backbone, 1992

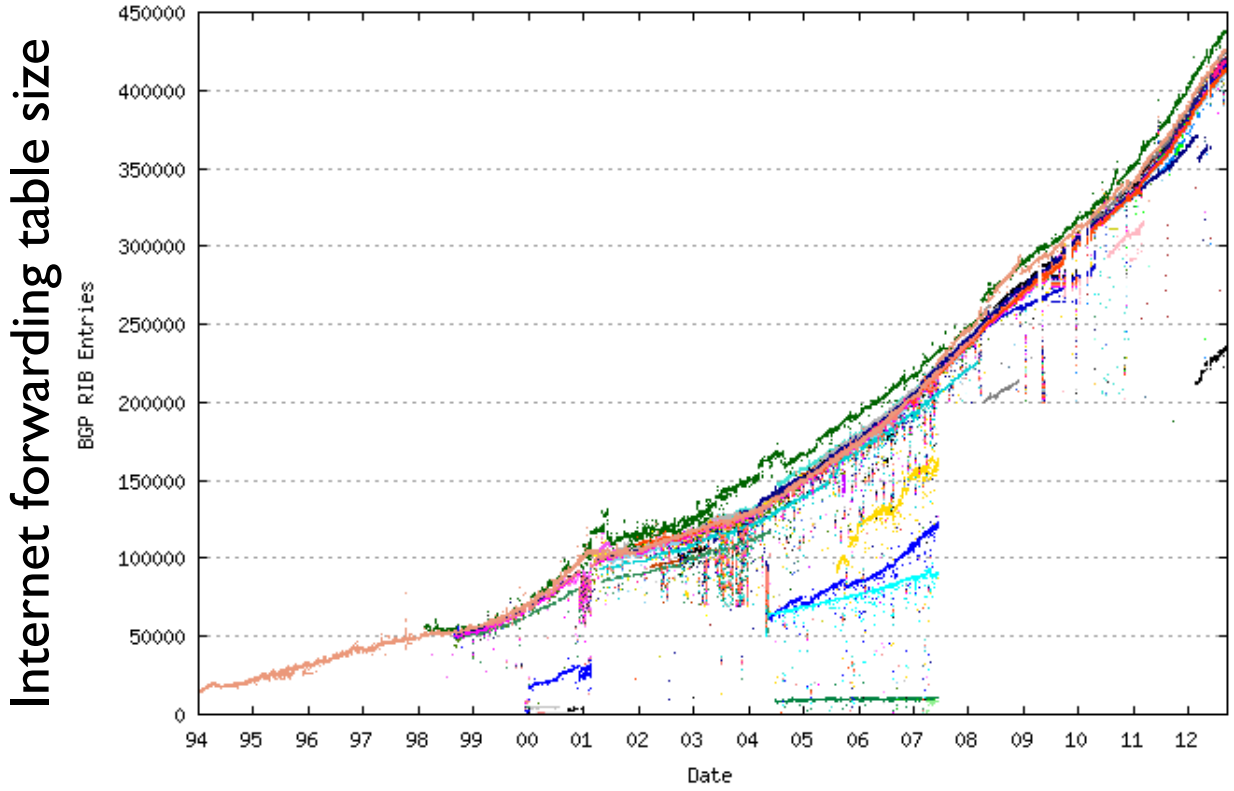
Explosive growth!

In hosts



Explosive growth!

In networks



Year

(Colors correspond to measurements from different vantage points)

[Huston '12]

Explosive growth!

In devices & technologies

O(100 million) times as many devices
Link speeds 200,000x faster
NATs, firewalls, DPI, ...
Wireless everywhere
Mobile everywhere
Tiny devices (smart phones)
Giant devices (data centers)
...

In applications

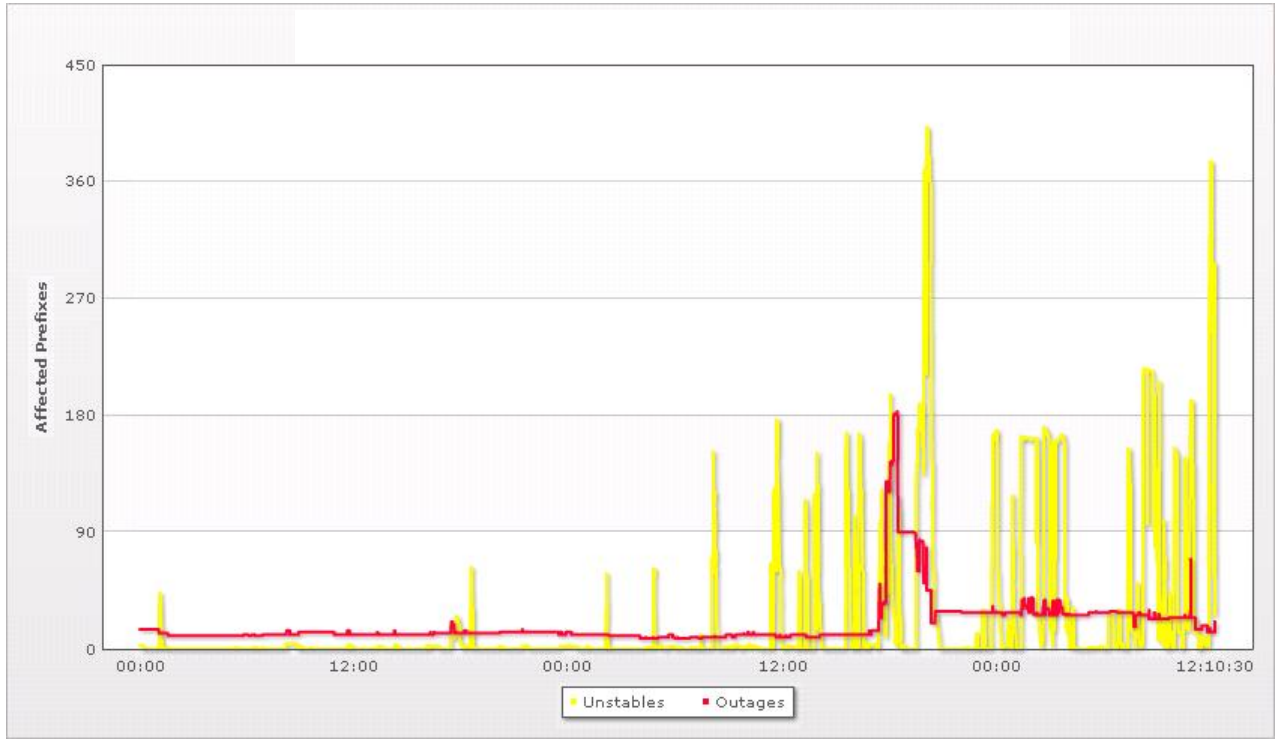
Morris Internet Worm (1988)
World wide web (1989)
MOSAIC browser (1992)
Search engines
Peer-to-peer
Voice
Radio
Botnets
Social networking
Streaming video
Cloud computing
Mobile apps

The results of your class projects!

