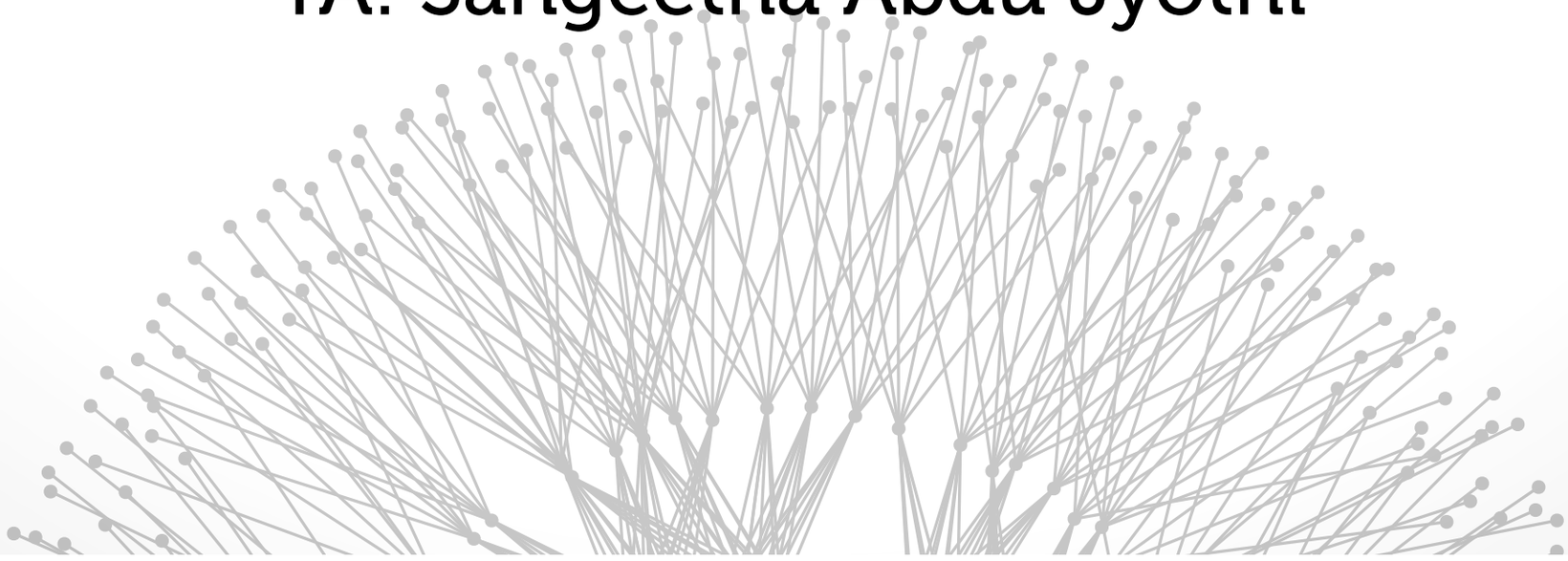
Advanced Computer Networks

UIUC CS 538 Spring 2018
Instructor: Brighten Godfrey
TA: Sangeetha Abdu Jyothi



Today

Course Overview

Internet History

Your Future

This course

is instructed by Brighten Godfrey

- pbg@illinois.edu, 3211 Siebel

is TA'd by Sangeetha Abdu Jyothi

- abdujyo2@illinois.edu

takes place Mon & Wed, 11:00 - 12:15 pm, in 1105 SC

comes with FREE office hours in 3211 SC: currently,

- Wednesdays 9-10am (Brighten)
- Thursdays 2:30-3:30pm (Sangeetha)

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. Readings

The classics: core architecture

- Classic Internet architecture
- Data plane: switch hardware & forwarding
- Routing & interdomain connectivity
- Congestion control

The challenges

- Resilience
- Scalability
- Selfishness
- Security
- Complexity

1. Readings

The classics: core architecture

The challenges

The latest, such as:

- Hyperscale cloud & data center networks
- SDN, NFV, & network virtualization
- Content distribution
- Applications: video, big data
- Censorship

1. Readings

One or two papers per lecture

Reviews due 11:59pm night before we discuss the paper

- Submit in the paper's review thread on Piazza

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

- subject to ongoing revision

2. Project

Research project that could be developed into a conference submission

Work in groups of 2-3 (preferred)

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

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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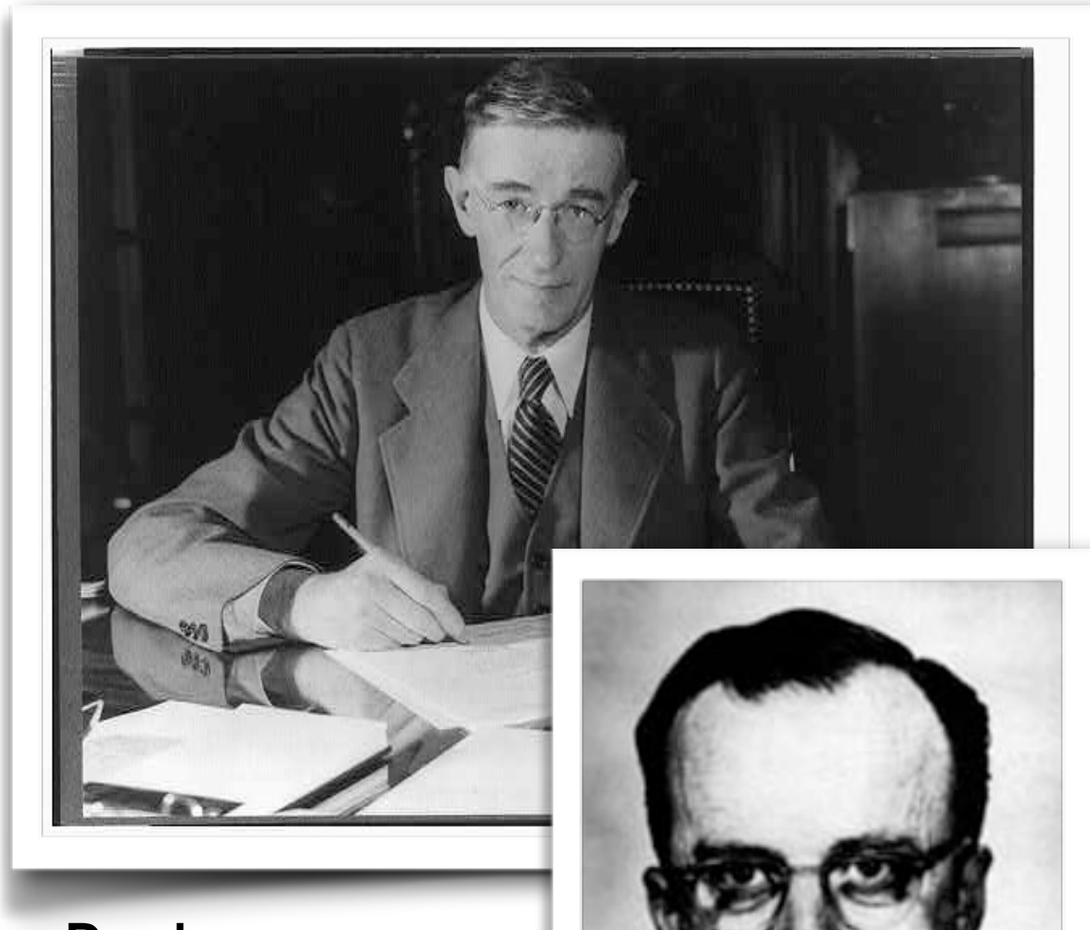
Your Future

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

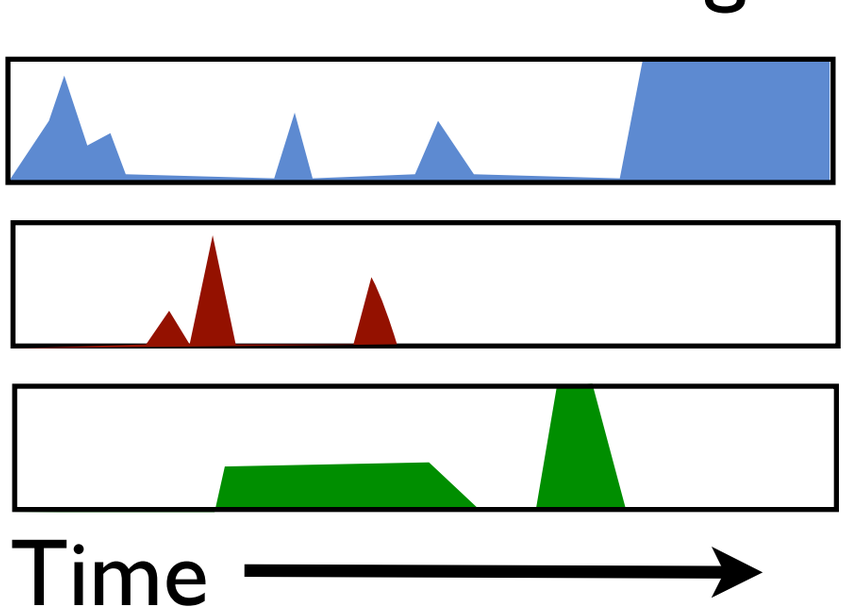
Circuit Switching	Packet switching
Physical channel carrying stream of data from source to destination	Message broken into short packets, each handled separately
Three phase: setup, data transfer, tear-down	One operation: send packet
Data transfer involves no routing	Packets stored (queued) in each router,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

1961-64: Packet switching

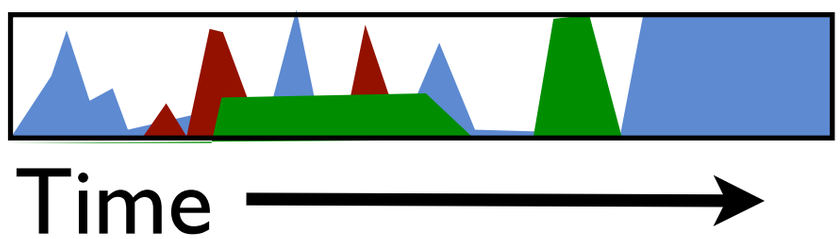
One key benefit: Statistical Multiplexing

- (what else?)

