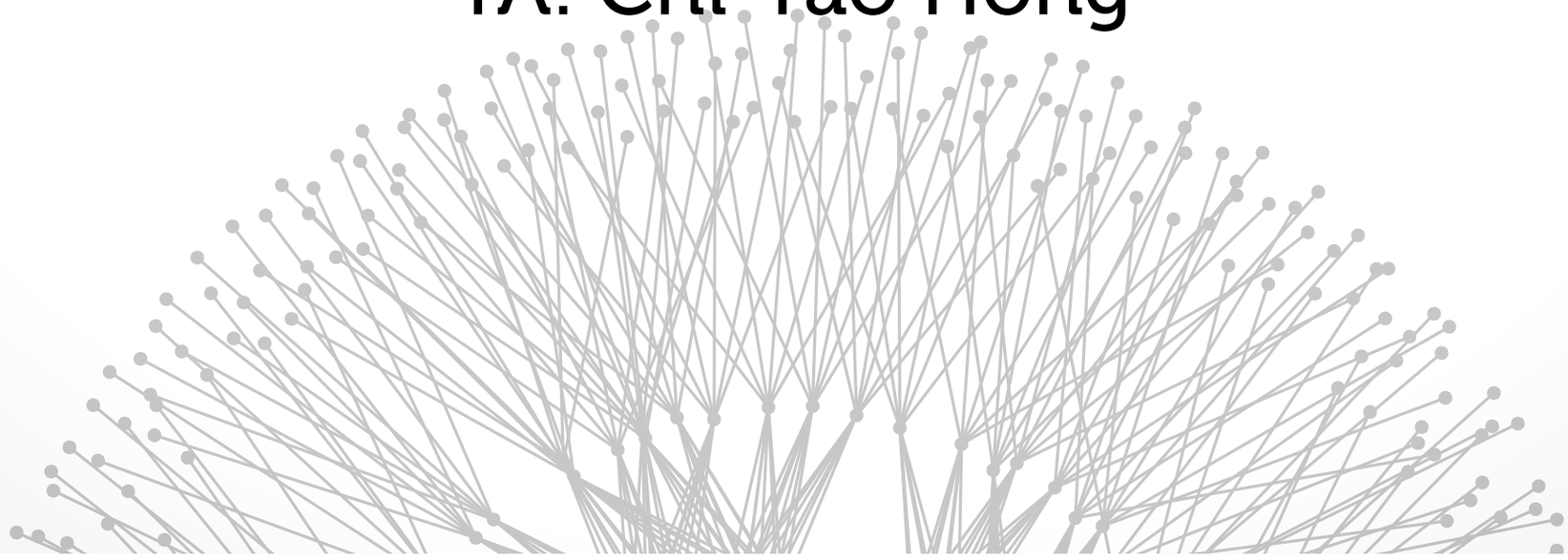
# Advanced Computer Networks

UIUC CS 538 Fall 2013

Instructor: Brighten Godfrey

TA: Chi-Yao Hong



# Today

**Course Overview**

Internet History

Your Future

# This course

is instructed by Brighten Godfrey

- pbg@illinois.edu, 3211 Siebel

is TA'd by Chi-Yao Hong

- cyhong@illinois.edu

takes place Tue & Thu, 2:00 - 3:15 pm, in 0216 SC

comes with FREE office hours: currently, Tuesdays after class (3:30-4:30pm) and by appointment

has a web site: http://courses.engr.illinois.edu/cs538/

# Course goal

Prepare to perform high-quality research advancing the field of networking

# Main course components

Networking literature

- The classics
- The challenges
- The latest

Research project

How to read, criticize, and present research

# Requirements & grading

Project (40%)

- Midterm presentation (10%)
- Final paper and poster presentation (30%)

Readings & paper reviews (40%)

Assignments (20%)

# 1. Project

Research project that could be developed into a conference submission

Work alone or in groups

Project topics

- Explore your own ideas
- Or, one of our suggestions

Steps

- Project proposal (4 weeks from now)
- Midterm presentation
- Final poster presentation and paper

# 2. Readings

The classics: core architecture

- Classic Internet architecture
- Congestion control
- Forwarding
- Routing

The challenges

- Reliability, scalability, selfishness, security, complexity

The latest

- SDN, enterprise, data center, content distribution, ...

# 2. Readings

One or two papers per lecture

Submit a review on Piazza by 11:59pm the night before we discuss the paper

For each paper, a review is

- At least 2 comments
- About one paragraph (longer is not better)
- Don't just repeat what we already read in the paper!

Draft reading schedule online

# 3. Assignments

Assignment 1: Experimental networking tools

Assignment 2: Take-home exam on course content

# 4. Class participation

Comment, question, and interact!

Discuss on Piazza

# Today

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**Internet History**

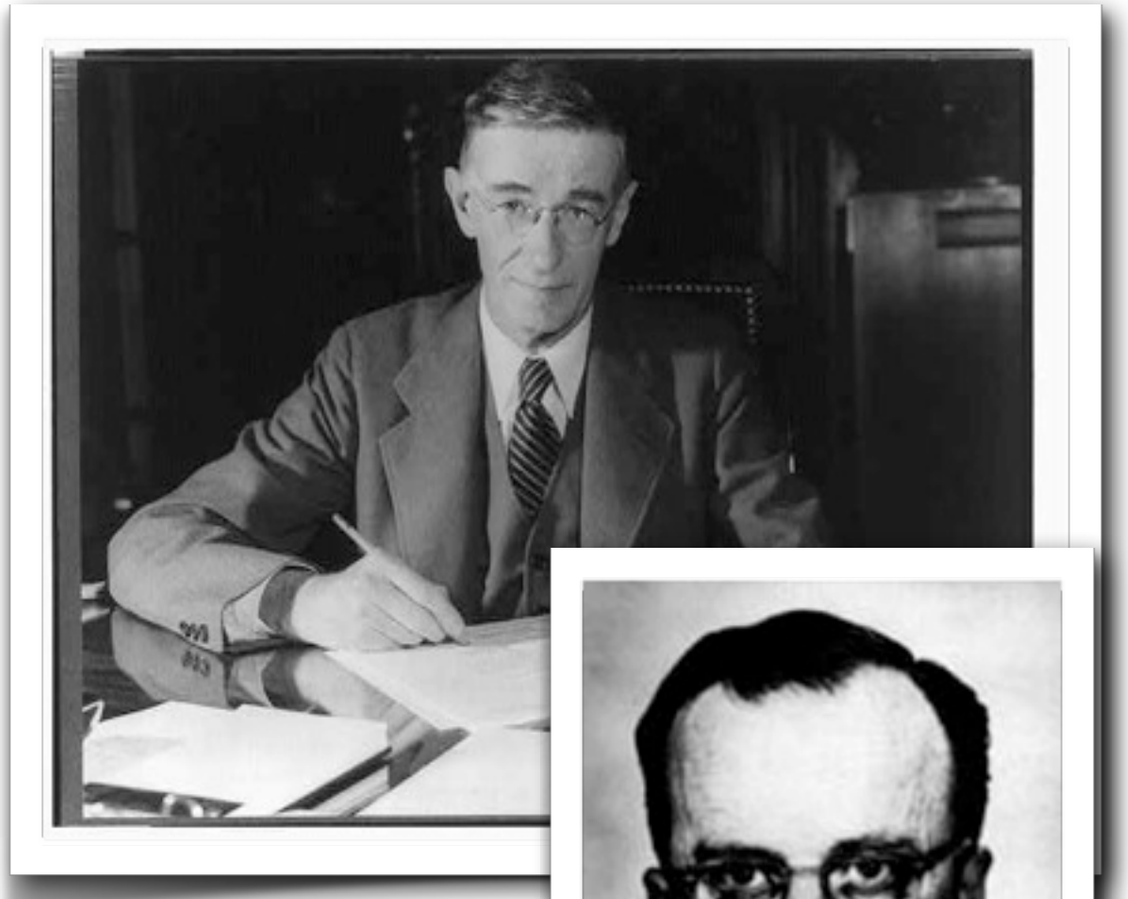
Your Future

# 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


1920s

[Getty Images]

1967

[US Air Force]