Huge societal relevance

Routing instabilities and outages in Iranian prefixes following 2009 presidential election

Affected prefixes



Friday June 12 2009

Saturday June 13

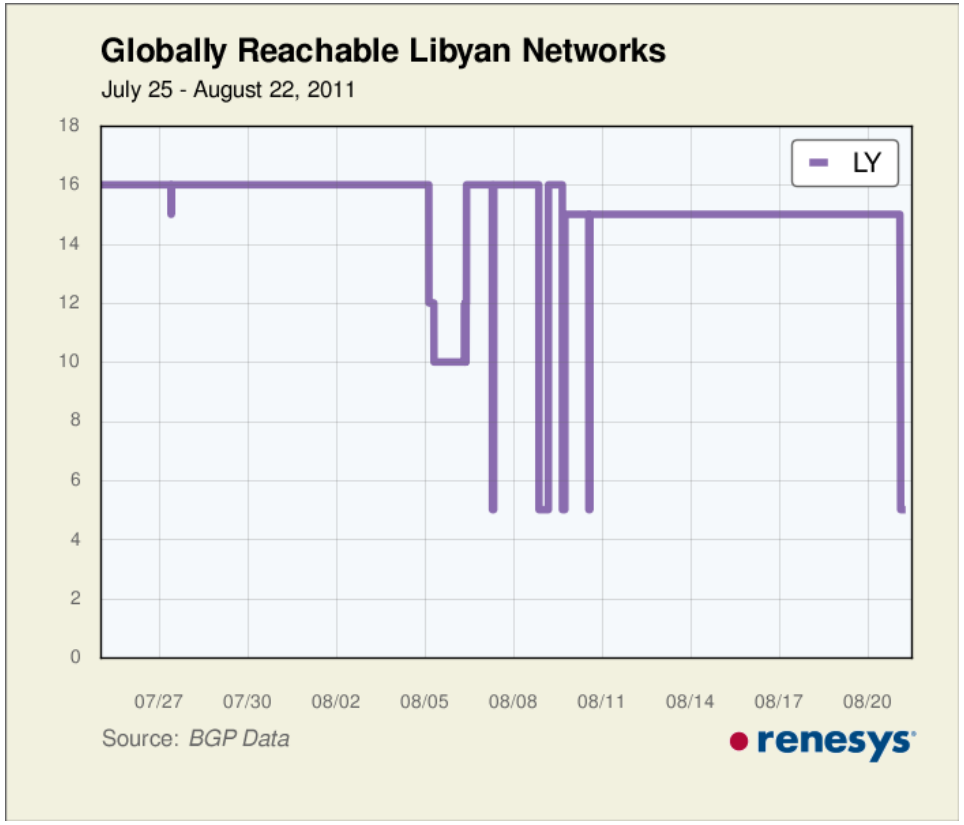
Sunday June 14

[James Cowie, Renesys Corporation]

Huge societal relevance

Reachability to Lybia

Reachable prefixes



July - August 2011

[James Cowie,
Renesys Corporation]

Top 30 inventions of the last 30 years

1. Internet/Broadband/World Wide Web
2. PC/Laptop Computers
3. Mobile Phones
4. E-Mail
5. DNA Testing and Sequencing/Human Genome Mapping
6. Magnetic Resonance Imaging (MRI)
7. Microprocessors
8. Fiber Optics
9. Office Software
10. Non-Invasive Laser/Robotic Surgery
11. Open Source Software and Services
12. Light Emitting Diodes (LEDs)
13. Liquid Crystal Displays (LCDs)
14. GPS
15. Online Shopping/E-Commerce/Auctions
16. Media File Compression
17. Microfinance
18. Photovoltaic Solar Energy
19. Large Scale Wind Turbines
20. Social Networking via Internet
21. Graphic User Interface (GUI)
22. Digital Photography/Videography
23. RFID
24. Genetically Modified Plants
25. Biofuels
26. Bar Codes and Scanners
27. ATMs
28. Stents
29. SRAM/Flash Memory
30. Anti-Retroviral Treatment for AIDS

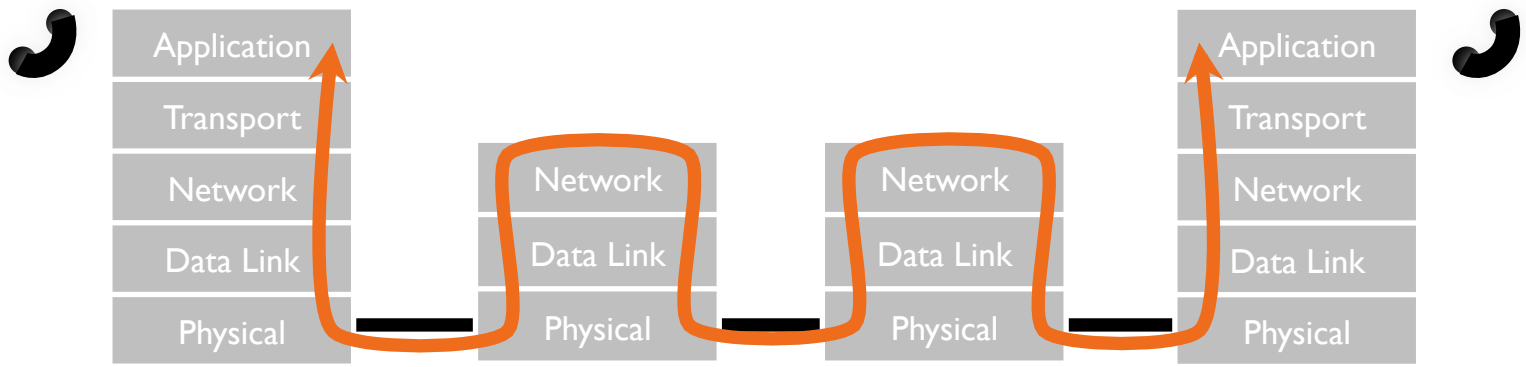
Compiled by the Wharton School @ U Penn, 2009

So we're done! ... right?