Circuit switching



Packet switching: multiplexed



$$cost = \sum_{c} \max_{t} demand(c,t)$$

$$cost = \max_{t} \sum_{c} demand(c,t)$$

(*c* indexes connections, *t* indexes time)

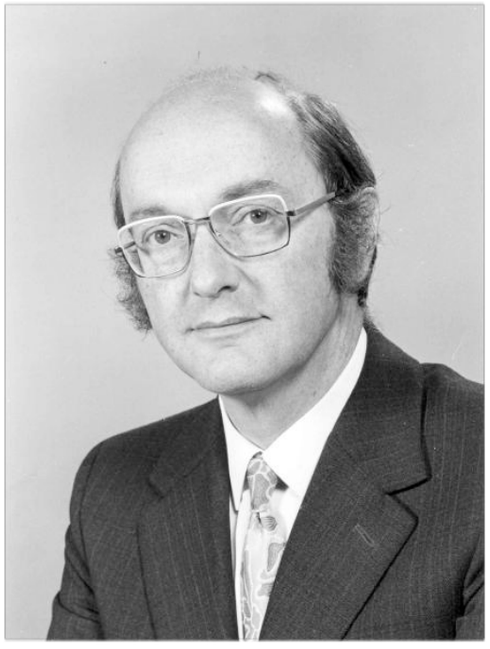
1961-64: Packet switching

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

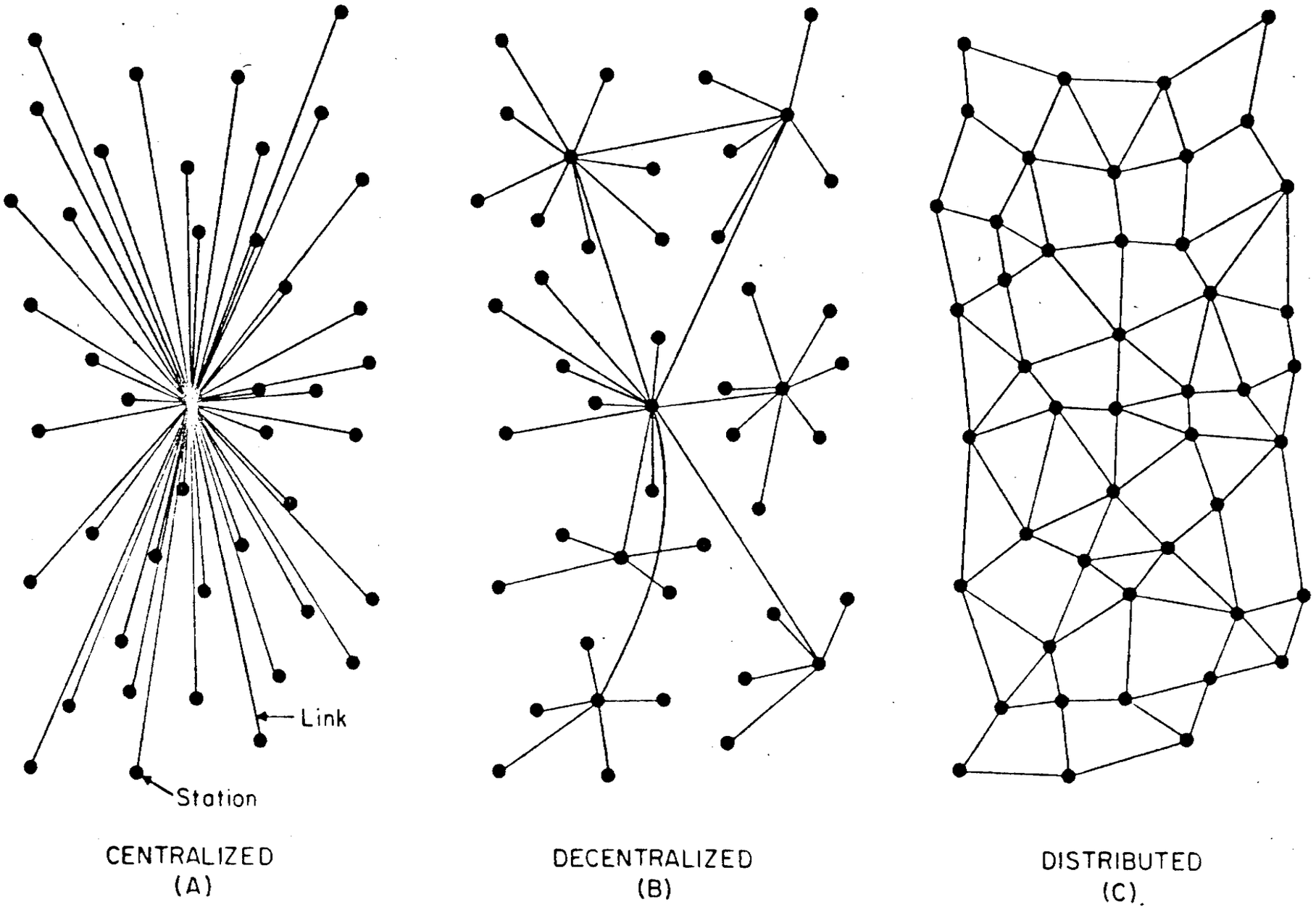


FIG. 1 — Centralized, Decentralized and Distributed Networks

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

Baran's packet switching

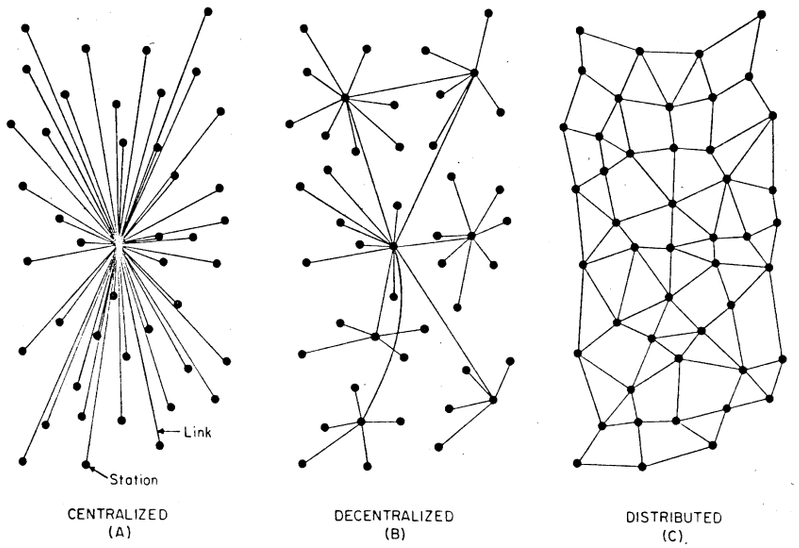


FIG. 1 — Centralized, Decentralized and Distributed Networks

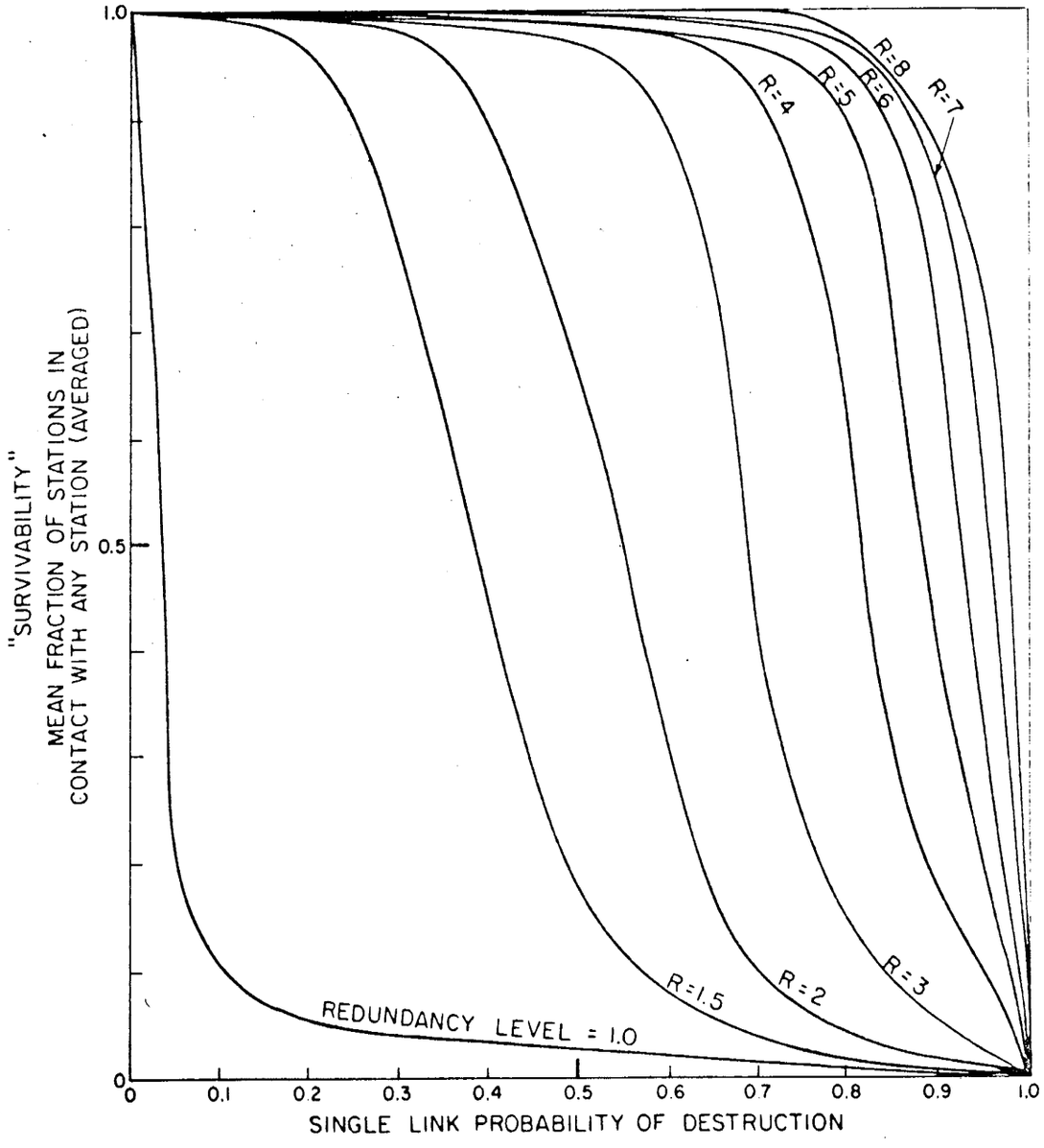


FIG. 5 — Perfect Switching in a Distributed Network — Sensitivity to Link Destruction, 100% of Nodes Operative.

