50 Years Ago: The Arpanet And Now: Current Problems

Steve Crocker

My involvements

- UCLA undergrad. Spent lots of time programming. Brief time as grad student at MIT in AI. Came back to UCLA in 1968. Arpanet project was starting. Seemed useful but not "real" research. Decided to lend a hand.
- Led the Network Working Group and created the RFCs.
- Research in formal methods, network security, etc. Various management and business jobs.
- First IETF area director for security
- Spent last fifteen years with ICANN – SSAC and Board

The Arpanet and the Beginnings of the Internet

All of History Explained

+ Technology Improves
✓Human Nature Doesn't
Good Luck Helps

History

Mid 1960s to Early 1970s

The 1960s Computing Milieu

Primarily

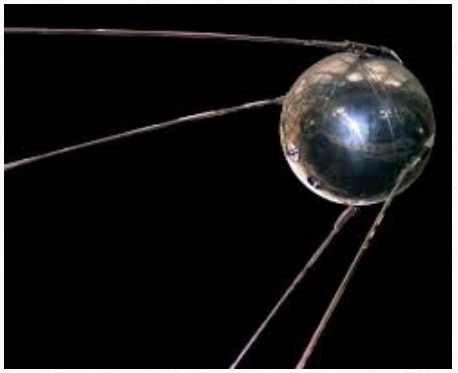
- Main frames
- Batch Processing
- NSF: Computer centers to support physicists

But in a few places

- Time-sharing
- Graphics
- Man-machine and AI research
- (D)ARPA funding

(D)ARPA Origin

- Sputnik launched in October 1957
- U.S. Dept of Defense space research was split between Air Force and Navy
- Advanced Research Projects Agency (ARPA) formed in early 1957 to pull together space program
- NASA late 1958; ARPA refocused on other advanced research via several semi-independent offices



ARPA or DARPA?

1958: Created as ARPA within the Office of the Secretary of Defense

1972: Moved from OSD to become a separate Defense agency. Renamed DARPA. No change in mission. Minimal change in structure.

1993: Under Bill Clinton, renamed to ARPA to emphasize the dual use of the technology, both military and civilian. No change in structure or mission.

1996: Renamed back to DARPA

(D)ARPA's Information Processing Techniques Office (IPTO)

- IPTO started in 1962
- Centers of computer science excellence – MIT, CMU, Berkeley, others
- Time-sharing for interactive computing
- Artificial intelligence
- Advanced graphics
- High-speed multiprocessors (supercomputers)
- And networking

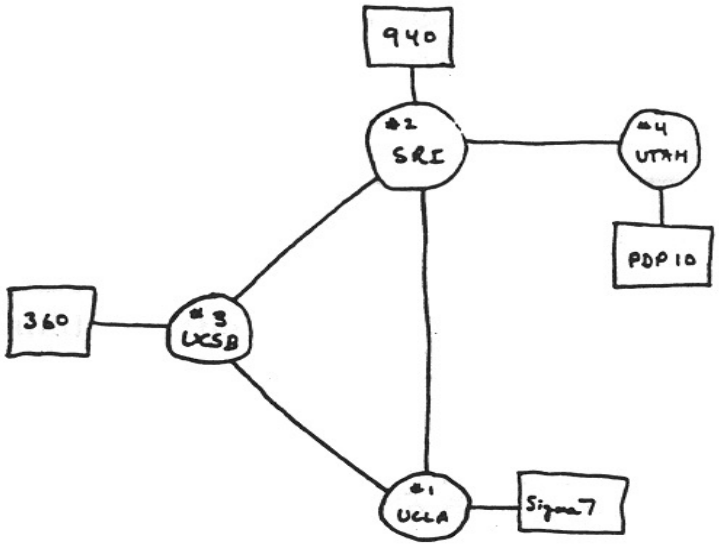
Before the Arpanet

- Special purpose uniform networks existed in military and business, e.g. American Airlines SABRE system.
- Small research efforts to connect two or three disparate computers. Results were mixed
- By mid 1960s, ARPA/IPTO was sponsoring major research projects in several universities across the U.S. and a handful of other research labs
- Arpanet was the next big push

The Arpanet

1969 Arpanet

- Connect diverse computers
  - Start with 4 in western U.S.
  - Success even if some not working
- Overlay on existing research sites
  - No politics, no cost, lots of smart computer scientists
- Use packet-switching for efficiency
- Use small computers at each site to separate network from local issues (IMPs)



Arpanet purpose

- Strong emphasis on interactive computing
- Facilitate multi-computer technology, e.g. graphics + supercomputing
- Focus on cooperation across laboratories – computers AND people
- Packet-switching for efficient use of long-distance communication lines
- NOT nuclear warfare survival
- Unclassified, civilian use. Military to use technology later if proven effective

The ARPANET IMP – the first router

- BBN built the Interface Message Processors (IMPs). Each cost $100,000 USD in 1969.
- Capable of connecting to 3-4 computers and 3-4 “high-speed” leased lines – 50,000 bits/second.