- Core protocols changed little, but the context has...
  - Criminals and malicious parties
  - Everyone trying to game the system
  - Incredible growth
  - Constant mobility
  - Extreme complexity
- ...and fixing the net involves fundamental challenges
  - It's distributed
  - Components fail
  - Highly heterogeneous environments
  - Highly complex systems components and interactions
  - Must get competing parties to work together

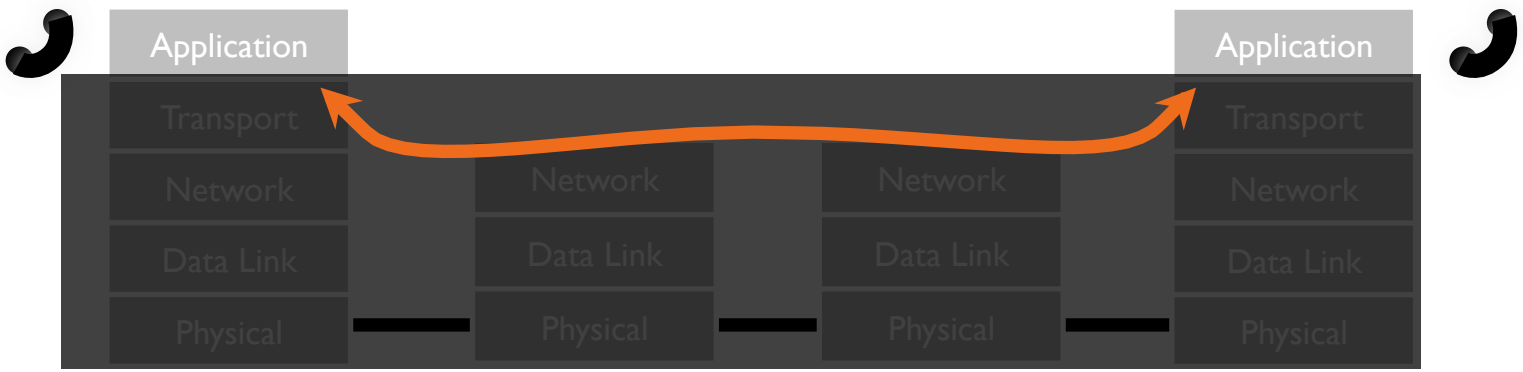
Review of Basics before Grand Challenges

Layering



- A kind of modularity
- Functionality separated into layers
  - Layer n implements higher-level functionality by interfacing only with layer n-1
  - Hides complexity of surrounding layers: enables greater diversity and evolution of modules

Layering

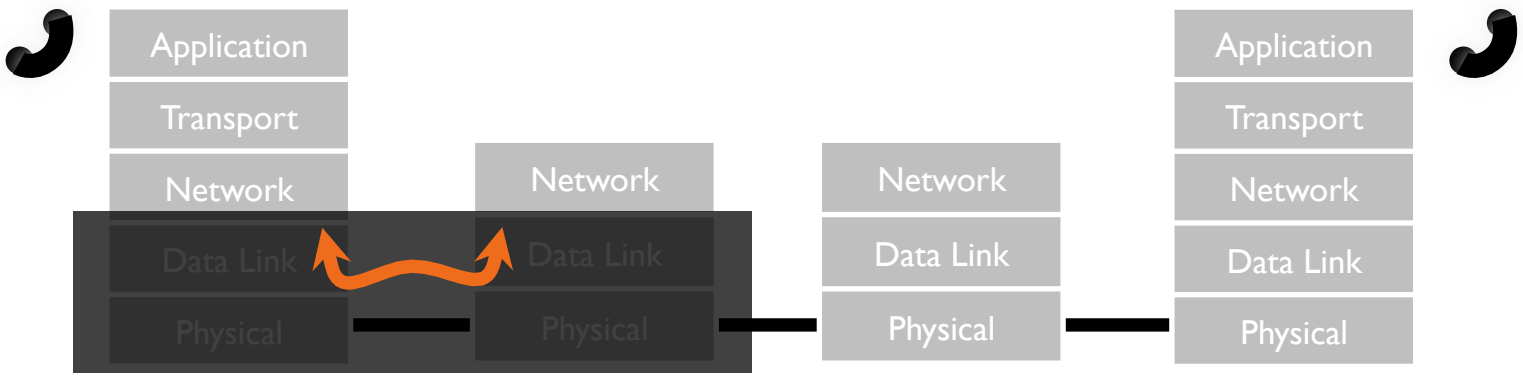


- A kind of modularity
- Functionality separated into layers
  - Layer *n* implements higher-level functionality by interfacing only with layer *n*-1
  - Hides complexity of surrounding layers: enables greater diversity and evolution of modules

Layering

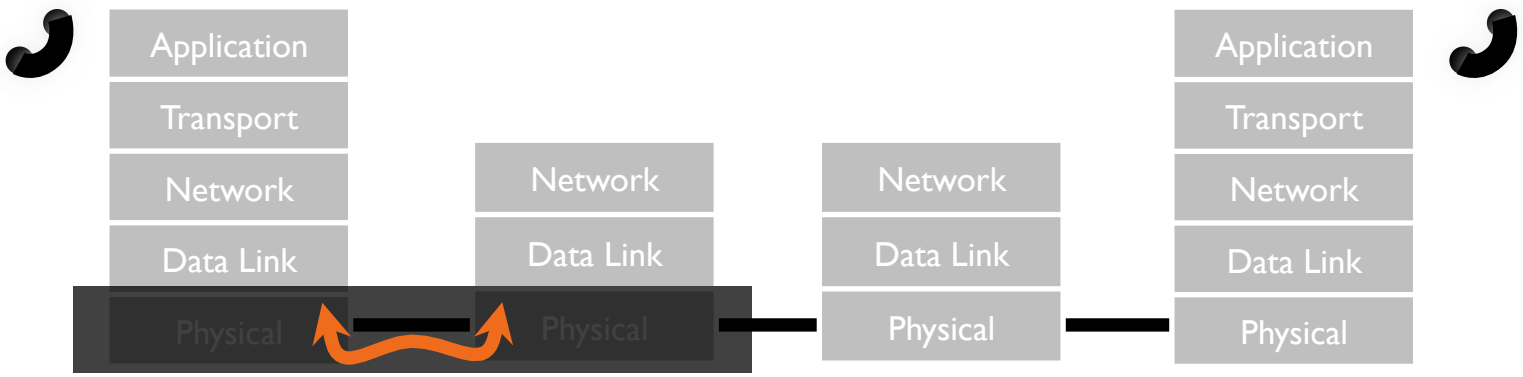
- A kind of modularity
- Functionality separated into layers
  - Layer *n* implements higher-level functionality by interfacing only with layer *n*-1
  - Hides complexity of surrounding layers: enables greater diversity and evolution of modules