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

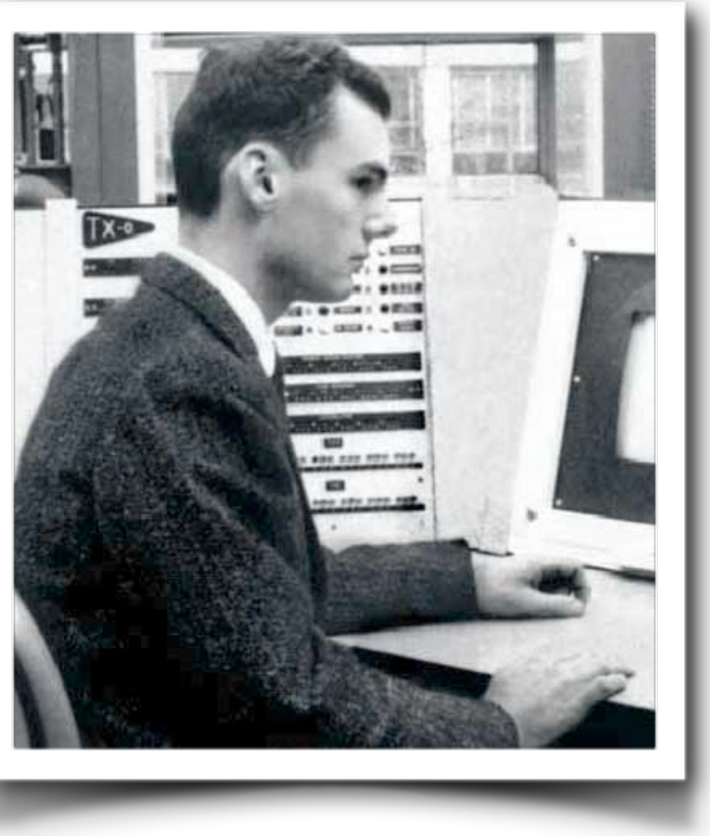
1965: First computer network

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


HONEYWELL
RP·61R
POWER DISTRIBUTION UNIT
HONEYWELL
RP·61R


INTERFACE
MESSAGE
PROCESSOR

IMP LOG

COMPANY

ADDRESS

MONTH OF

ENGINEER IN CHARGE

COMPUTER SERIAL NO.

DATE	METER	PROBLEM & REMEDY	OPERATOR	DOWNTIME
10/9/69	10 35	Operational Program Running at Request of SRI		
"	11:00	Loaded SL1000 at request of SLT Punching on Tape		
10/9/69	1:30pm	Call Admit stops John using SRI called - Didn't Tried Debug test pr SL1000 but it did work.		
10/9/69	4:00 pm	SRI called. we tried things at their inst Nothing worked.		
10/10/69	0007	Reload Operation a/t I left the tape a		

CUSTOMER SERVICE

IMP LOG

COMPANY

ADDRESS

MONTH OF

ENGINEER IN CHARGE

COMPUTER SERIAL NO.

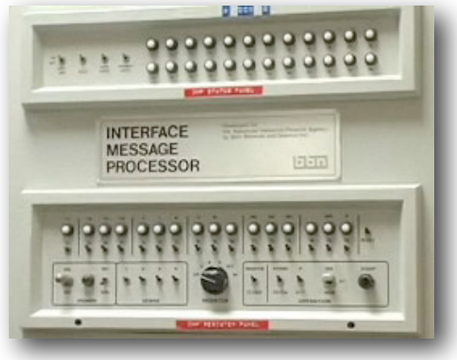
DATE	METER	PROBLEM & REMEDY	OPERATOR	DOWNTIME
10/13	9:36	Imp? is halted (I don't know when)	OIC	
		P= 1057B		
		A = 0		
		B = 0		
		OP = 24 200		
		X = 0		
		M = 76		
10/13	9:45p	Test skeletal Please do not touch.		
10/14	4:46	Test in progress - will be checked tomorrow AM	MJT	
10/14	6:50 pm	The above is unreadable and Not signed Please try harder.		
10/15	8:50	Sorry. Please leave imp running - test in progress	Jon Marty Thrope	

CUSTOMER SERVICE

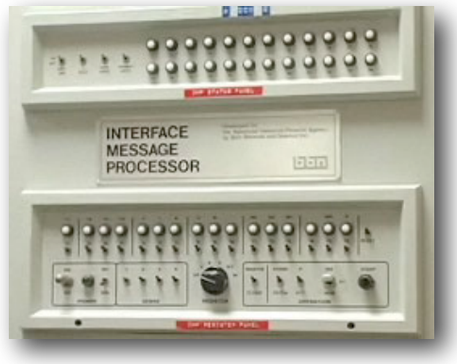
SDS-S-324

ARPANET comes alive

Stanford Research Institute
(SRI)