# 1961-64: Packet switching

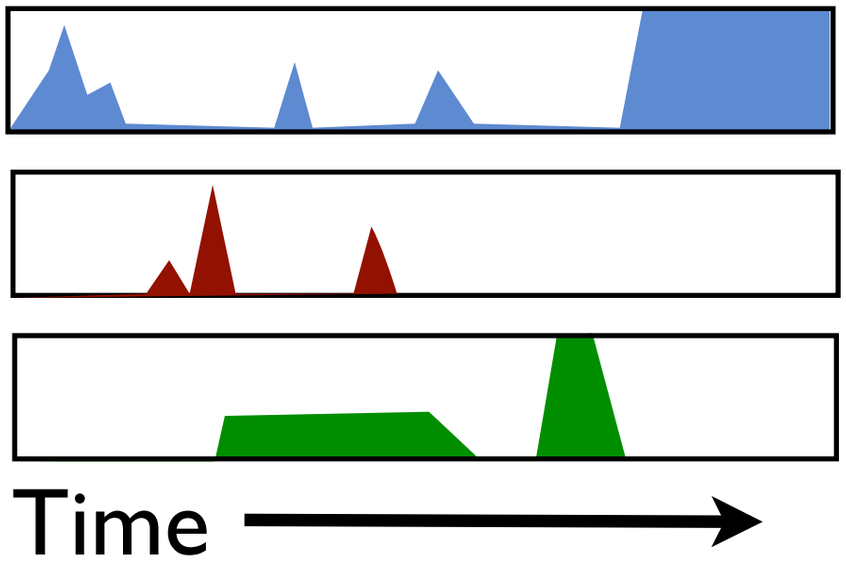
| Circuit Switching | Packet switching |
|---|---|
| Physical channel carrying stream of data from source to destination | Message broken into short packets, each handled separately |
| Three phase: setup, data transfer, tear-down | One operation: send packet |
| Data transfer involves no routing | Packets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

# 1961-64: Packet switching

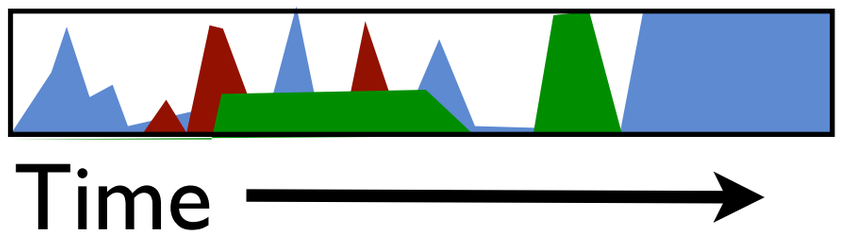
Key benefit: Statistical Multiplexing

- (what else?)