Layering



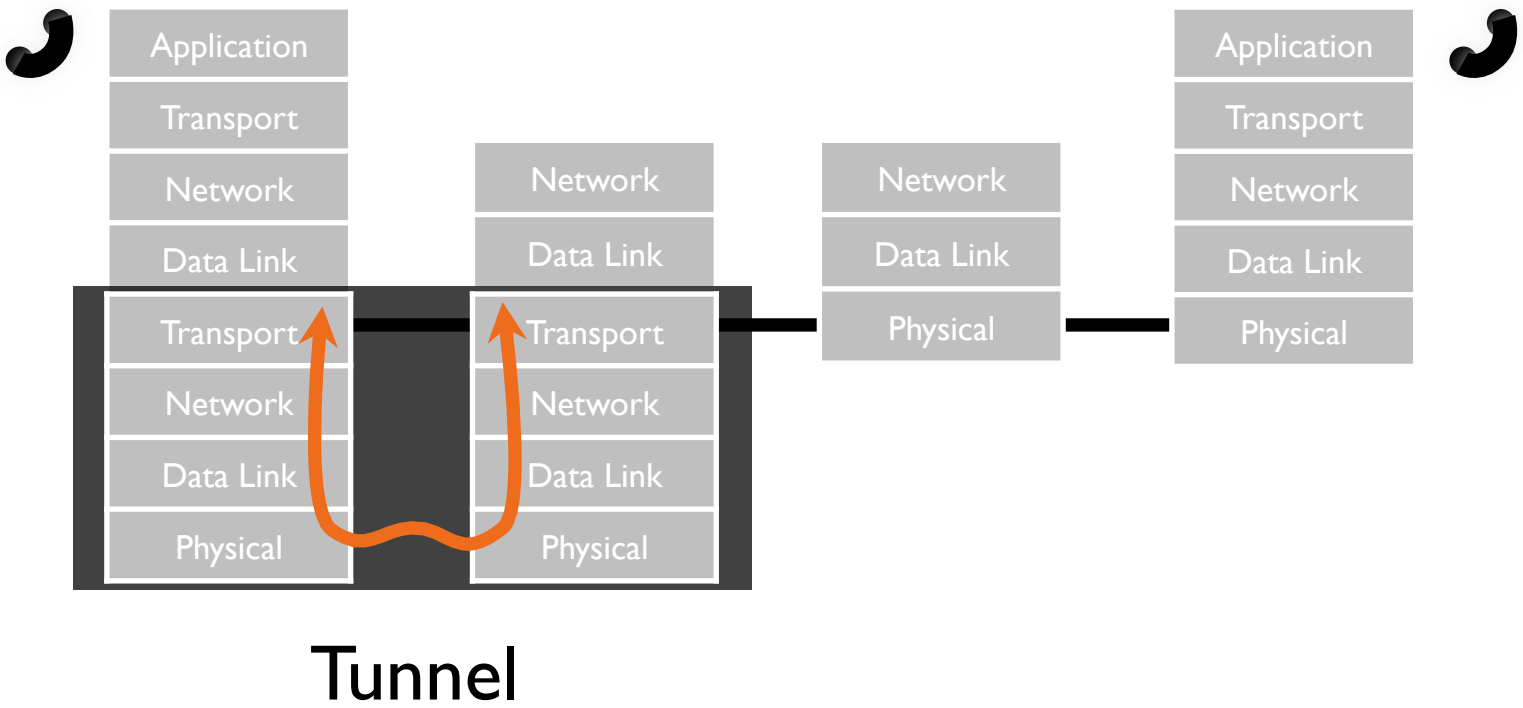
- A kind of modularity
- Functionality separated into layers
  - Layer *n* implements higher-level functionality by interfacing only with layer *n*-1
  - Hides complexity of surrounding layers: enables greater diversity and evolution of modules

Layering



- A kind of modularity
- Functionality separated into layers
  - Layer *n* implements higher-level functionality by interfacing only with layer *n*-1
  - Hides complexity of surrounding layers: enables greater diversity and evolution of modules

Layering


Application
Transport
Network
Data Link
Transport
Network
Data Link
Physical
Network
Data Link
Transport
Network
Data Link
Physical
Network
Data Link
Physical
Application
Transport
Network
Data Link
Physical
Tunnel

Common functionality & problems

Application	*Anything you want...*	*Life, the universe, and everything*
Transport	Process-level communication	Reliability, flow control, ordering, congestion, ...
Network	Packets across domains	Independent parties, scale, routing
	Packets across networks	Addressing, heterogeneity, routing
Data Link	Packets on a 'wire'	Framing, errors, addressing
Physical	Encoding of bits	Physics

Grand Challenges

Grand Challenges

- Widely recognized as among the most important unsolved problems in a field
  - P vs. NP
  - natural language understanding
  - bug-free programs
  - moving society to carbon-neutral energy
  - preventing cancer
  - ...

Grand Challenges in networking?

- Getting an A in this class?