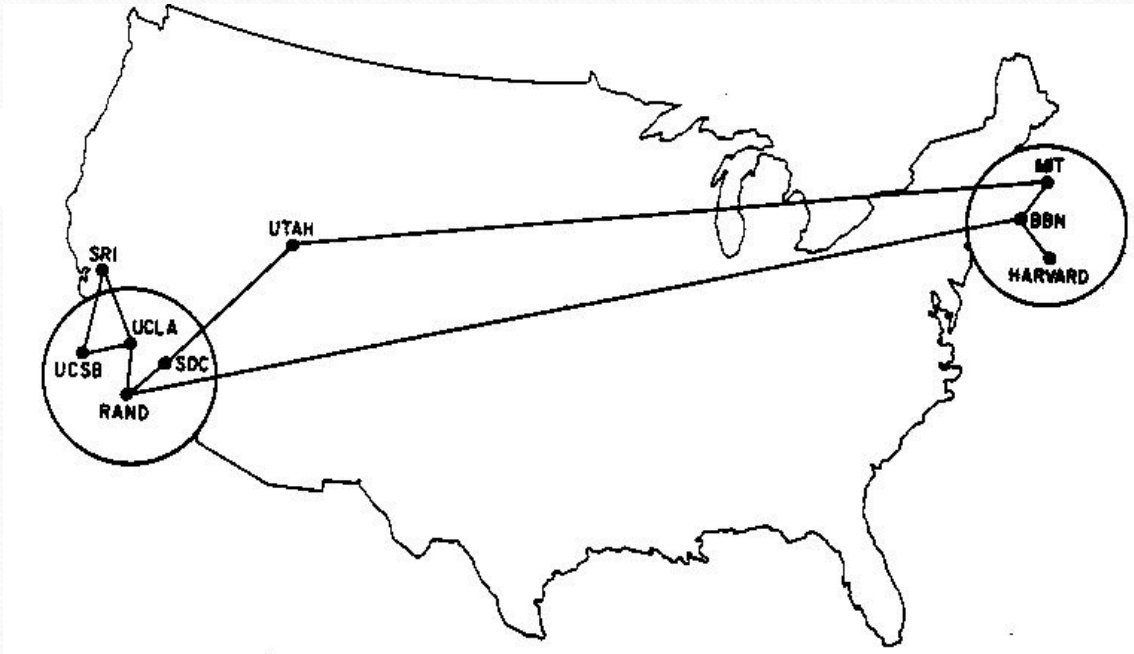
Packet vs Circuit Switching

	Packet Switching	**Circuit Switching**
Set up	Zero	Several seconds
Efficiency	50-70%	<1%
Jitter	Variable	Zero
Speed	1-10 ms/hop + 10μs/mile	10 μs/mile

Timeline

- 1967-68 General concept
- 1968 RFP for the routers
- Aug 1968 UCLA, UCSB, SRI, Utah first meeting. All graduate students(!)
- BBN starts work in early 1969
- April 1969 Informal notes (RFCs)
- 1 Sept 1969 First IMP delivered to UCLA
- Monthly after that

Arpanet – June 1970



Leased lines: 12 voice grade lines bonded together for 50,000 bits/sec

Arpanet "Game Plan"

Connect existing ARPA/IPTO research sites

- Lots of expertise; already paid; forward-looking

+ Separate computers for routing (the IMPs)

+ Government rate for 50 Kb/s circuits

- Standard contracts for routers and communication lines
  - BBN for IMPs; AT&T for communication lines

User-driven protocol process

Planning by the senior technology group

- Lots of attention to topology, packet size, routing
- Major decisions: 50 Kbs lines; IMPs, dynamic routing updates
- Start with four sites in the western U.S.
- Implicit assumption: remote login and file transfer
- Let the sites figure out the details…