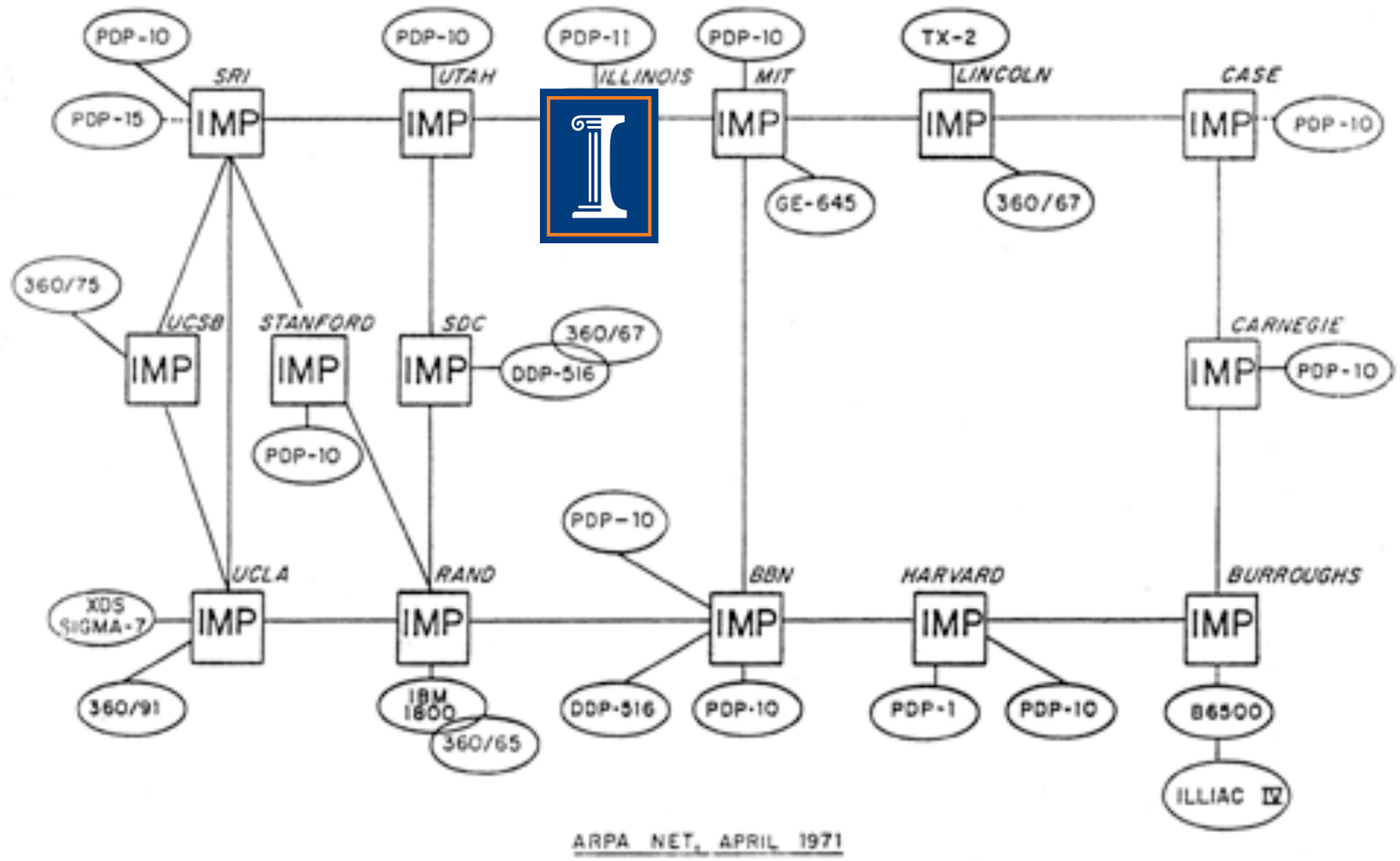
"LO"
Oct 29, 1969



UCLA

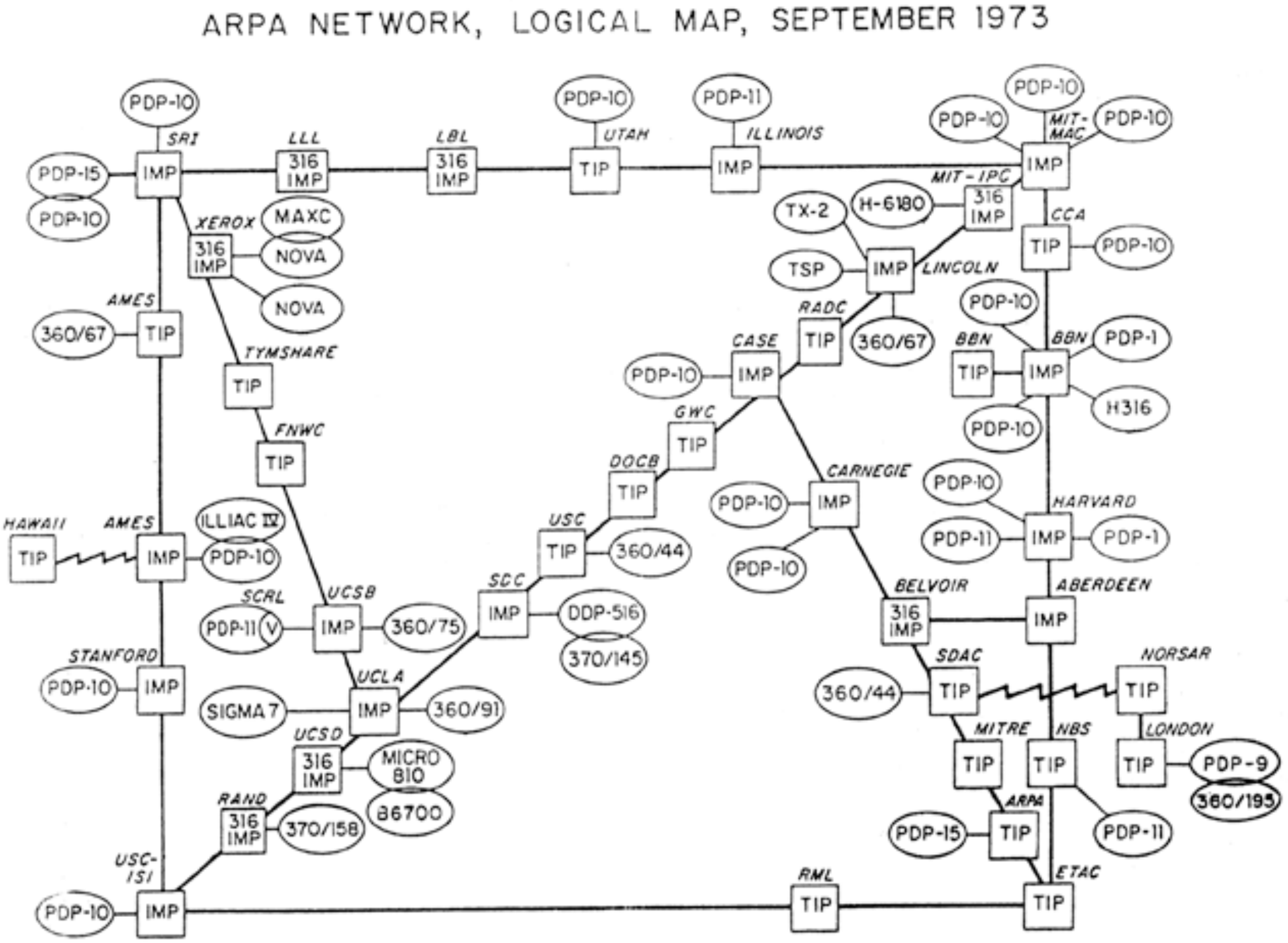
ARPANET grows

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



ARPANET, April 1971

ARPANET grows

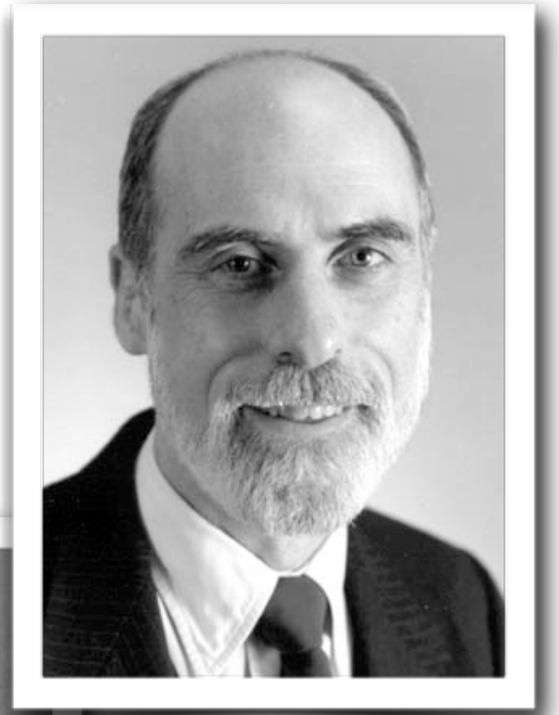


ARPANET to Internet

Meanwhile, other networks such as PRnet, SATNET developed

May 1973: Cerf & Kahn present first paper on interconnecting networks with concepts of

- connecting diverse networks
- unreliable datagrams
- global addressing, …
- what became TCP/IP



Vinton G. Cerf

Robert E. Kahn

TCP/IP deployment

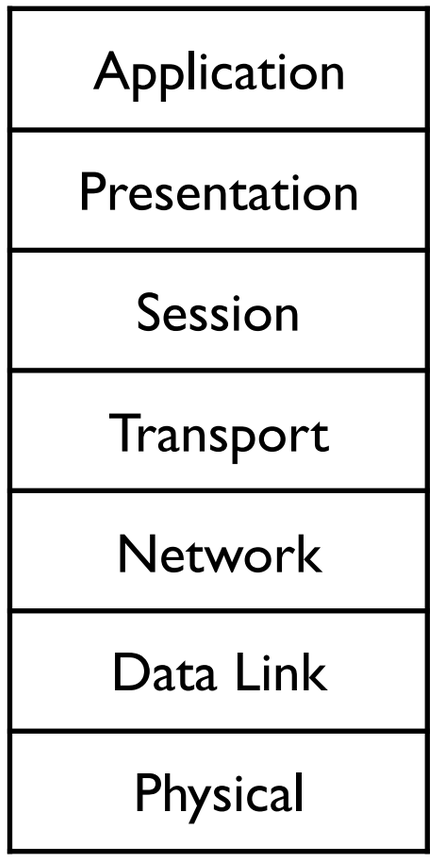
TCP/IP implemented on mainframes by groups at Stanford, BBN, UCL

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



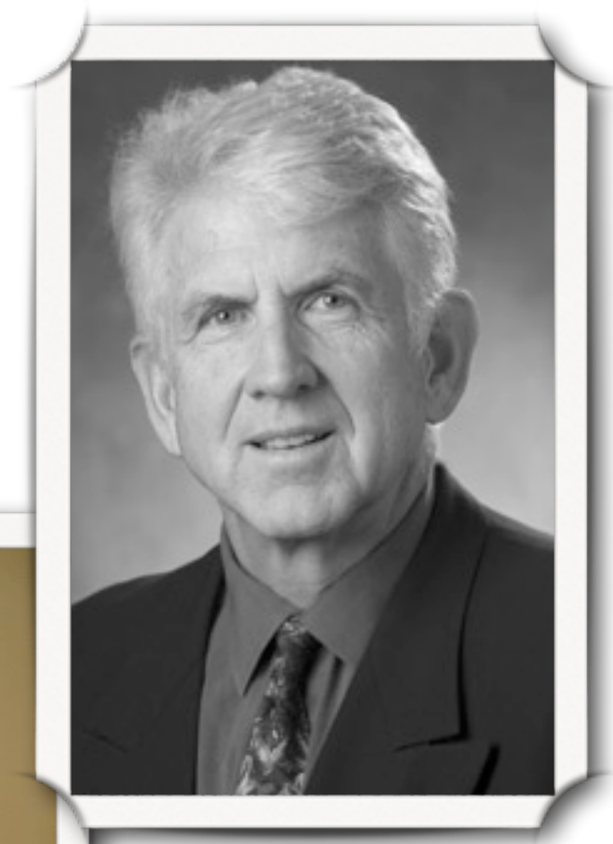
OSI Reference Model's layers

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

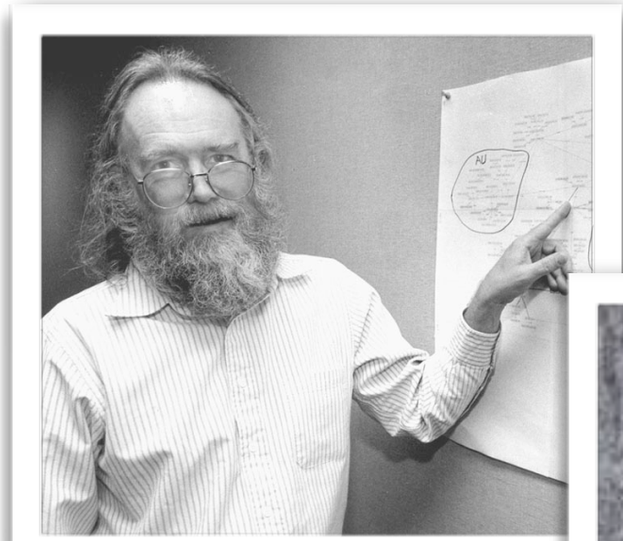
- CSNET, BITNET, MFENet, SPAN (NASA), ...

Nov 1983: DNS

- Developed by Jon Postel, Paul Mockapetris (USC/ISI), Craig Partridge (BBN)