GC's in networking

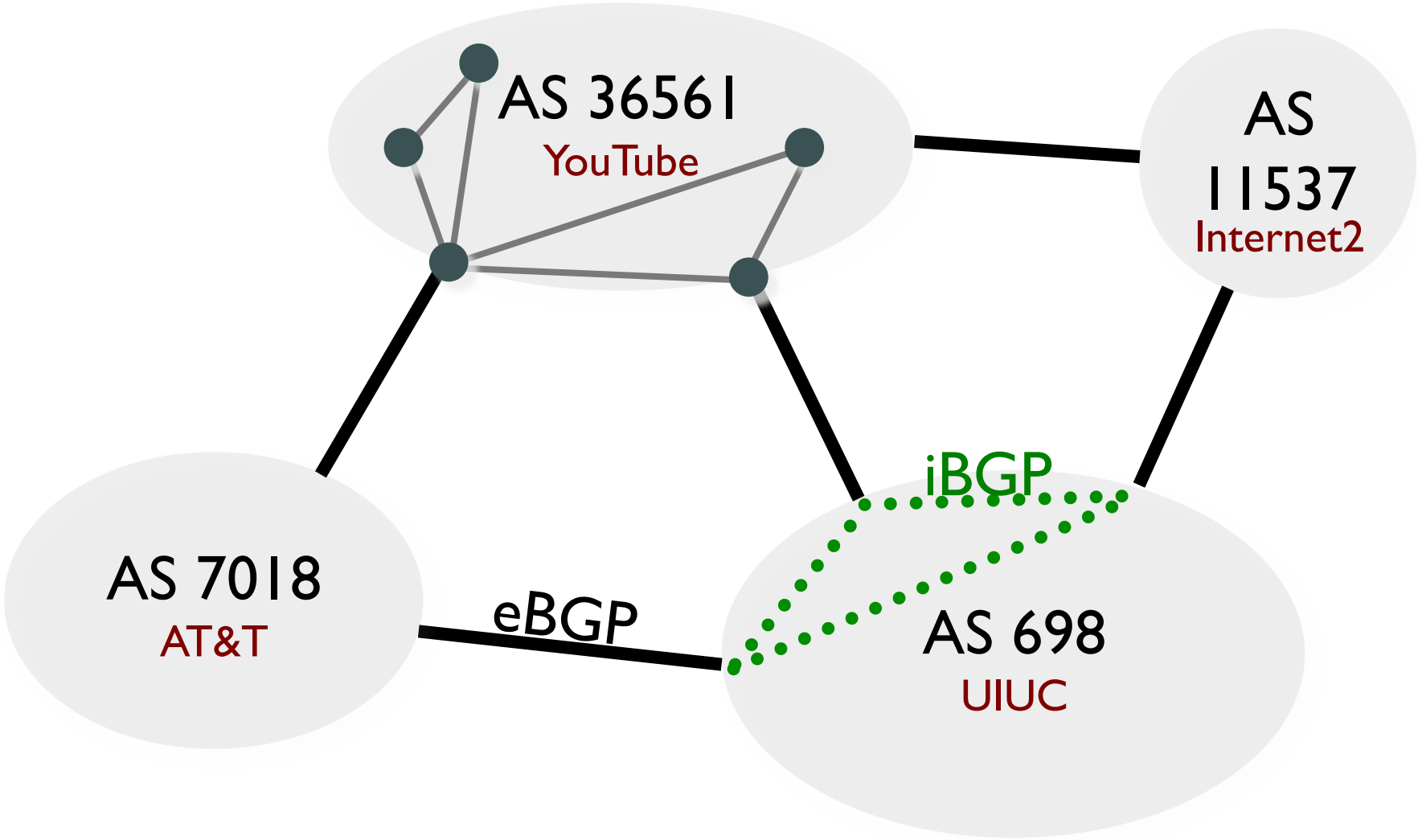
An Informal Survey

- "What I'm working on!"
- High level objectives
  - Security & privacy
  - Reliability
  - Usability

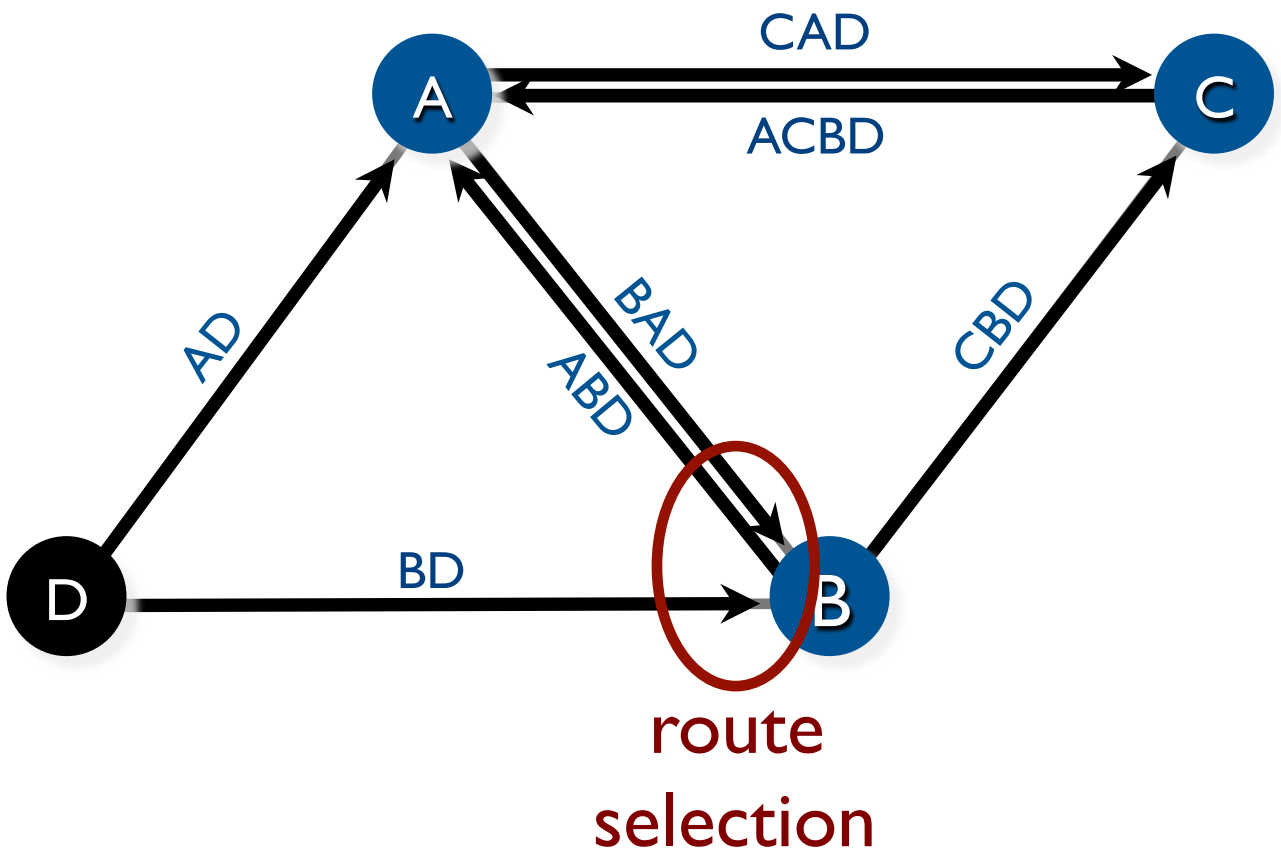
  - Different than P vs. NP: hard to even define "security"; objectives involve tradeoffs