At the junior level

- 2nd level people from each site, primarily graduate students
- Basic outline presented: 50 Kbs lines, IMP at each site
- No grand plan. Implicit goal of interactive computing and file transfer

- Grad students had strong operating system and programming language backgrounds
- Focused on a framework and building blocks

The Protocol Framework

- Virtual circuit is a useful building block. Hide the details of packets.
  - Remote terminal and file transfer could then be built on top
- Overall framework should be open to permit more general forms of intercomputer communication.
  - E.g. download local interaction module to overcome network delays

The Host-Host Protocol

- Flow control – needed a way for the receiving end to control the sender
  - Bytes not yet standardized. Measured the flow in both bits and messages
- Needed a way to convey interrupts, e.g. control-C or control-Z
- Connections were simplex. Needed one in each direction.
- How to initiate connections?
- Implementation required code inside the operating system ("root access")
  - This code was call the Network Control Program (NCP)
- "NCP" gradually became Network Control Protocol

Internet, TCP and IP

- Arpanet connected heterogenous computers but it was a single network with a single operator
- Interconnection of multiple independent networks was necessary
- Lessons learned from NCP were incorporated into TCP
  - 8 bit bytes, duplex connections, in-band connection set up
- IP layer created underneath so packets could be routed across networks

Emergence of the Community

- Software development at each site resulted in multiple "experts"
  - Natural emergence of neighborly assistance – each one teach one, consultants
  - Local initiative. Stars emerge. Prague is a pinnacle.
  - Open documentation was natural – no competition, high level of cooperation. Request for Comments was a temporary expedient(!)
- Small face-to-face Network Working Group meetings. Grew unwieldy when 50 people started to show up. (IETF meetings now have 1000 to 2000.)

Arpanet Results

+ Networks are feasible!
  + Everyone wanted to join; countries wanted their own networks
+ Heterogeneous network (not vendor specific)
+ Layered protocol architecture
  + Ok to add functionality on top, underneath, in between
+ Open protocol stack (permission-less innovation)
+ Open standards process: NWG => IETF
+ Open (free) documentation – the RFCs