Circuit switching




Packet switching: multiplexed



# 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

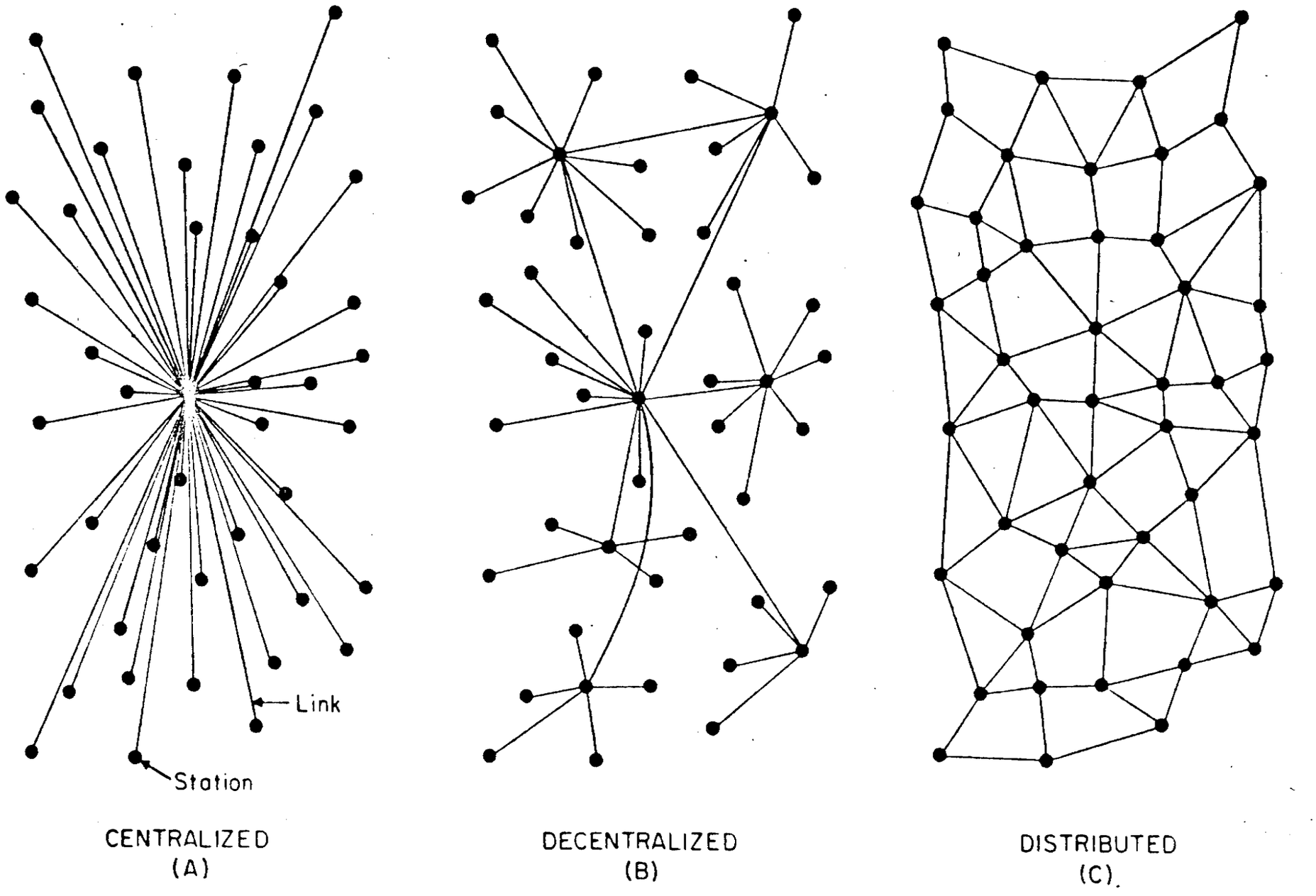



FIG. 1 — Centralized, Decentralized and Distributed Networks

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

# Baran's packet switching

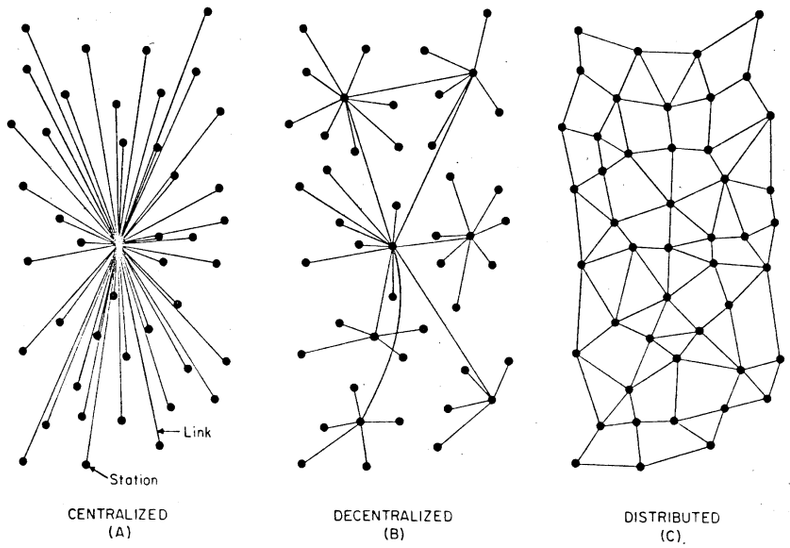



FIG. 1 — Centralized, Decentralized and Distributed Networks

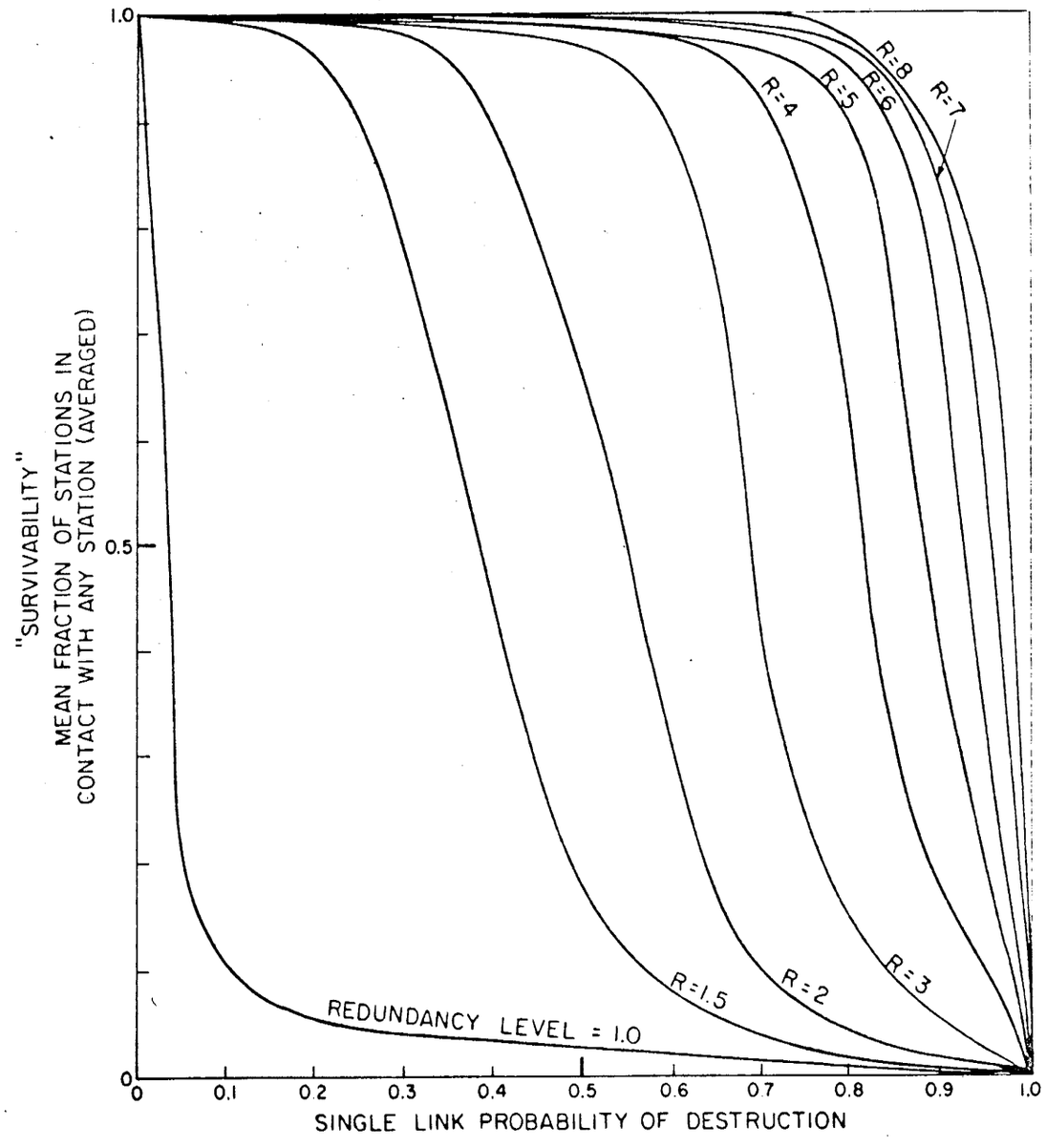



FIG. 5 — Perfect Switching in a Distributed Network — Sensitivity to Link Destruction, 100% of Nodes Operative.

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

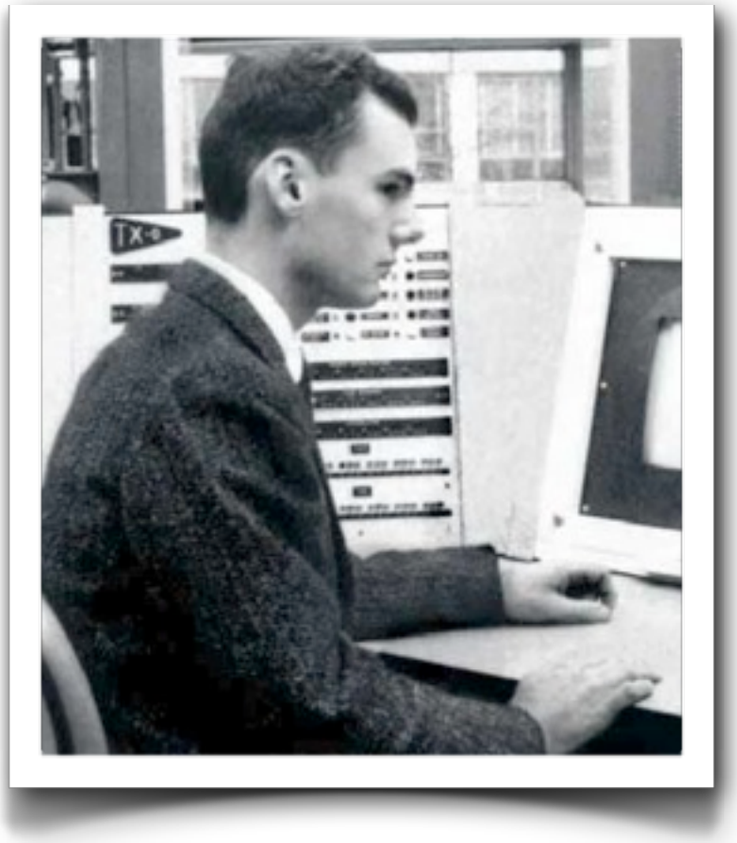
# 1965: First computer network

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

# The ARPANET begins

Roberts joins DARPA (1966), publishes plan for the ARPANET computer network (1967)

December 1968: Bolt, Beranek, and Newman (BBN) wins bid to build packet switch, the Interface Message Processor

September 1969: BBN delivers first IMP to Kleinrock's lab at UCLA

An older Kleinrock with the first IMP

# ARPANET comes alive

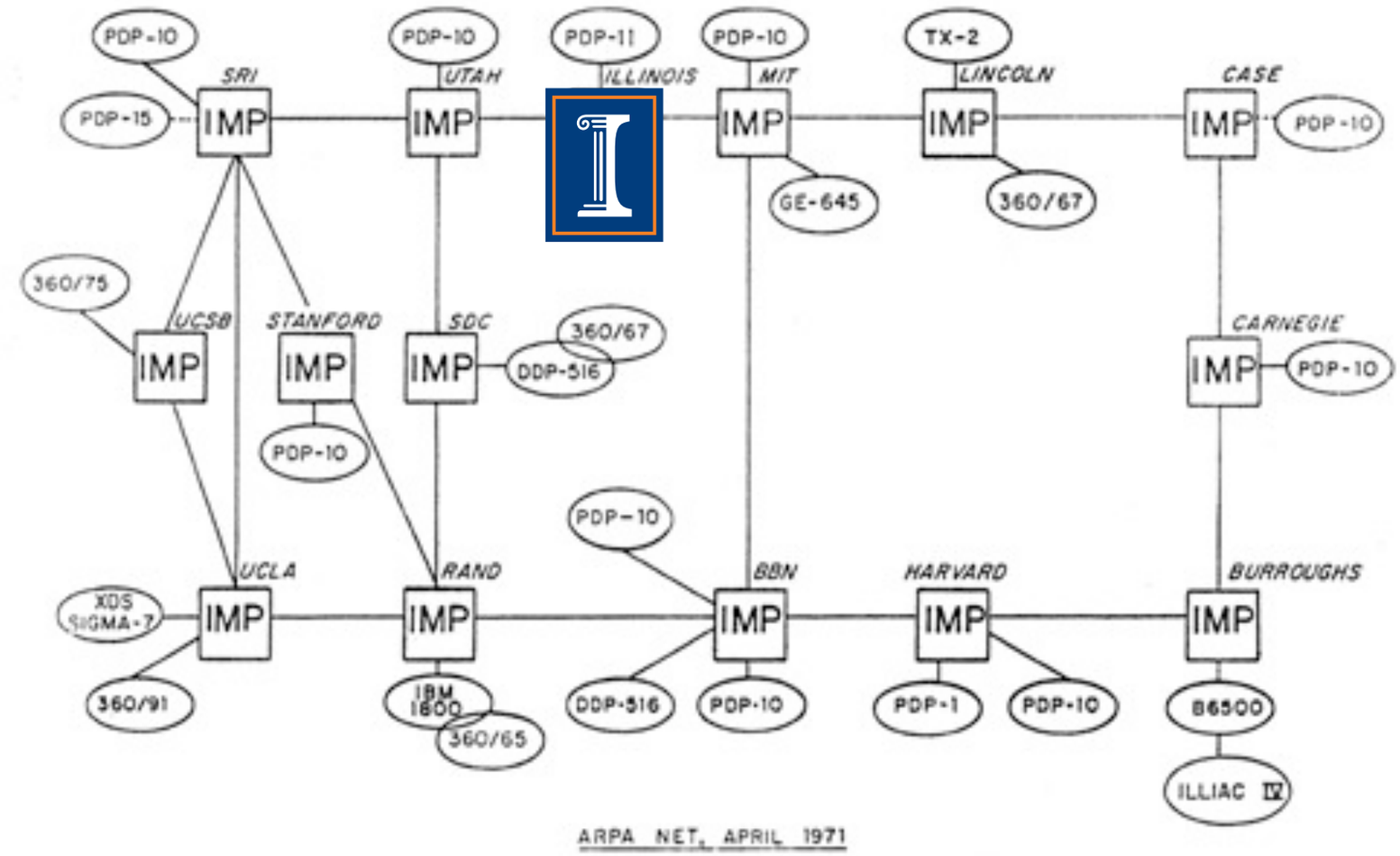
Stanford Research Institute
(SRI)