Unreliability: One Example

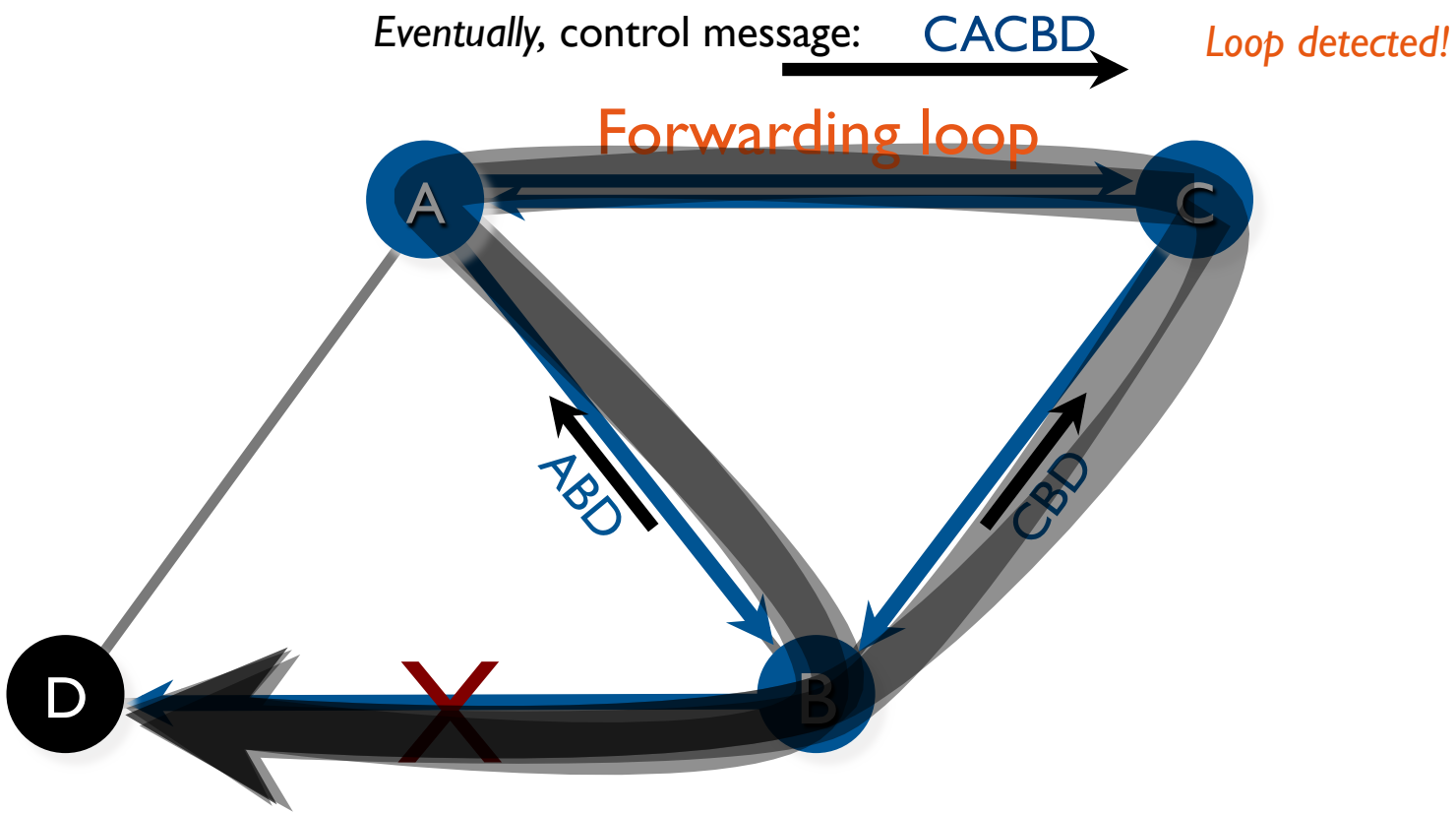
Internet Routing



Border Gateway Protocol



Instability causes outages



- Link state changes
- Router failures
- Config. changes
- ...