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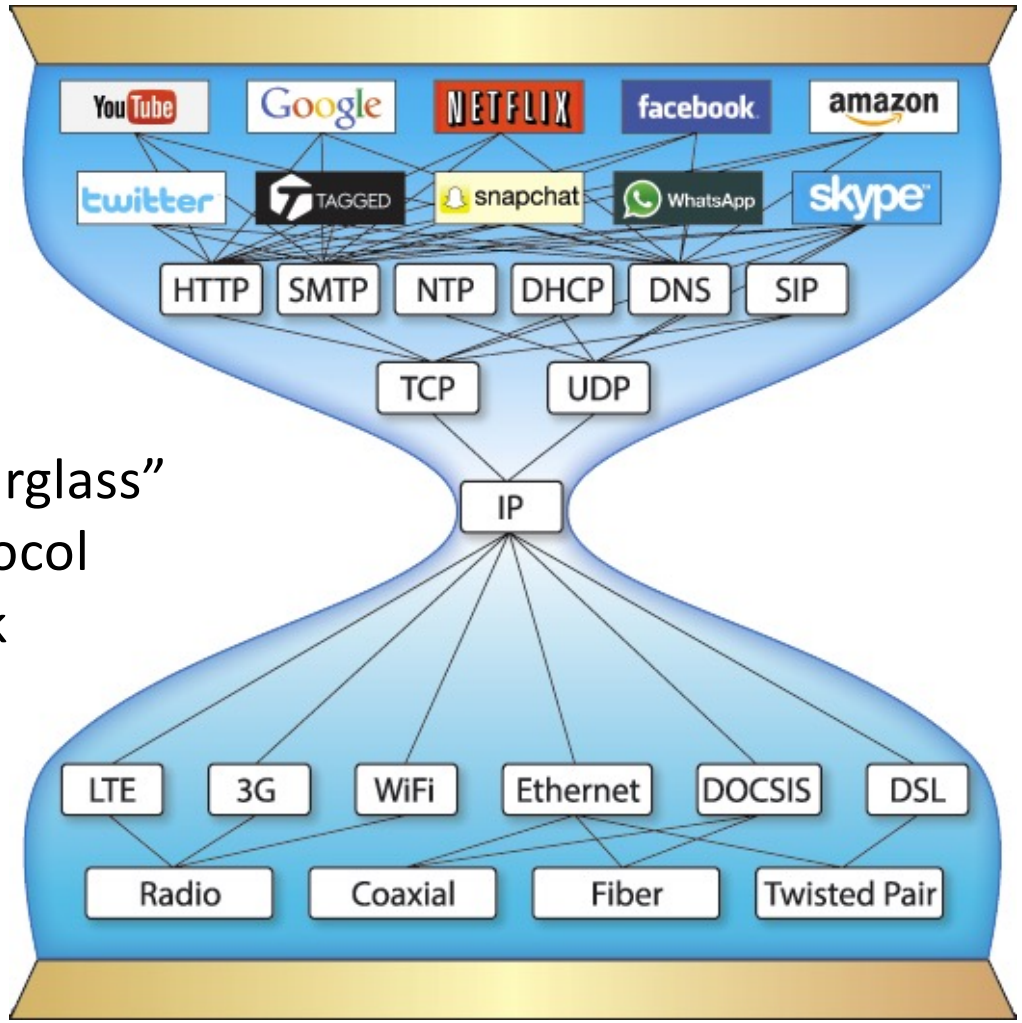