"LO"
Oct 29, 1969


UCLA

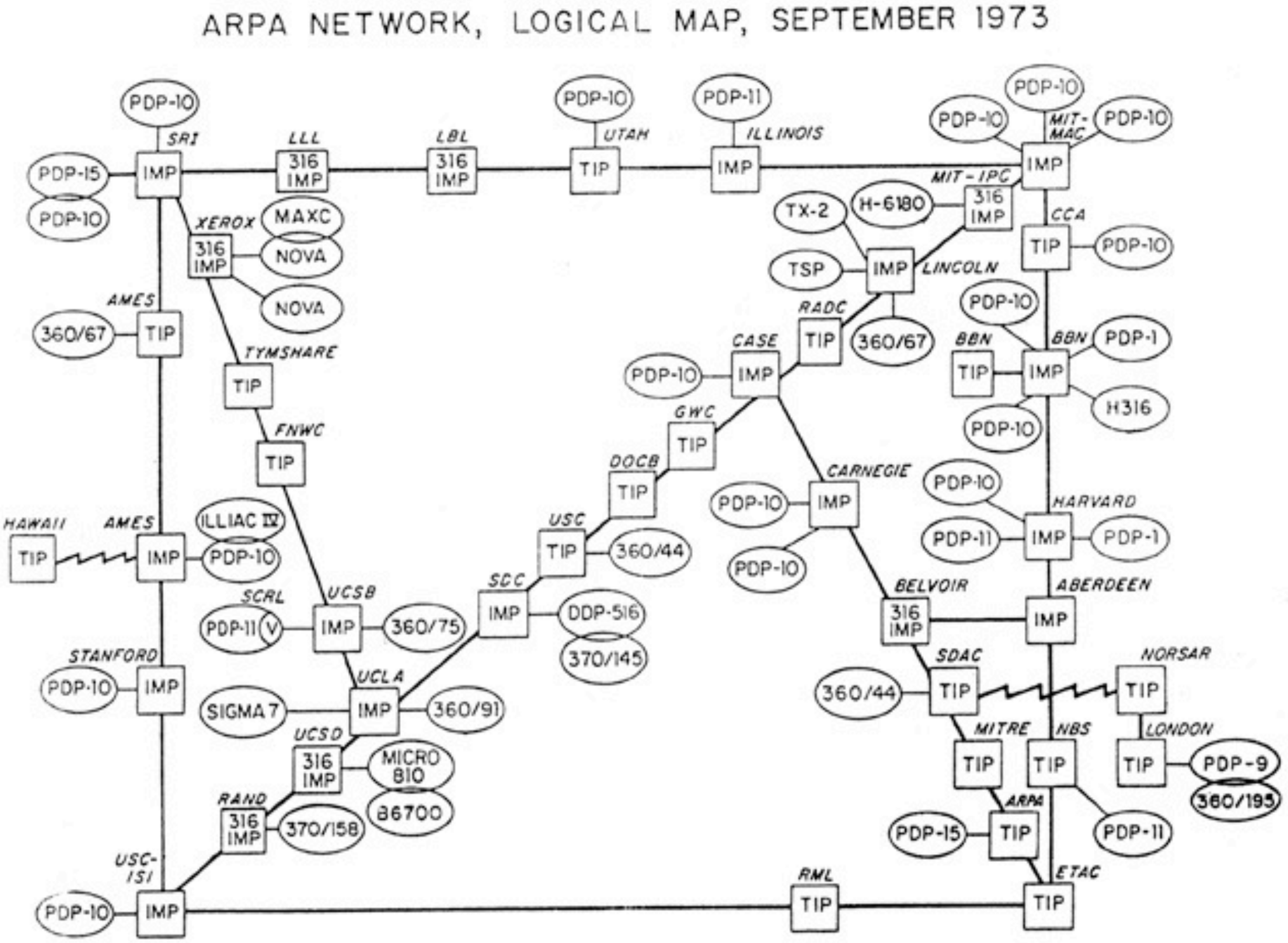
# ARPANET grows

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




ARPANET, April 1971

# ARPANET grows



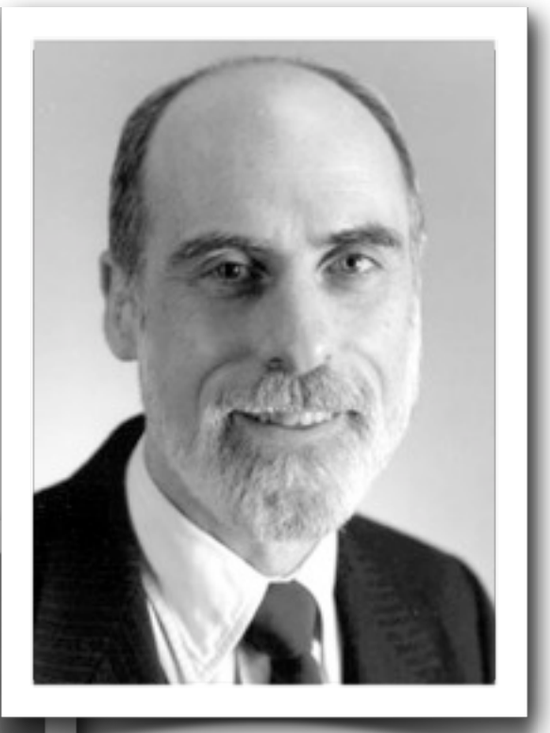
# ARPANET to Internet

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

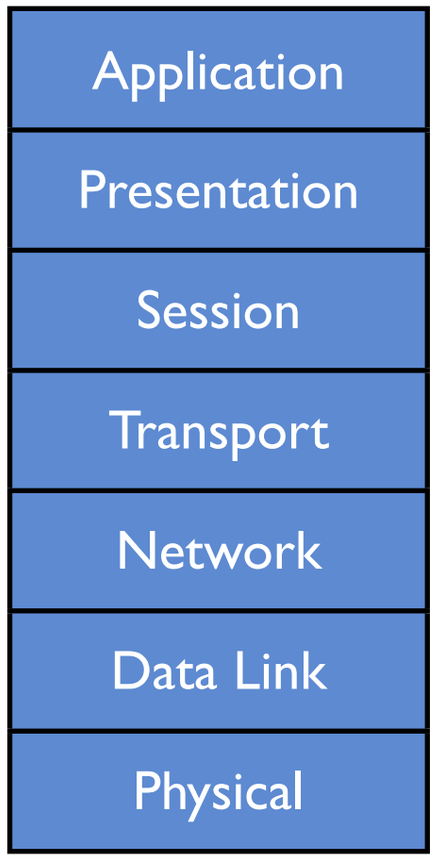
TCP/IP implemented on mainframes by groups at Stanford, BBN, UCL