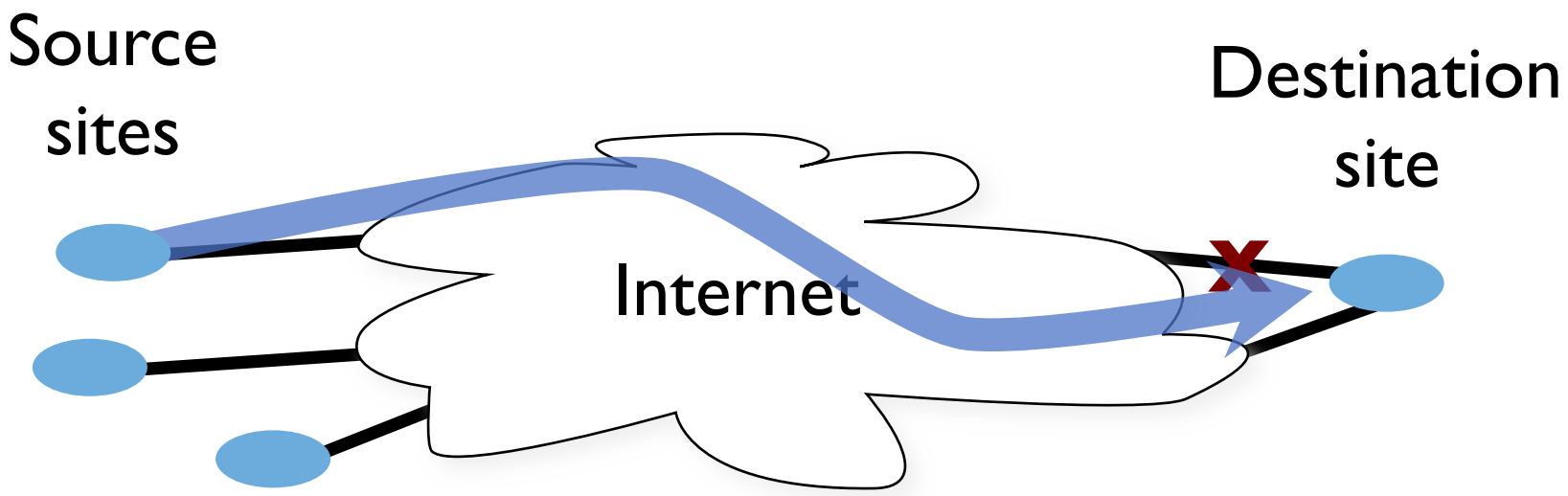
⇒

- Loops
- Detection delay
- Black holes

⇒ FAIL

Instability causes outages

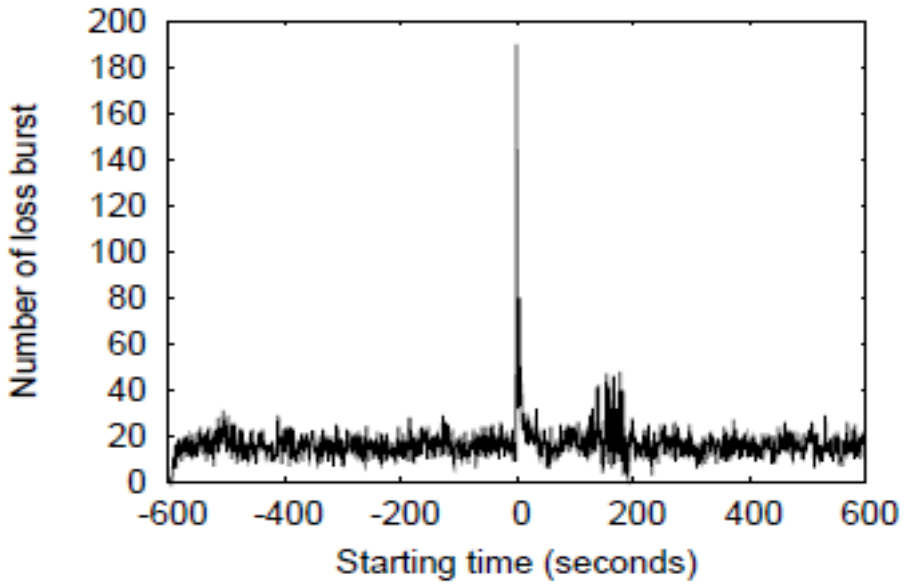
[F. Wang, Z. M. Mao, J. Wang, L. Gao, R. Bush SIGCOMM'06]



Instability causes outages

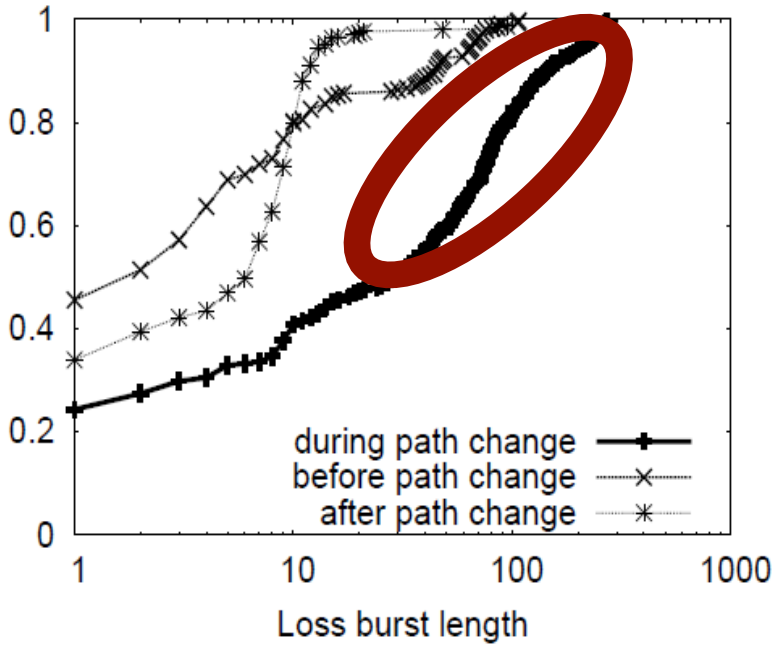
[F. Wang, Z. M. Mao, J. Wang, L. Gao, R. Bush SIGCOMM'06]

More outages



Failure injected

Longer outages



Outage length (sec)

(...and higher latency, packet reordering, router CPU load during instability)

Many sources of unreliability

- Congestion
  - no end-to-end bandwidth reservations in the Internet
- Configuration or software bugs
- Failures or delays
  - in network, DNS servers, caches, application servers, ...

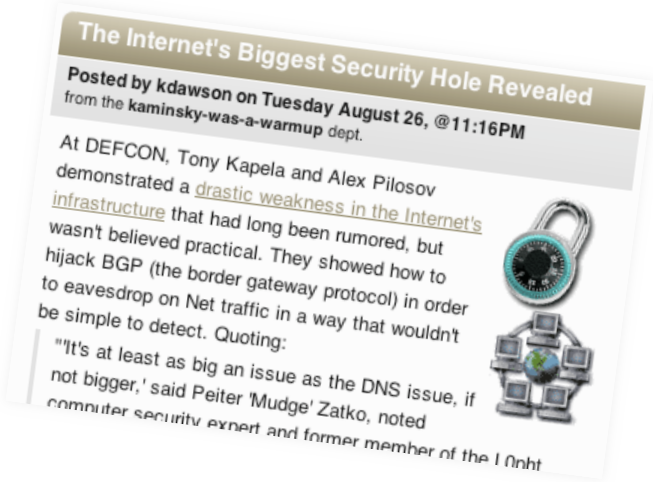
Insecurity: one example

Prefix hijacking

- Anyone can advertise routes for any IP prefix!
- How can hijacker get the advertised routes to actually be used by other ASes?
  - Announce more specific (longer) prefix than real owner
  - Now everyone's traffic is "blackholed"
- Can protect against this (Secure BGP), but...
  - it's not deployed today
  - and even then, can still cleverly (or accidentally) attract traffic and eavesdrop

From hijacking to MITM

- August ’08, Kapela and Pilosov
- Man in the Middle (MITM) attack
  - Traffic to a destination redirected (not blackholed) through an attacker
  - Attacker can watch everything you do without you noticing
- What’s the key problem here?



The Internet's Biggest Security Hole Revealed

Posted by kdawson on Tuesday August 26, @11:16PM
from the kaminsky-was-a-warmup dept.