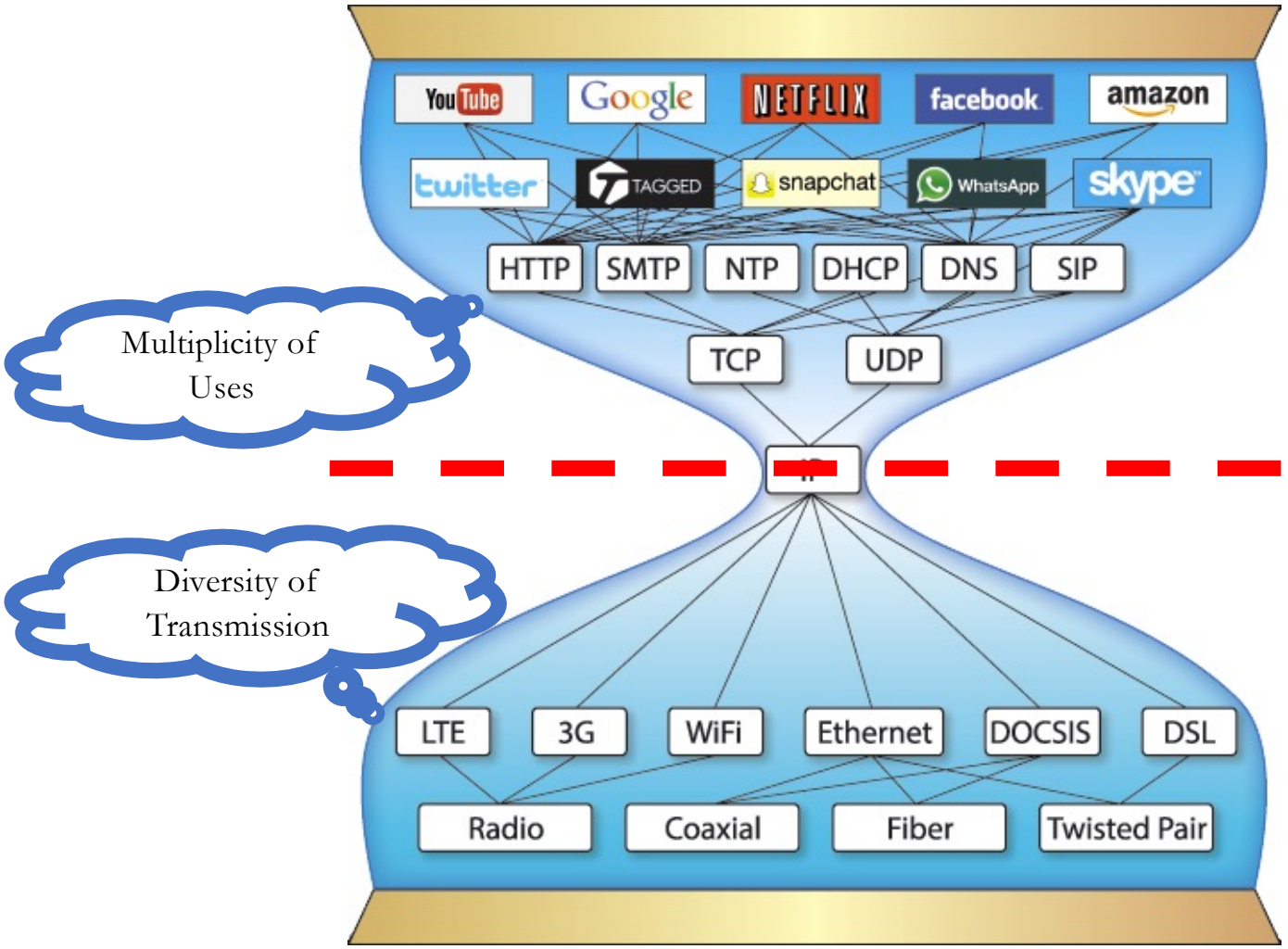
The “hourglass” protocol stack