1984: Hierarchical routing

- EGP and IGP
- Later became eBGP and iBGP

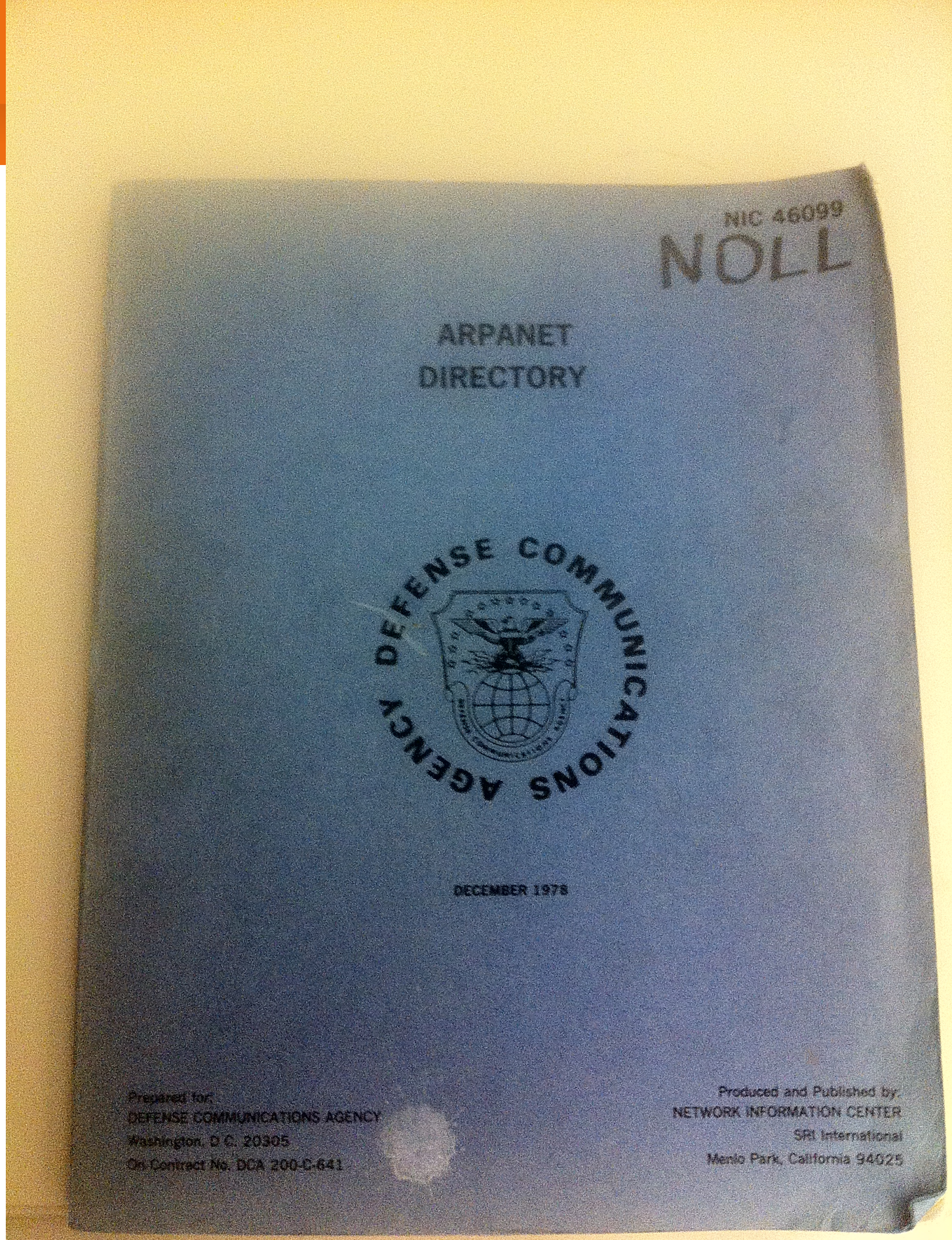


Mockapetris

Postel

Partridge

Before DNS…


NIC 46099
NOLL
ARPANET
DIRECTORY
DEFENSE COMMUNICATIONS AGENCY
DECEMBER 1978
Prepared for:
DEFENSE COMMUNICATIONS AGENCY
Washington, D.C. 20305
On Contract No. DCA 200-C-641
Produced and Published by:
NETWORK INFORMATION CENTER
SRI International
Menlo Park, California 94025

IDA

Institute for Defense Analysis
100 Prospect Avenue
Princeton, New Jersey 08540

IFIP

International Federation of Information
Processing - Secretariat
3, Rue du Marche'
CH-1204 Geneva
SWITZERLAND

IIASA

International Institute For Applied Systems
Analysis
Computer Science
2361 Laxenberg
Schloss Laxenberg, AUSTRIA

ILL-UNIX

University of Illinois
Computing Services Office
Urbana, Illinois 61801

INFOMEDIA

Infomedia Corporation
430 Sherman Avenue
Palo Alto, California 94306

KENT

Kent State University
Department of Mathematics
Kent, Ohio 44242

COMPUTERS BY MANUFACTURER

MANUFACTURER COMPUTER	OP-SYS	HOST NAME	ADDR (Dec)	STATUS
BOLT BERANEK AND NEWMAN [BBN]				
PLURIBUS		BBN-PTIP	2/5	Terminal interface
PLI		BBN-UNIX	0/63	Private Line interface
PLURIBUS		SDAC-CCP	0/39	Seismic data processor
PLI		MOFFETT-SUBNET	1/45	Private Line interface
		FNWC-SECURE	3/64	Private Line interface
PLI		NOSC-SECURE1	1/3	Private Line interface
PLI		NOSC-SECURE2	0/35	Private Line interface
PLI		NOSC-SECURE3	3/35	Very distant host
PLI		WPAFB-AFAL	1/47	adapter
VDA				Very distant host
		WHARTON	1/46	adapter
VDA				
BURROUGHS				
B-5500	MCP	NCSC	1/53	Principal, USER
B-6700		I4-TENEX	0/15	Peripheral processor
ILLIAC-IV	ACL	I4-TENEX	0/15	Principal, SERVER
ILLIAC-IV	ACL	I4B-TENEX	2/15	Principal, SERVER
CONTROL DATA CORPORATION [CDC]				
		FNWC	1/64	Communication controller
CDC-3200	SESAME	LBL	0/34	Principal, SERVER
CDC-6400	NOS/BE	DTNSRDC	1/8	Principal, SERVER
		FNWC	1/64	Principal, USER
			2/8	Principal, Ltd SERVER
				Principal, Ltd SERVER

Software Sciences Section
(ISIS)
Griffiss Air Force Base, New
York 13441

CELLINI, Jr., James V. JVC Cellini
Rome Air Development Center @RADC-MULTICS
Software Sciences Section (315) 330-4325 (Autovon
(ISIS) 587-4325)
Griffiss Air Force Base, New RADC-TIP
York 13441

CERF, Vinton G. VGC CERF@USC-ISI
Advanced Research Projects (202) 694-3049 or 694
Agency -8096
Information Processing ARPA-TIP
Techniques Office
1400 Wilson Boulevard
Arlington, Virginia 22209

CHALLMAN, Nancy NC2 CULP@RAND-RCC
The Rand Corporation (213) 393-0411 ext 378
Rand Computation Center RAND-RCC
1700 Main Street
Santa Monica, California 90406