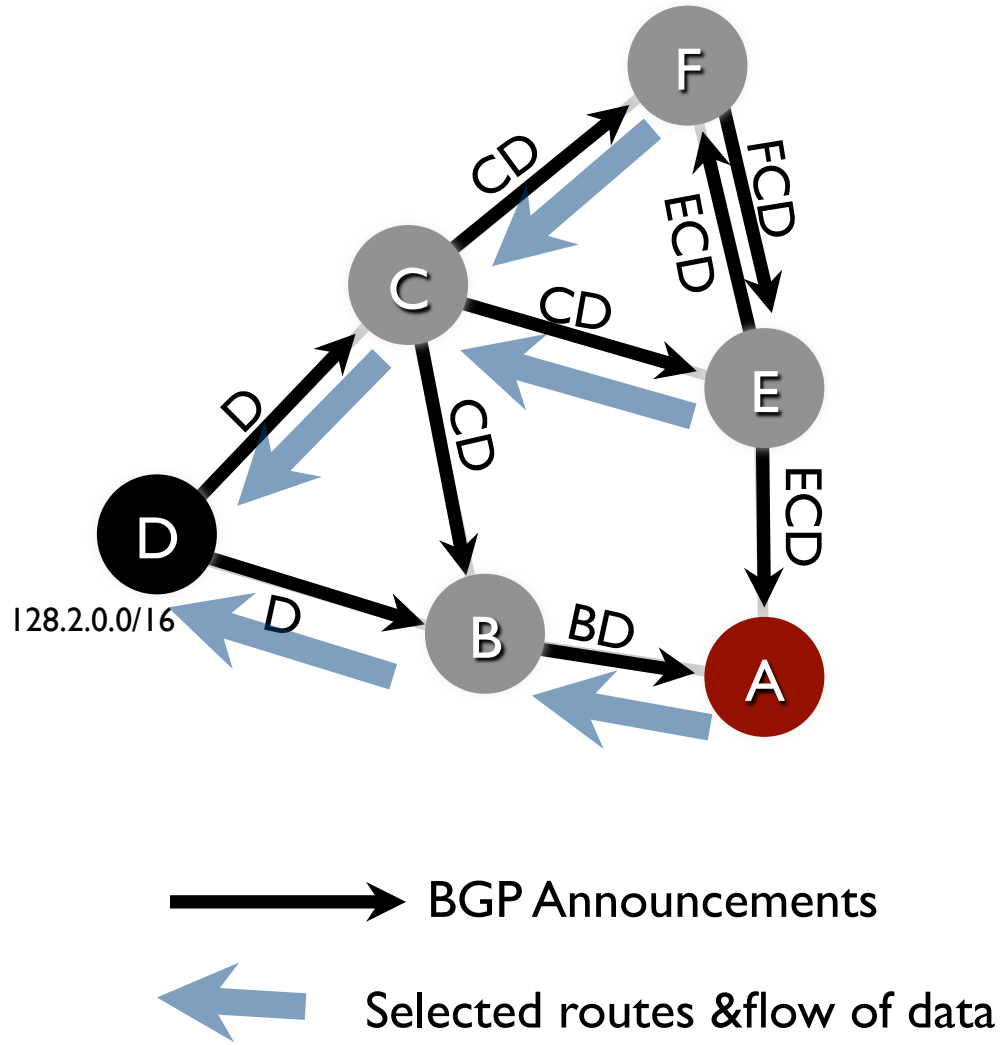
At DEFCON, Tony Kapela and Alex Pilosov demonstrated a drastic weakness in the Internet's infrastructure that had long been rumored, but wasn't believed practical. They showed how to hijack BGP (the border gateway protocol) in order to eavesdrop on Net traffic in a way that wouldn't be simple to detect. Quoting:

"'It's at least as big an issue as the DNS issue, if not bigger,' said Peiter 'Mudge' Zatko, noted computer security expert and former member of the L0pht

How can attacker forward traffic to destination, if attacker is pretending to *be* the destination?

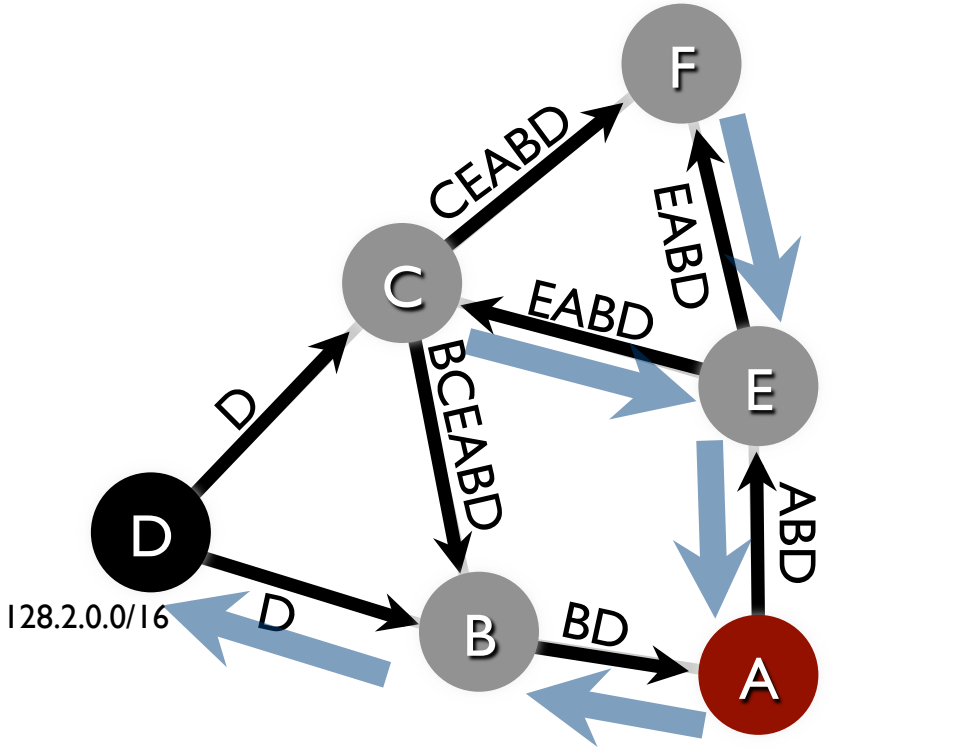
Hijacking + eavesdropping

- A finds legitimate path ABD for 128.2.0.0/16



Hijacking + eavesdropping

- A finds legitimate path ABD for 128.2.0.0/16
- A sends semi-bogus announcement of path ABD for 128.2.0.0/17
- Result:
  - ASes (here B) on real path keep using real path because of loop elimination
  - All other ASes use route through A (/17 beats /16)
- A forwards traffic to B



BGP Announcements

Selected routes &flow of data

Grand Challenges in networking

An Informal Survey

- "What I'm working on!"
- Nebulous high level objectives
  - Security & privacy
  - Reliability
  - Usability
- Why does networking lack a crisp Grand Challenge?
  - Infrastructure needs to support highly diverse and dynamic goals, applications, and environments

- Complexity

Grand Challenges in networking

Meta-challenge:

How do we make the Internet evolvable?