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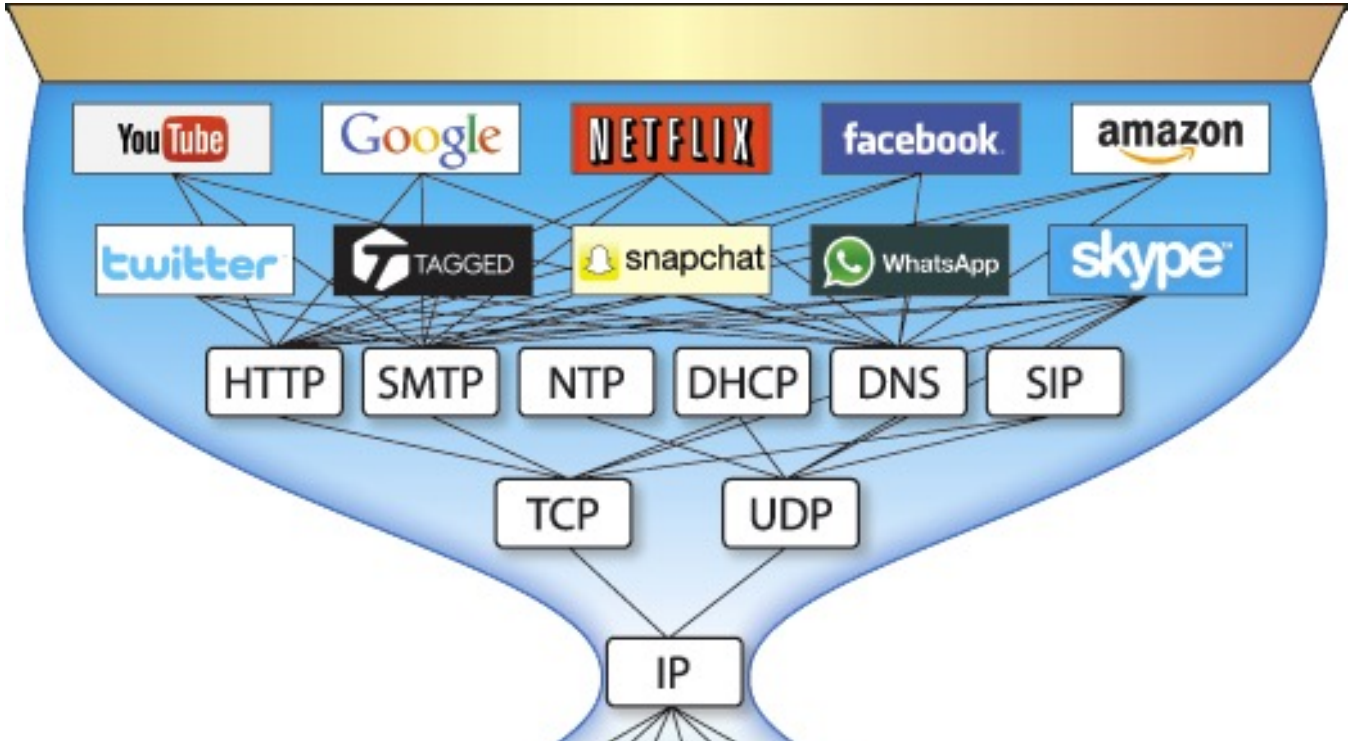
Twisted Pair
Multiplicity of Uses
Diversity of Transmission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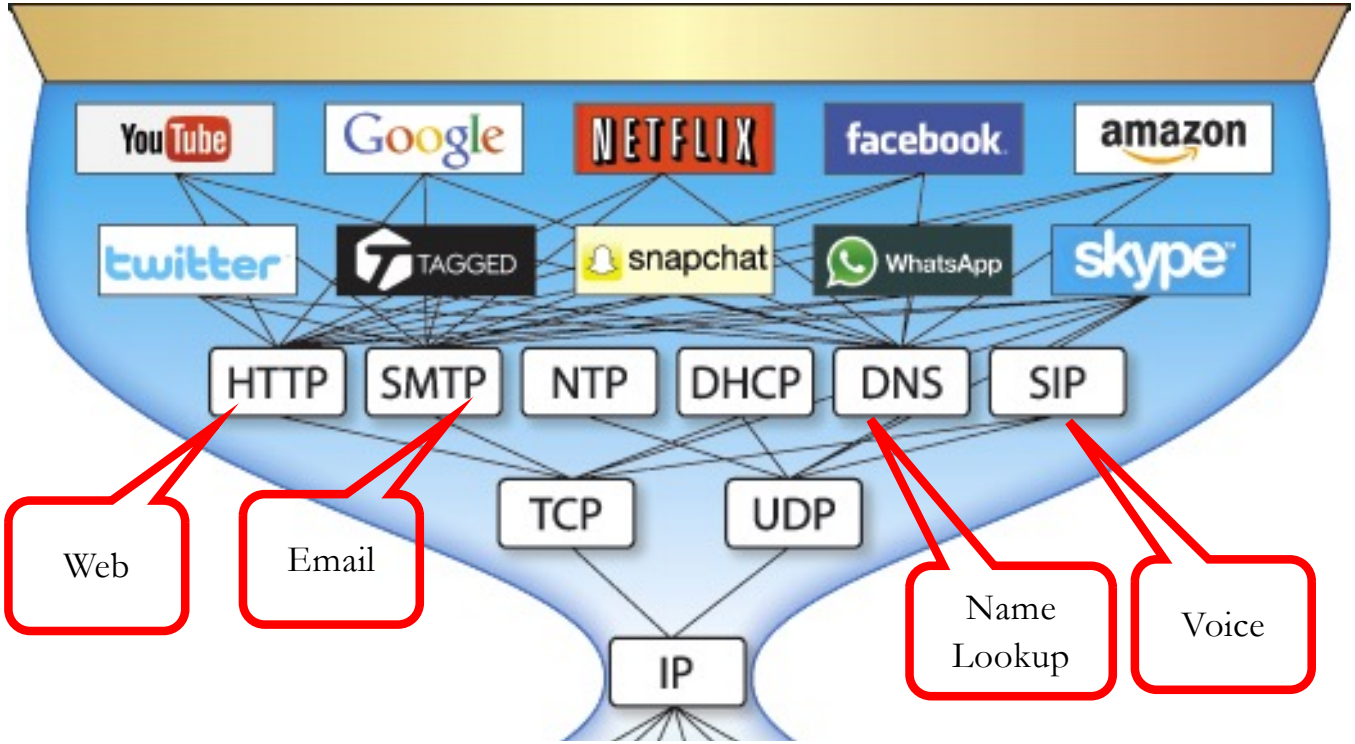
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skype
HTTP
SMTP
NTP
DHCP
DNS
SIP
TCP
UDP
IP
Web
Email
Name Lookup
Voice