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



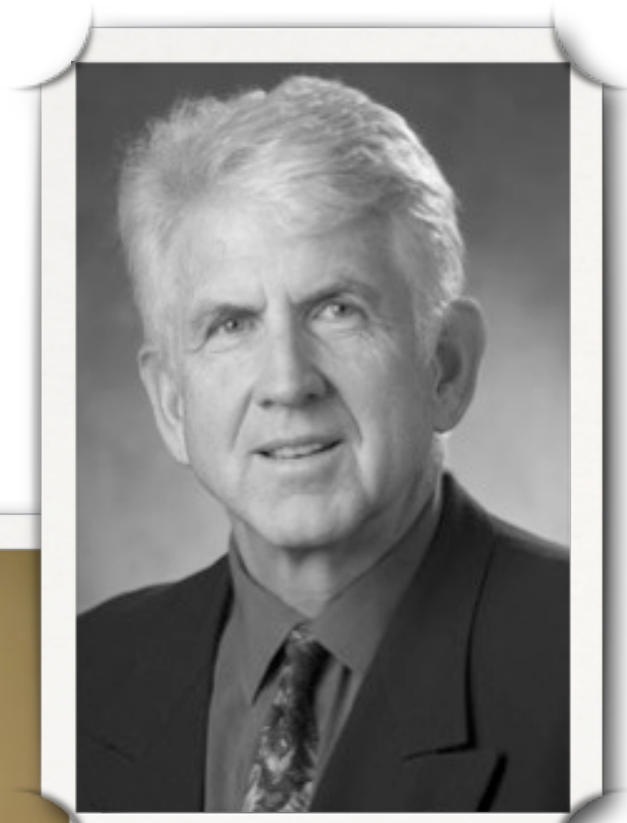

OSI Reference Model's layers

# Growth from Ethernet

Ethernet: R. Metcalfe and D. Boggs, July 1976

Spanning Tree protocol: Radia Perlman, 1985

Made local area networking easy



Metcalfe

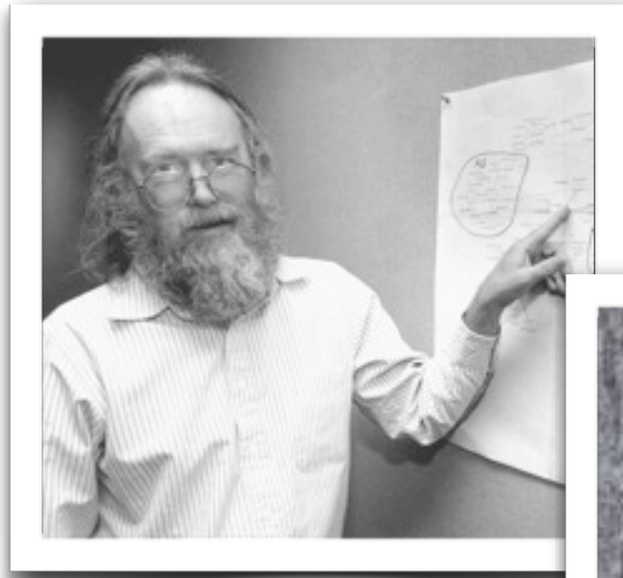
Perlman

# 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

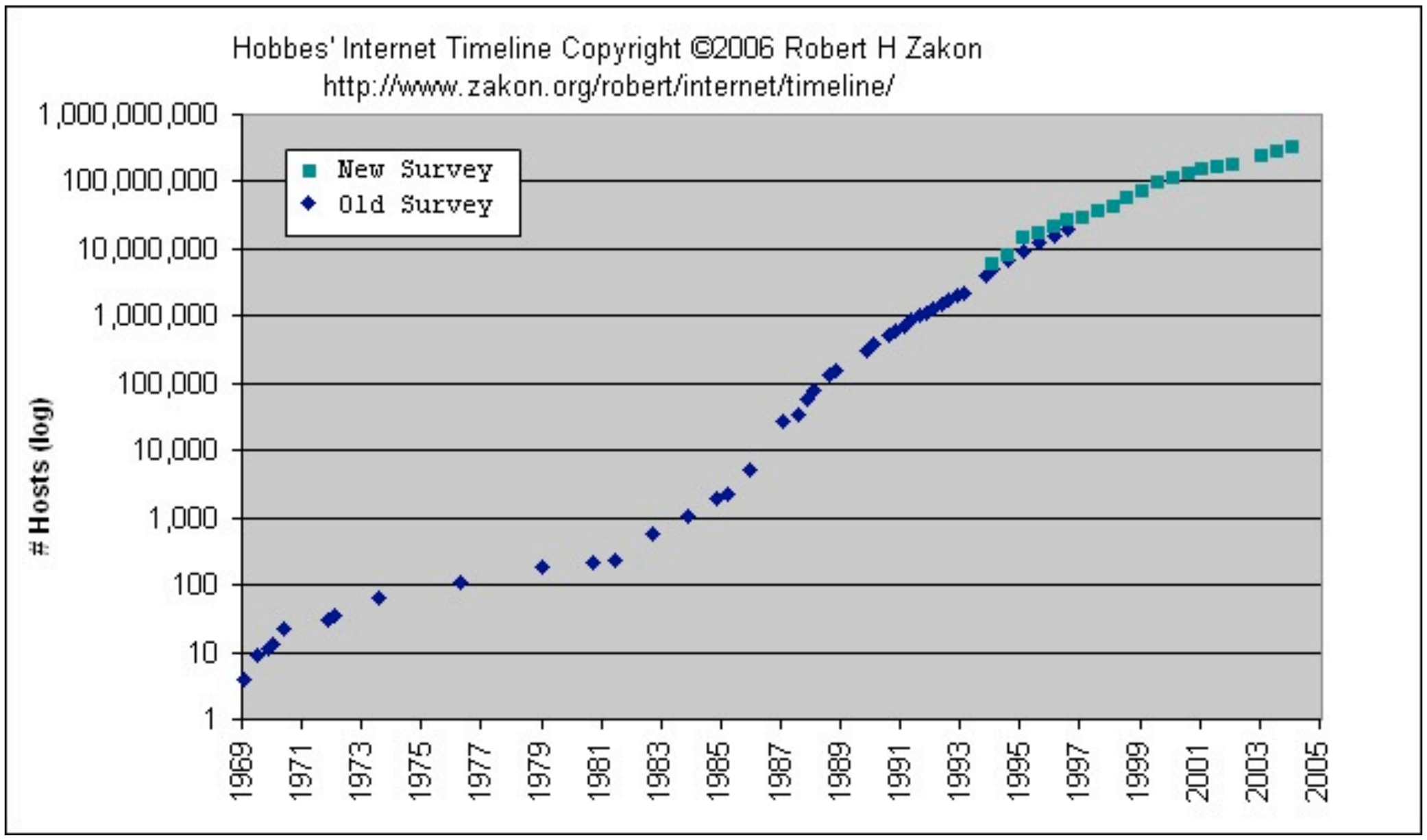
1990: ARPANET ends

1995: NSFNET decommissioned

NSFNET backbone, 1992

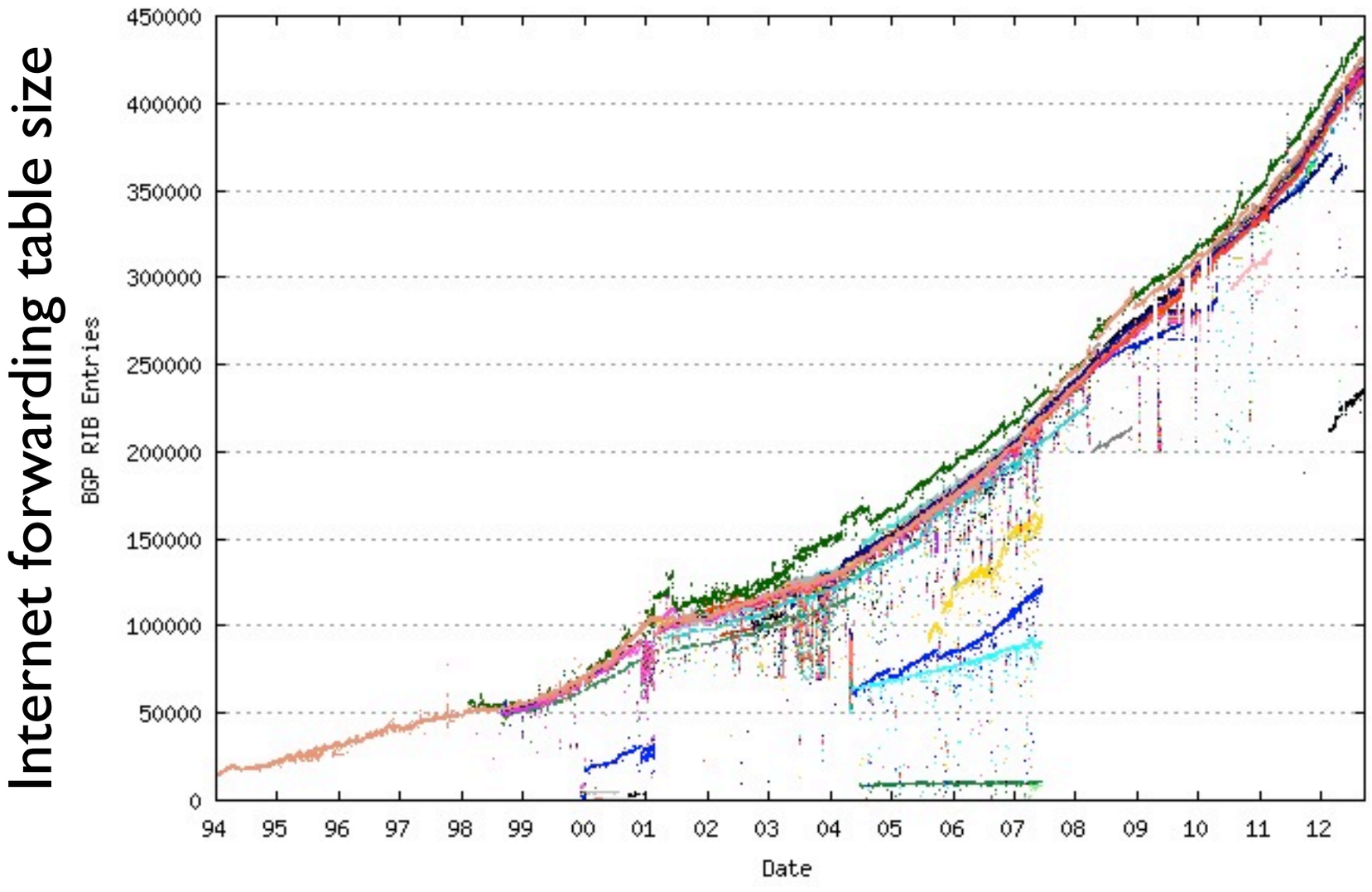
# Explosive growth!