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

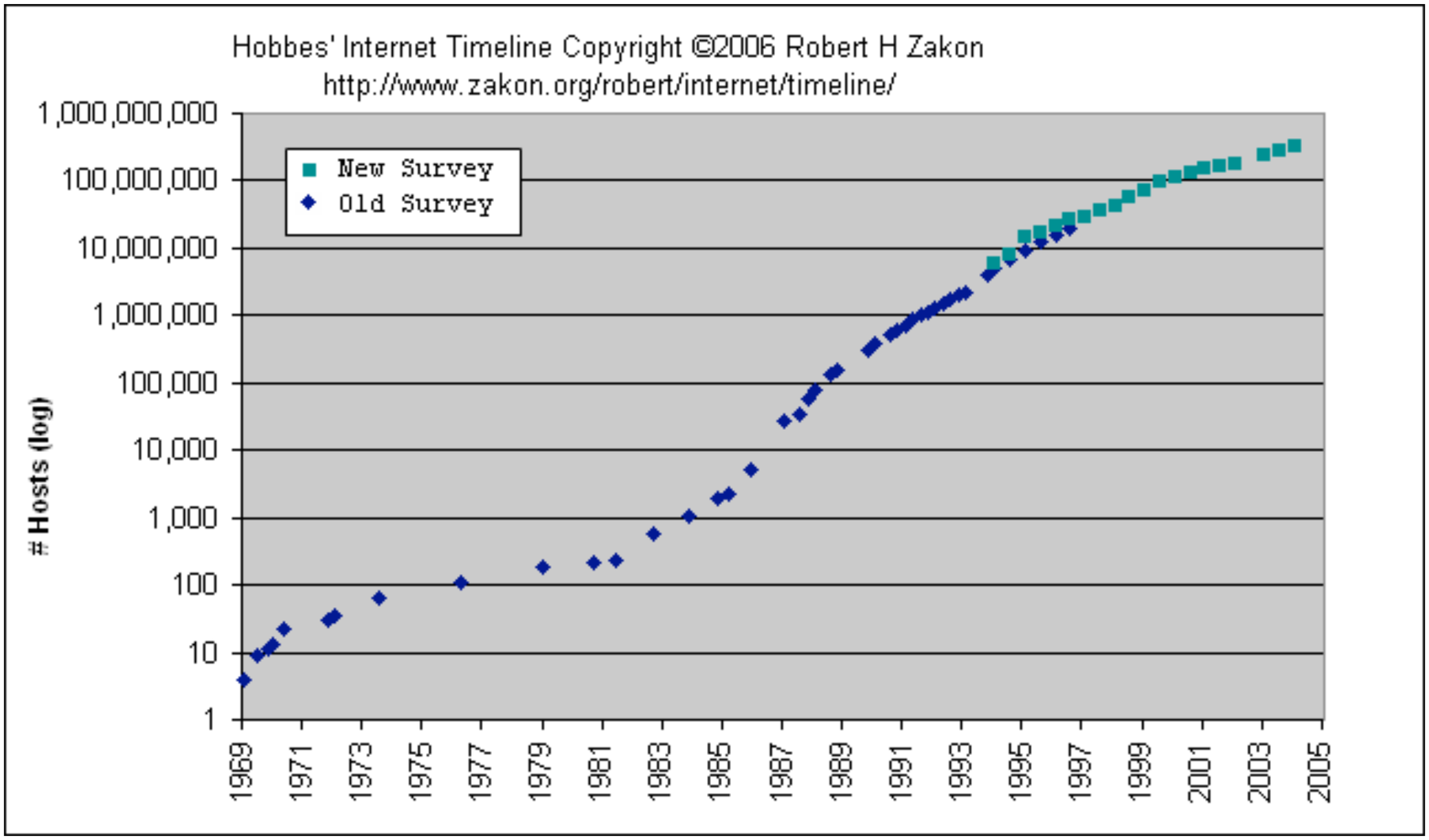
1990: ARPANET ends

1995: NSFNET decommissioned

NSFNET backbone, 1992

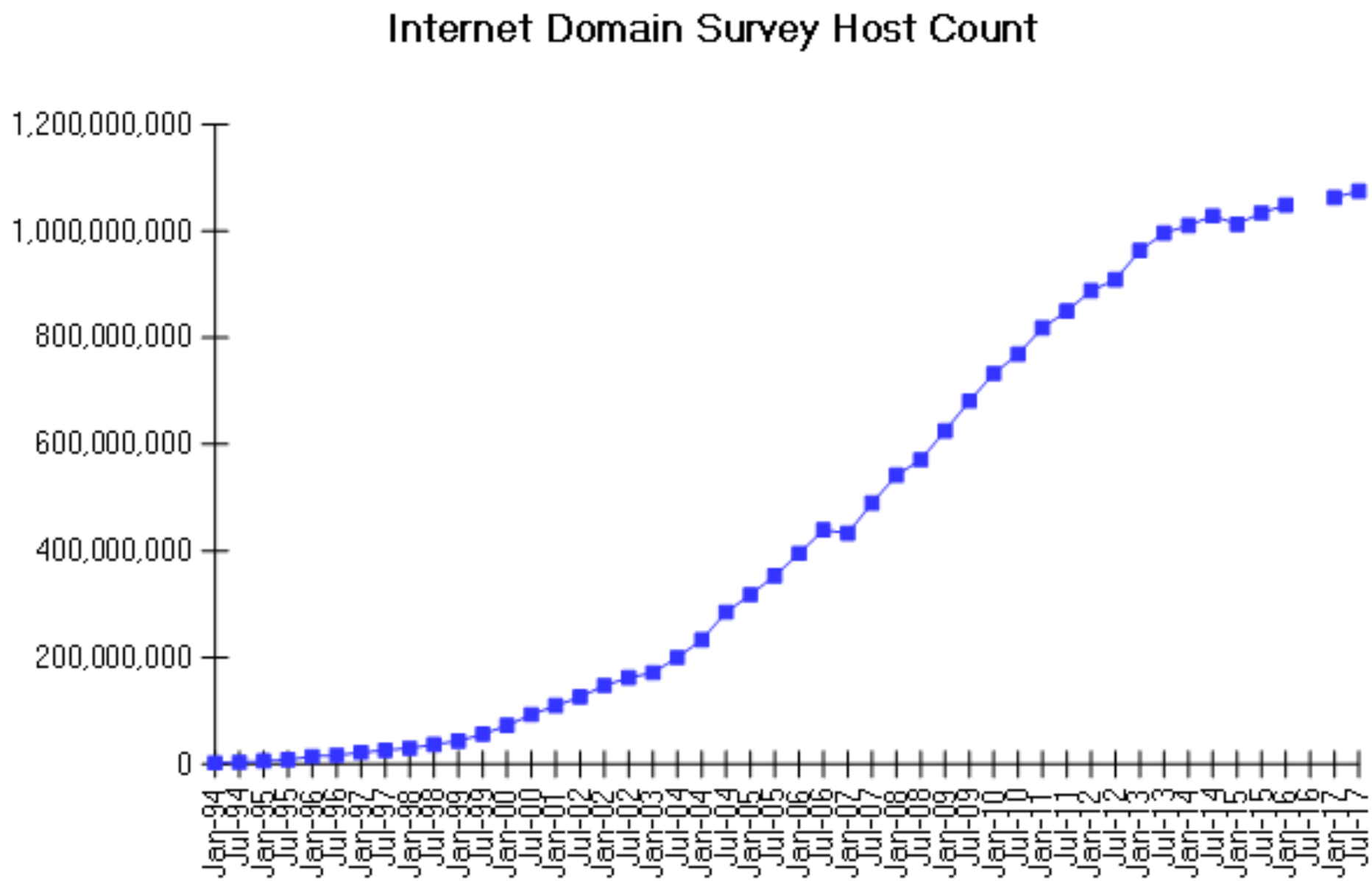
Explosive growth!

In hosts



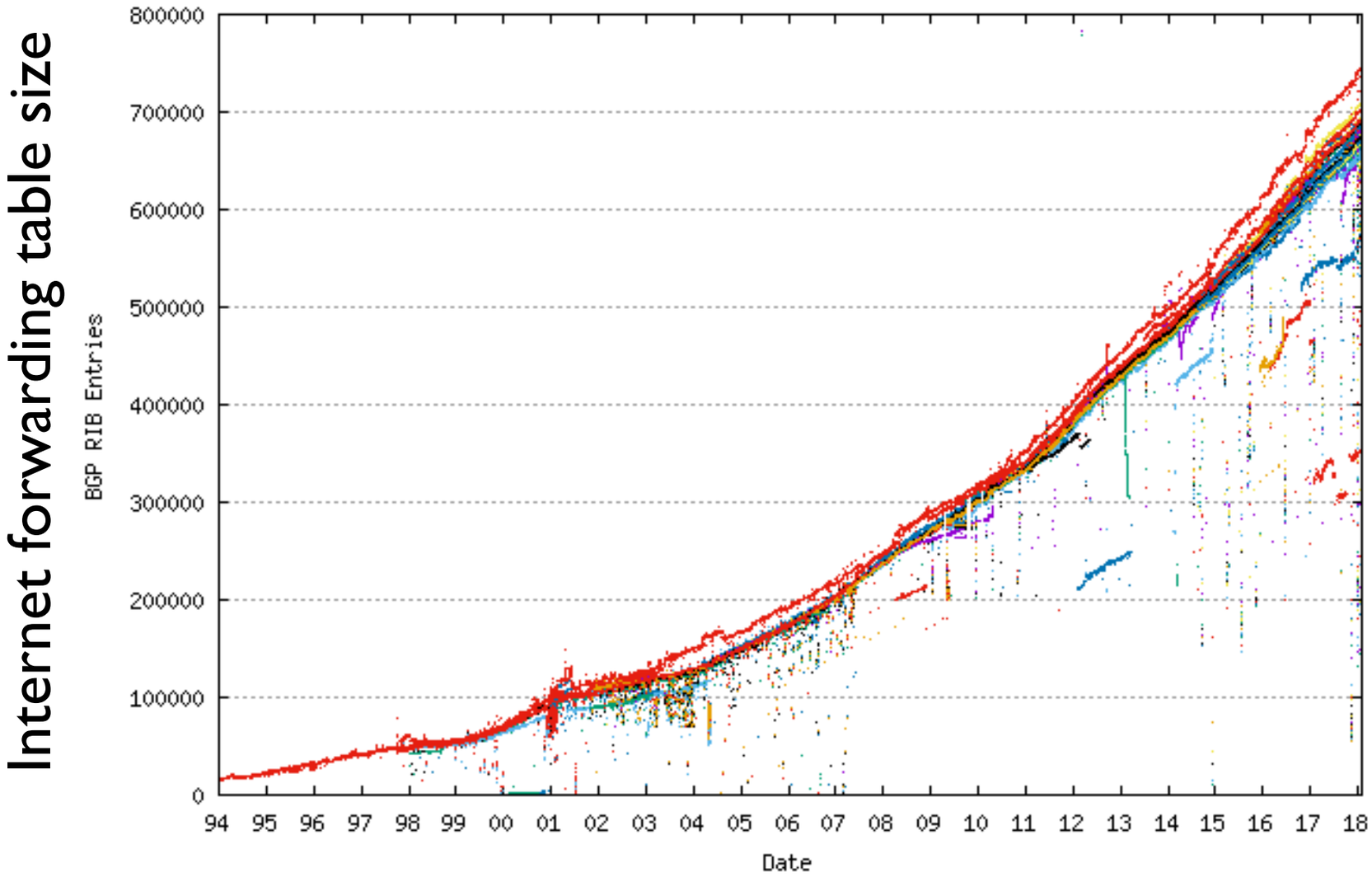
Explosive growth!

In hosts



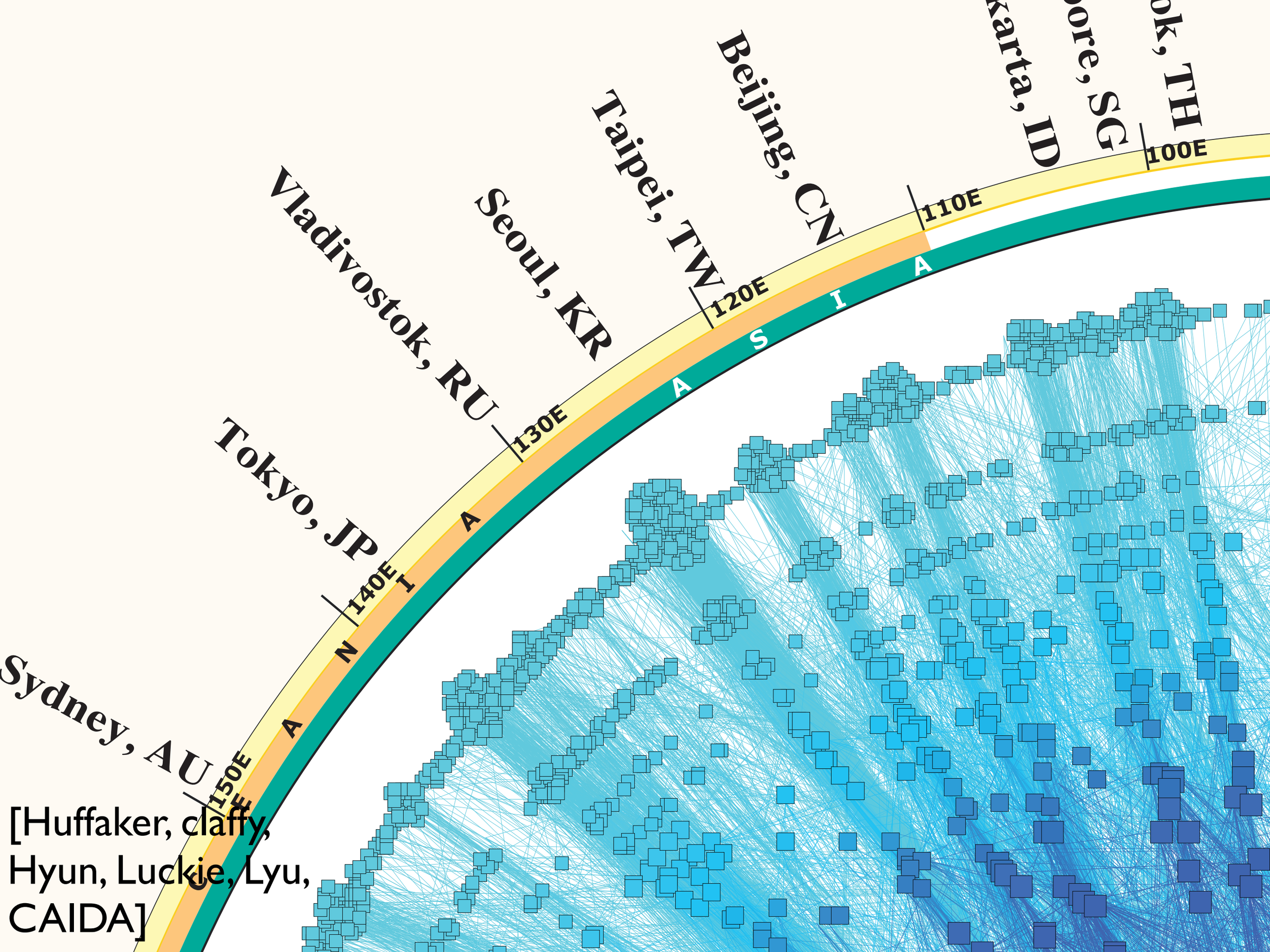
Explosive growth!