Open {Participation, Architecture}

Inventors	Nationality	Protocol/Service
Ahti Heinla Priit Kasesalu Jaan Tallinn	EE EE EE	Skype
Pierre Omidyar	IR-US	eBay
Larry Page Sergey Brin	US RU-US	Google
Tim Berners Lee	UK	World Wide Web

Major Forces Revisited

+ Technology Improves
✓Human Nature Doesn't
Good Luck Helps

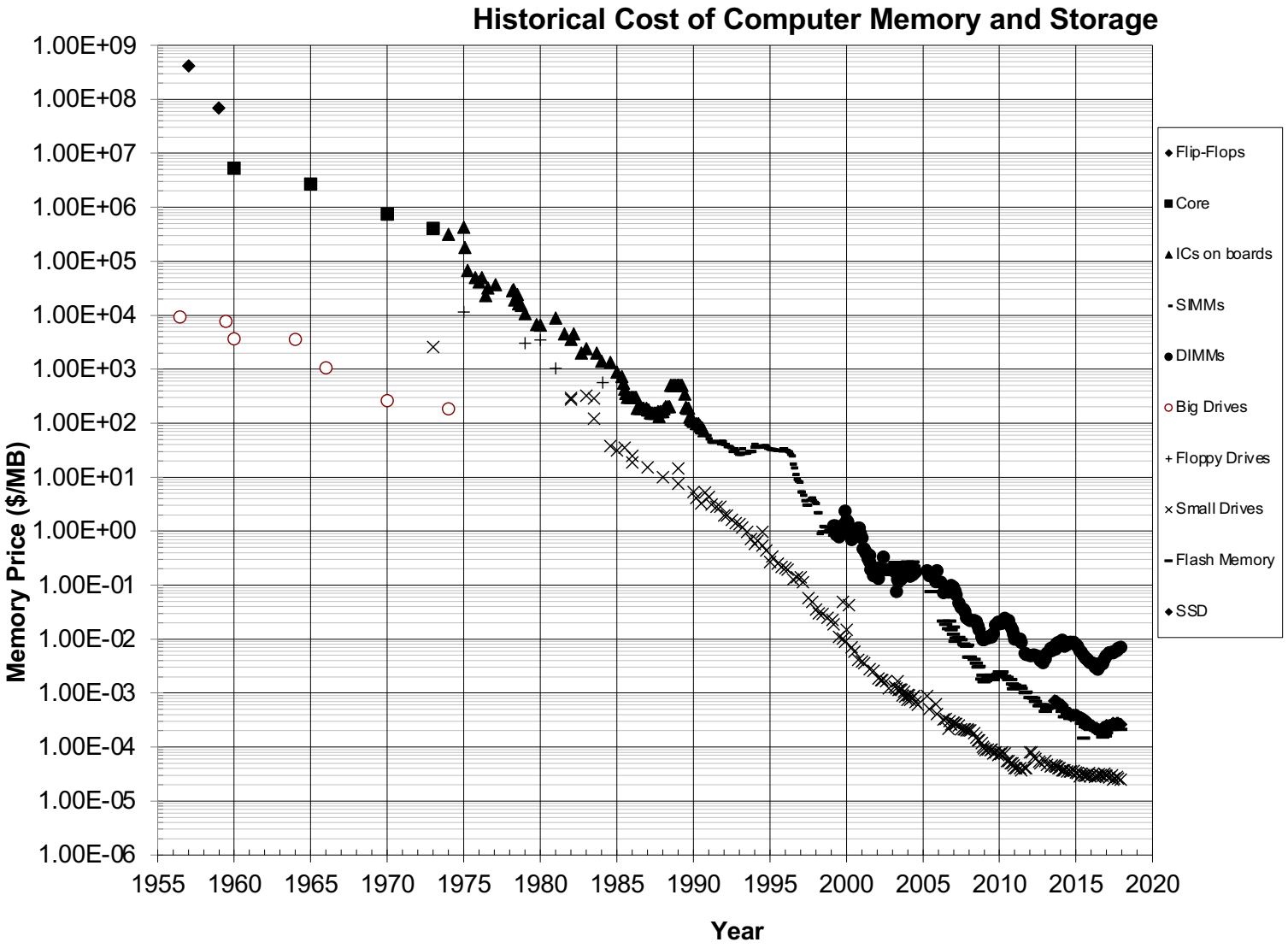
Technology Improves

Moore's Law

- 10x improvement every five years
- 10 years: 100x
- 40 years: 100,000,000x
- ~ 60%/year

Computer Science

- Algorithms
- Graphics
- Artificial Intelligence
- Speech Understanding
- Etc.


Historical Cost of Computer Memory and Storage
Memory Price ($/MB)
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1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year
Flip-Flops
Core
ICs on boards
SIMMs
DIMMs
Big Drives
Floppy Drives
Small Drives
Flash Memory
SSD

Technical Literacy

- J.B.S. Haldane – On Being the Right Size (1926?)

- In any dynamic system, scaling up (or down) necessarily changes proportions and may run into limits.
- Major changes in scale result in qualitative change in structure and function.

Human Nature

- Initiative
- Innovation
- Diversity
- Charity
- Community
- Cooperation
- Competition

- Greed
- Control
- Self-Interest
- Xenophobia
  - Fear of others
- Metathesiophobia
  - Fear of change

Innovation in Markets

- Pure market: Supply vs Demand determines price
- Innovation disrupts
- Suppliers prefer control
  - intellectual property laws, monopoly
  - Government regulation
- Governments prefer control too