## In hosts



# Explosive growth!

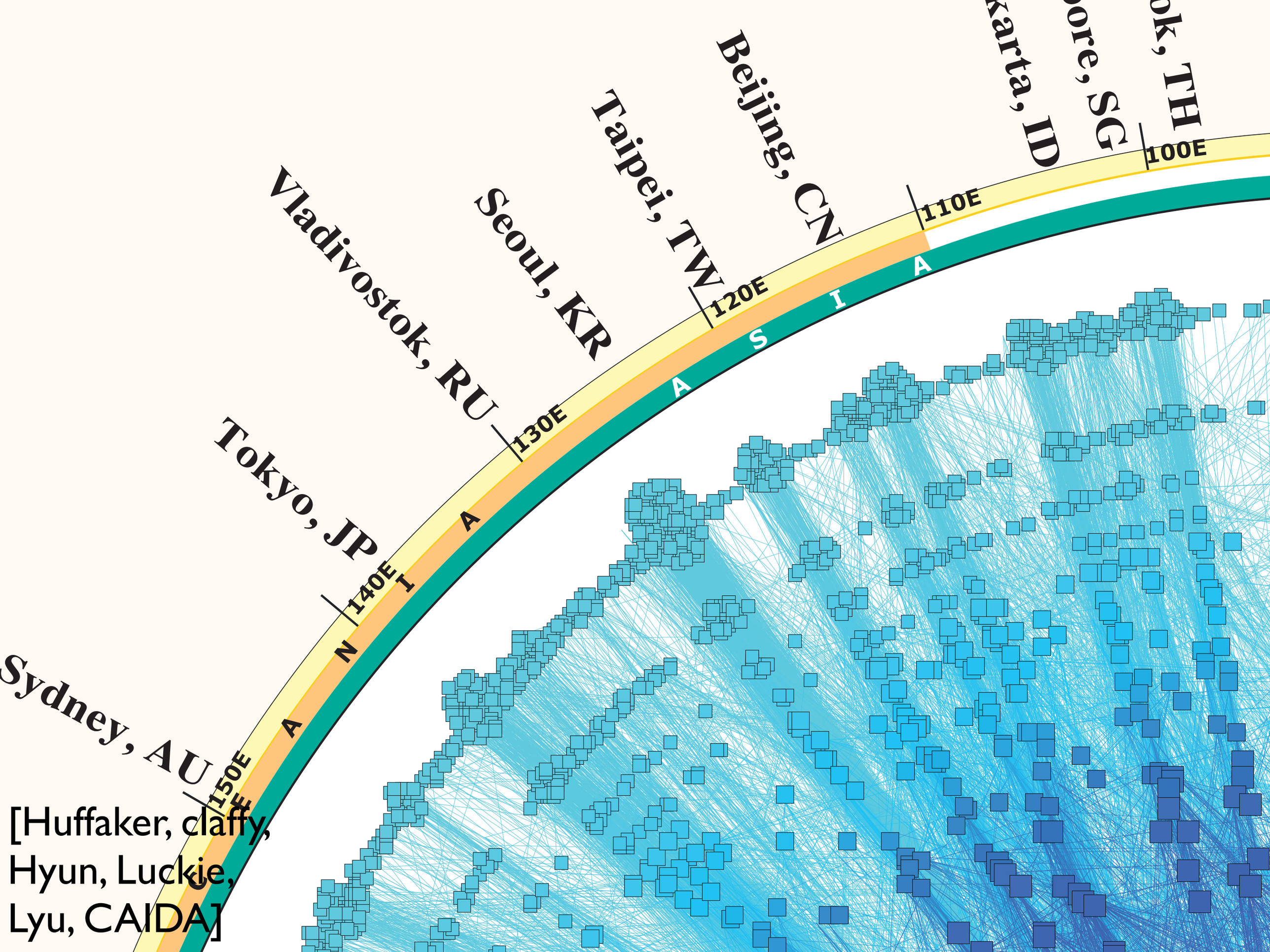
## In networks




Year

(Colors correspond to measurements from different vantage points)

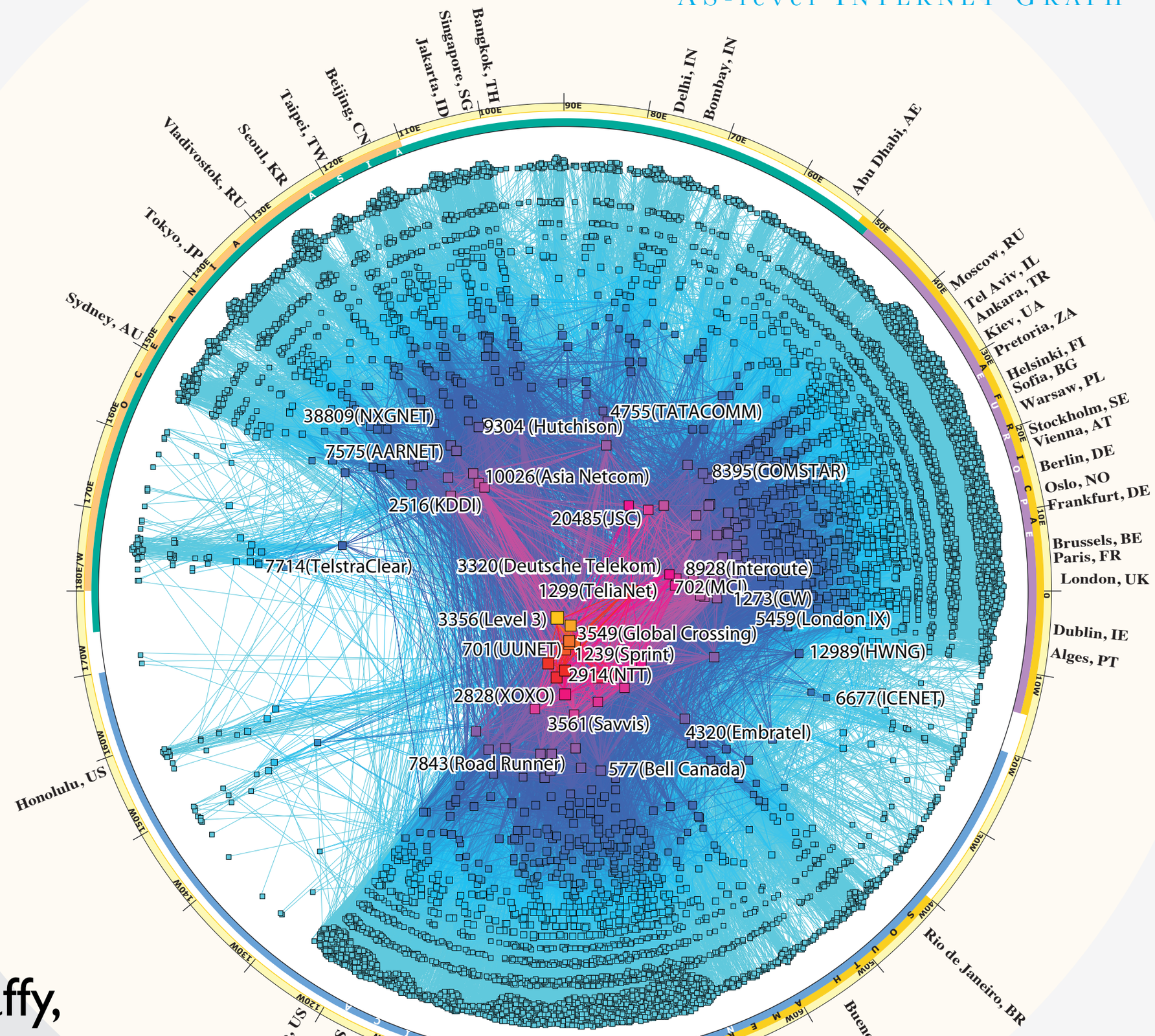
[Huston '12]