In networks



(Colors correspond to measurements from different vantage points)

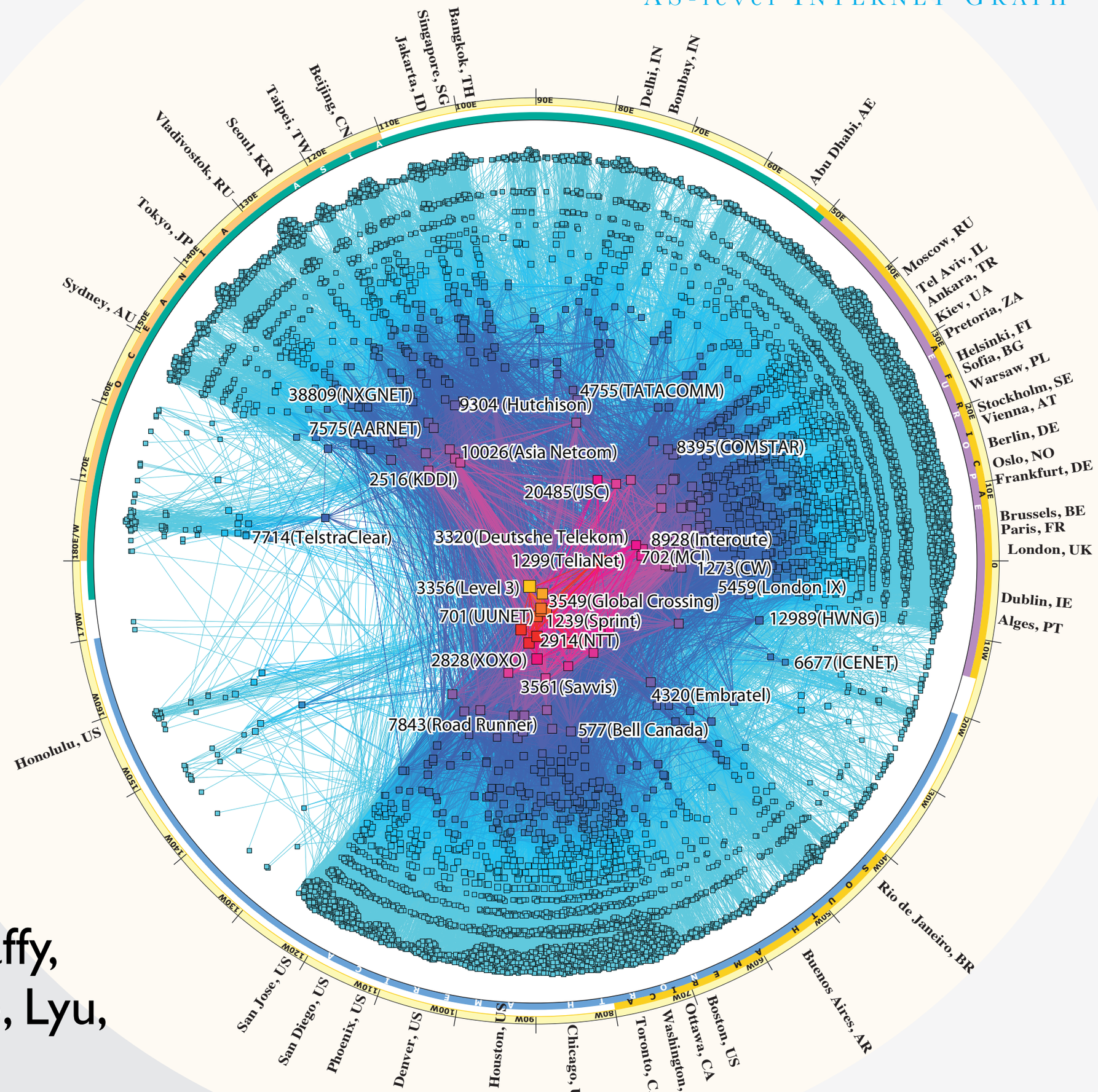
Source: Geoff Huston, Jan 2018
https://bgp.potaroo.net/index-bgp.html



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

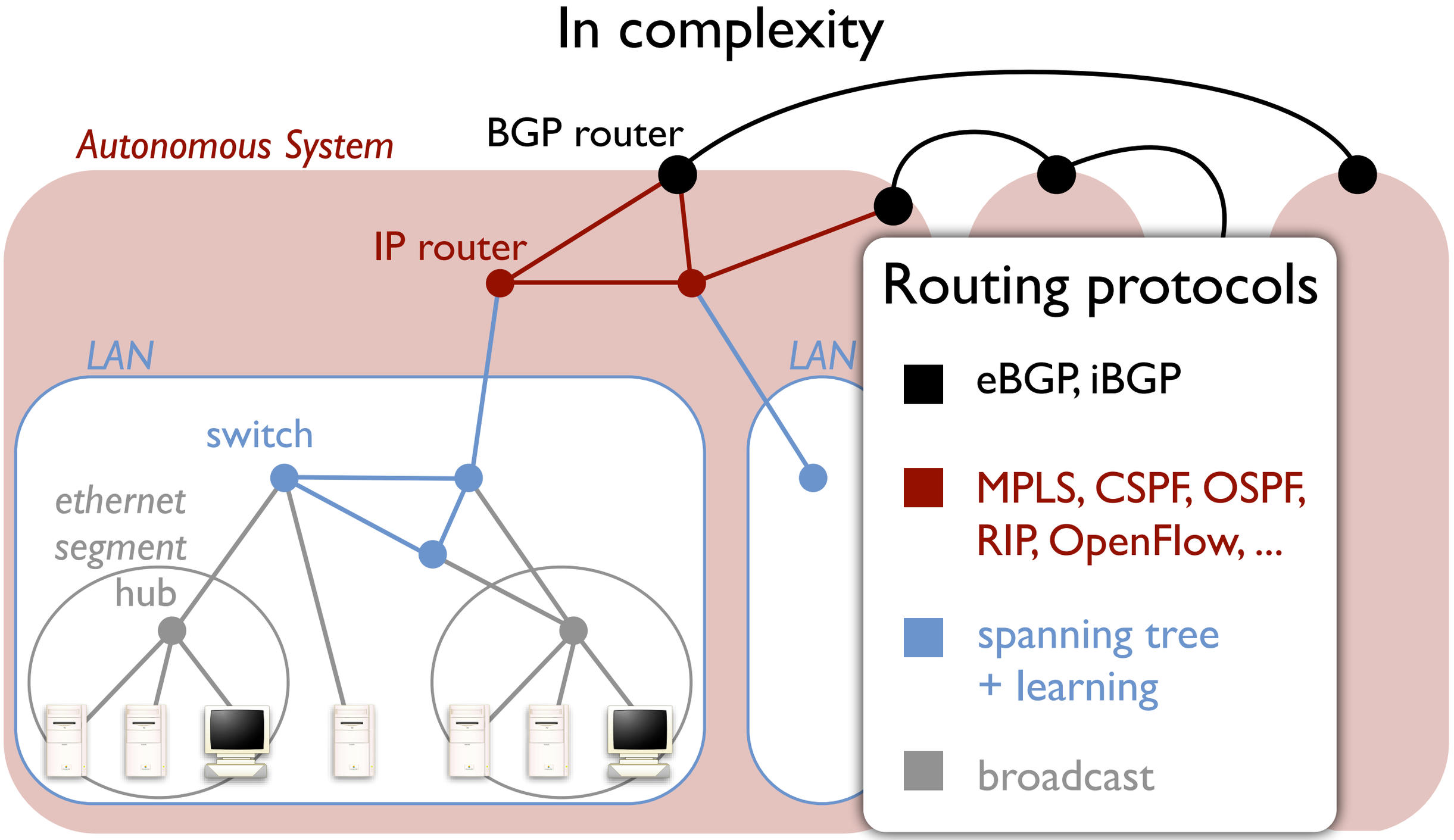
IPv4 & IPv6 INTERNET TOPOLOGY MAP JANUARY 2009

AS-level INTERNET GRAPH



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

Explosive growth!



Explosive growth!

In devices & technologies

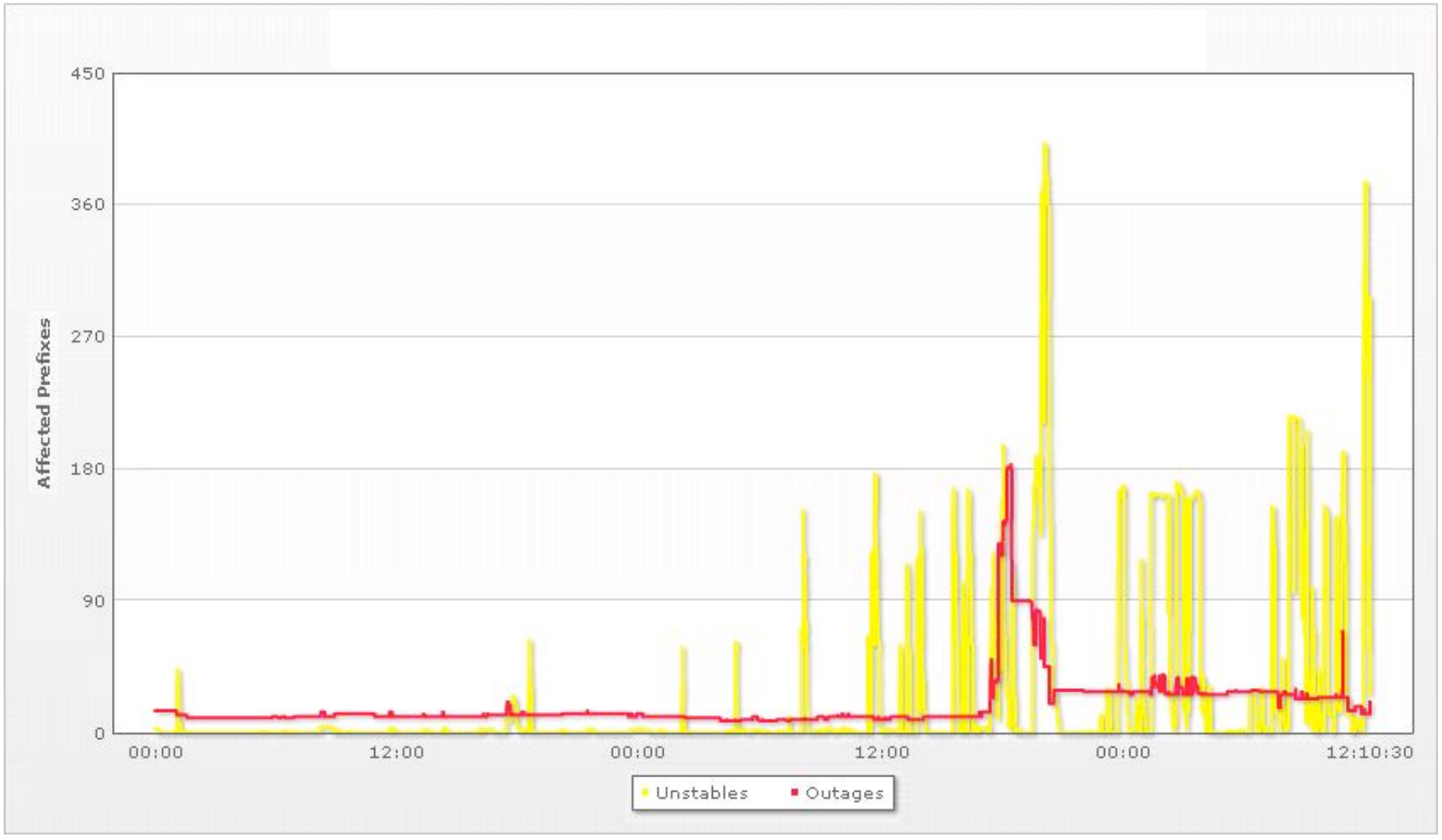
O(100 million) times as many devices
Link speeds 200,000x faster
NATs, firewalls, DPI, ...
Wireless everywhere
Mobile everywhere
Tiny devices (smart phones)
Giant devices (data centers)
...

In applications

Morris Internet Worm (1988)
World wide web (1989)
MOSAIC browser (1992)
Search engines
Peer-to-peer
Voice
Botnets
Social networking
Streaming video
Cloud computing
Mobile apps
Cryptocurrency
The results of your class projects!

Huge societal relevance

Routing instabilities and outages in Iranian prefixes following 2009 presidential election



Affected prefixes

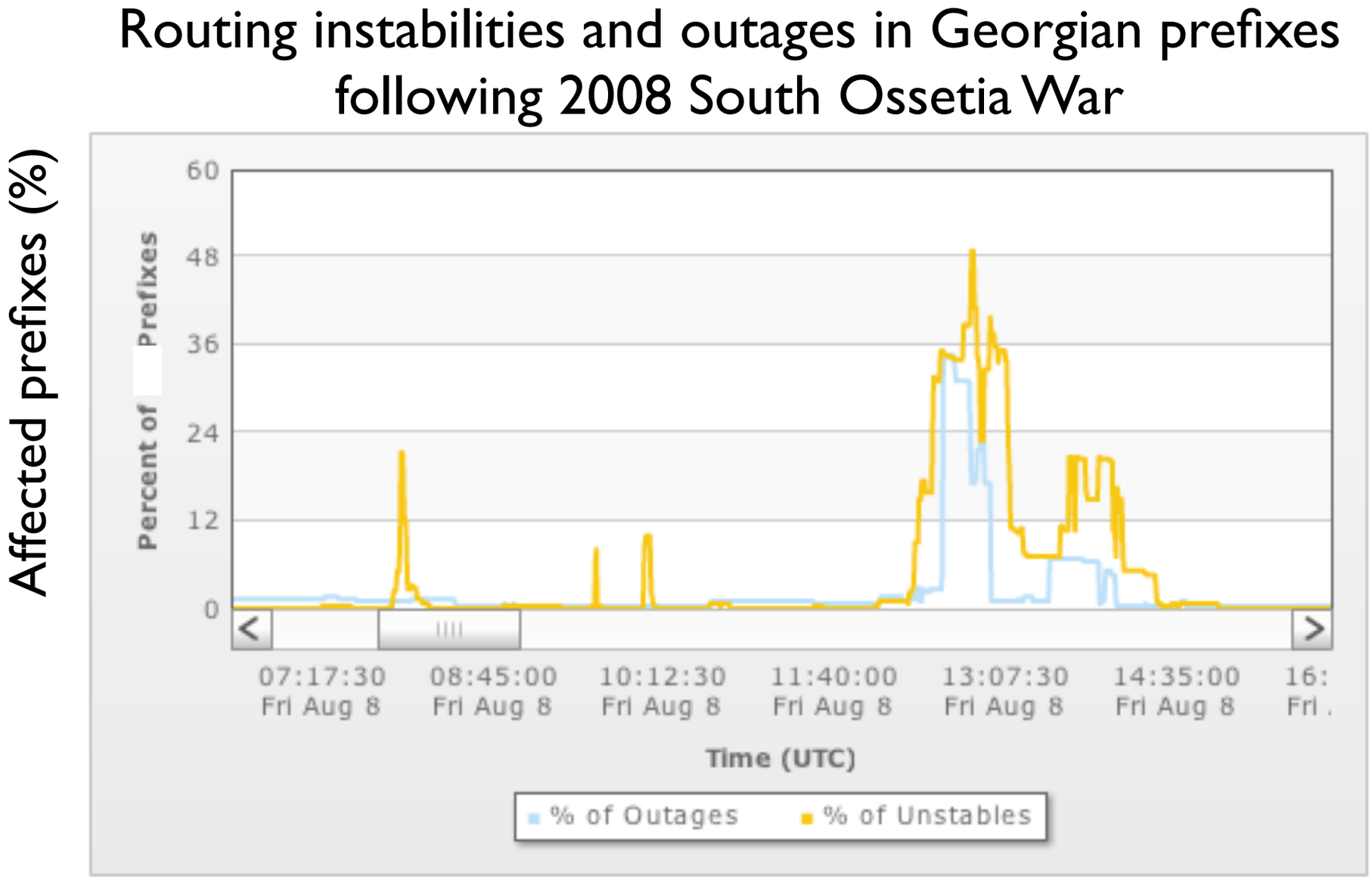
Friday June 12 2009

Saturday June 13

Sunday June 14

[James Cowie, Renesys Corporation]

Huge societal relevance

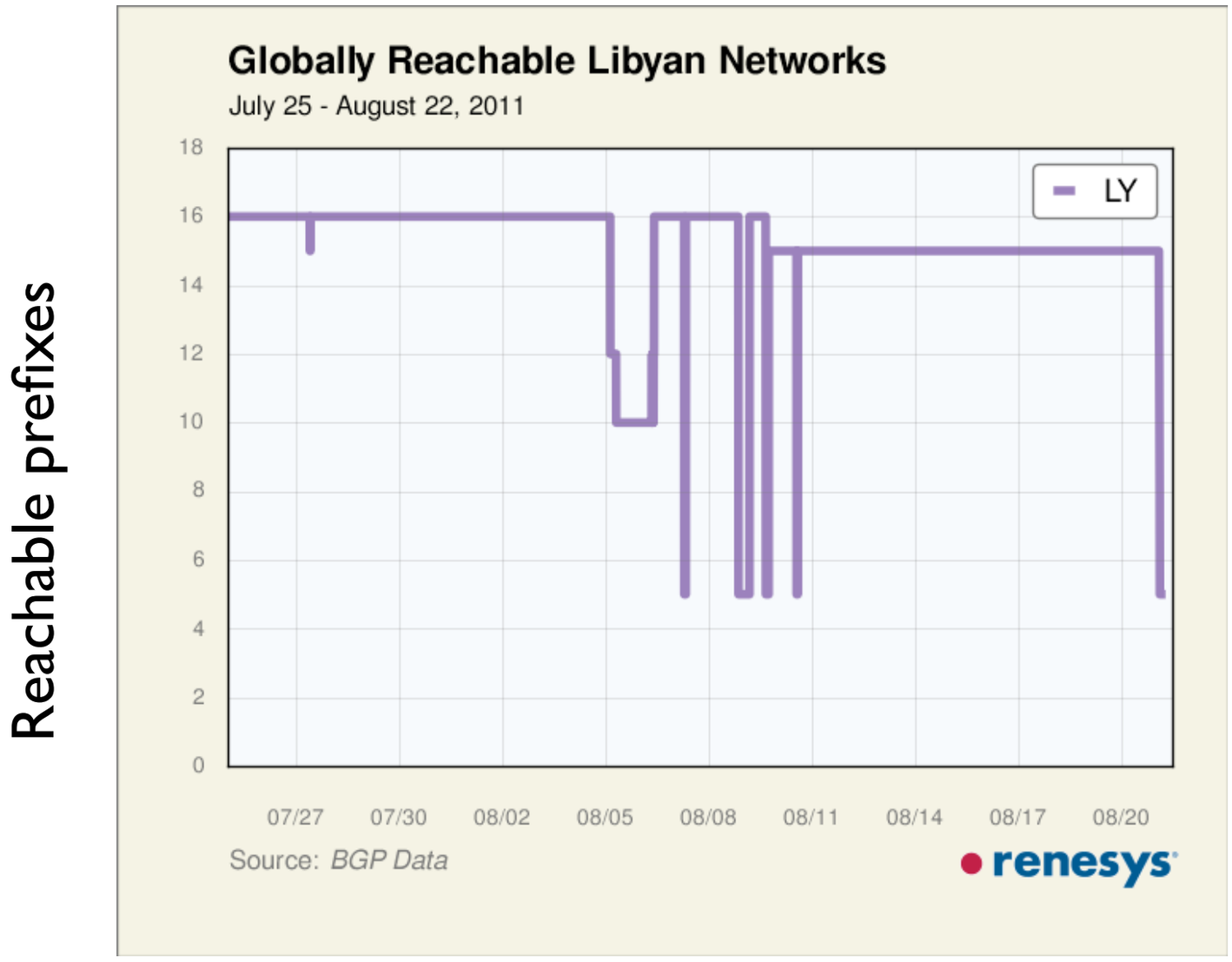


Fri, Aug 8, 2008

[Earl Zmijewski, Renesys Corporation]

Huge societal relevance

Reachability to Lybia



July - August 2011

[James Cowie, Renesys Corporation]

Huge societal relevance

[Source: The Internet]

Huge societal relevance

[Source: The Internet]

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...

- Malicious parties (criminals, nations, …)
- 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
- And it's now critical infrastructure

Today

Course Overview

Internet History

Your Future

Your (near-term) future

Now

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

Monday

- Lightning review of undergrad networking concepts
- Grand Challenges in computer networking
- Project "speed dating"

Next Wednesday

- Internet architecture technical overview
- Readings begin
- Assignment schedule finalized