[Huffaker, claffy, Hyun, Luckie, Lyu, CAIDA]

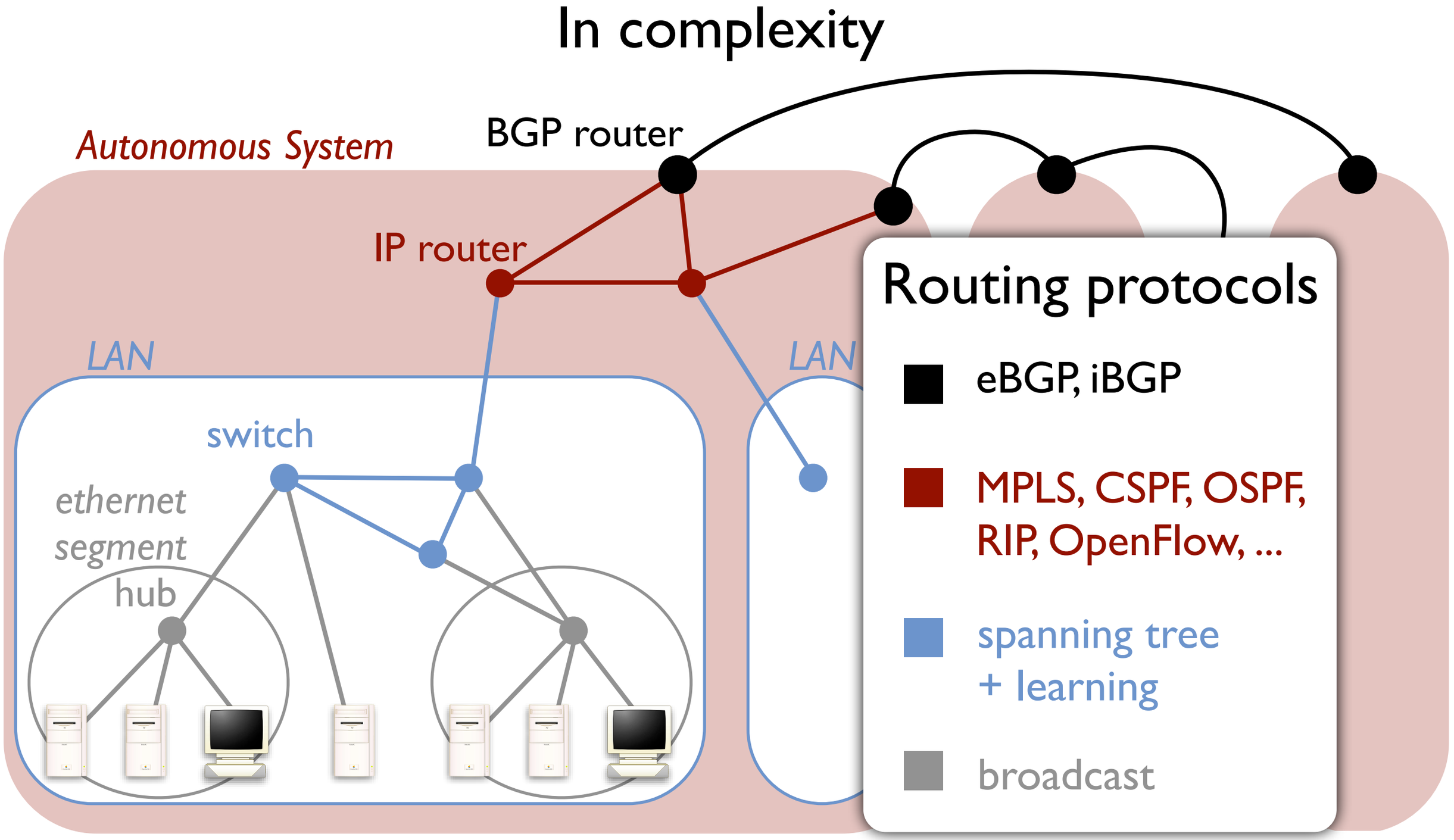
# IPv4 & IPv6 INTERNET TOPOLOGY MAP JANUARY 2009

## AS-level INTERNET GRAPH




[Huffaker, claffy, Hyun, Luckie, Lyu, CAIDA]

# Explosive growth!



# Explosive growth!

## In devices & technologies

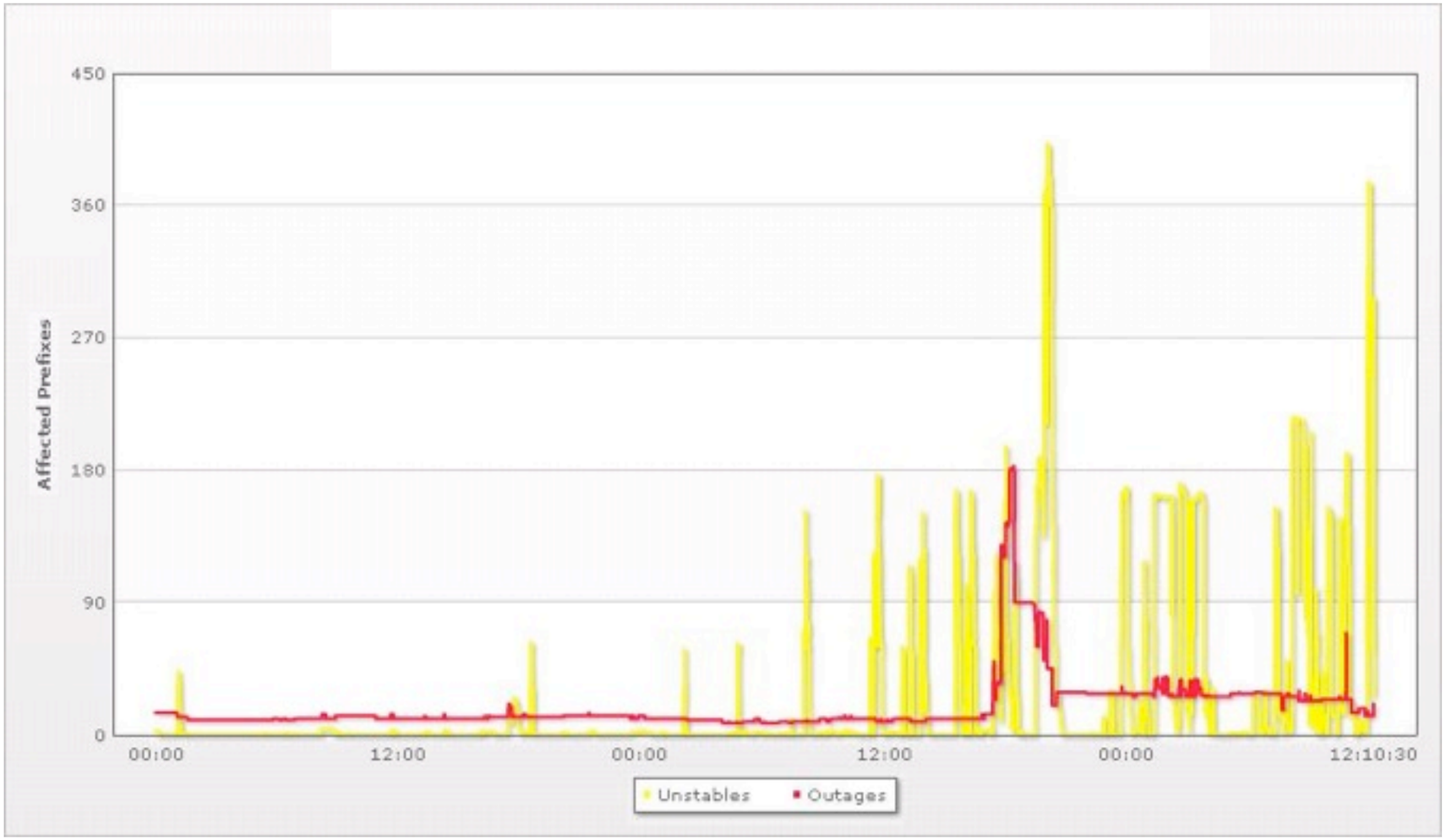
O(100 million) times as many devices
Link speeds 200,000x faster
NATs, firewalls, DPI, ...
Wireless everywhere
Mobile everywhere
Tiny devices (smart phones)
Giant devices (data centers)
...

## 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

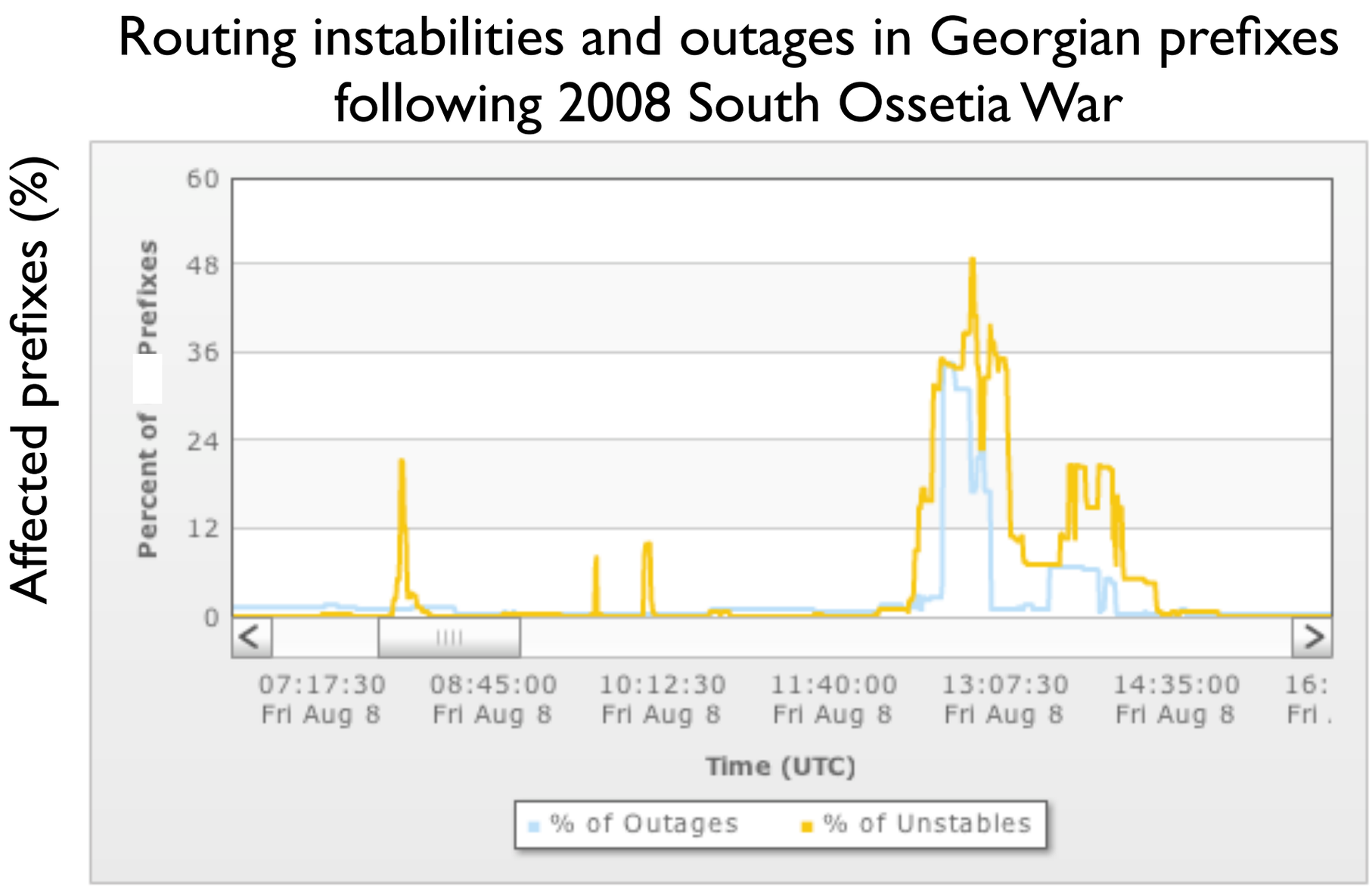
Friday June 12 2009

Saturday June 13

Sunday June 14

[James Cowie, Renesys Corporation]

# Huge societal relevance

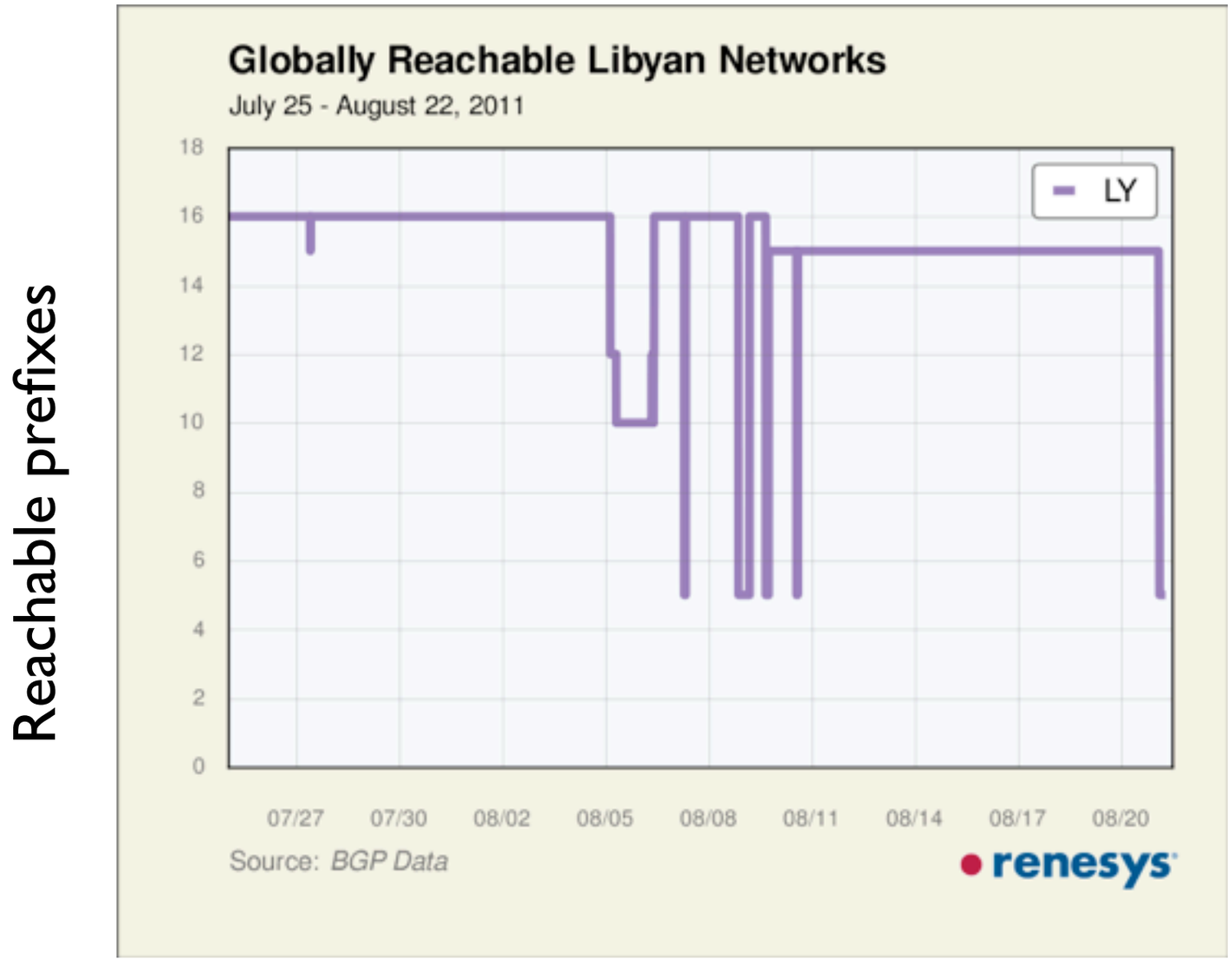



Fri, Aug 8, 2008

[Earl Zmijewski, Renesys Corporation]

# Huge societal relevance

## Reachability to Lybia




July - August 2011

[James Cowie, Renesys Corporation]

# Huge societal relevance

# Huge societal relevance

# 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

# Today

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Internet History

Your Future

# Your (near-term) future

## Thursday

- Brief review of some undergrad networking concepts
- Grand Challenges in computer networking
- [if time] project, project topic suggestions

- Sign up for Piazza account, say hello in the welcome thread (email me if you did not get a Piazza invitation)

## Next week

- Internet architecture technical overview
- Readings begin
- Assignment released