A Little History of Computers

Lecturer: Alexandru Iosup

The images used in this lecture courtesy of the Computer History Museum, Mountain View, California, USA, http://www.computerhistory.org/ ; the German Museum of Technology (Deutsches Technikmuseum Berlin, Germany, http://www.sdtb.de/Englisch.55.0.html ; the Science Museum, London, UK, http://www.sciencemuseum.org.uk/; and many anonymous contributors via Google Images. Many thanks!

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A History of Computers = A History of Performance

- Improving speed of operation by mechanical means

  = 5 x  *(1 order of magnitude)*  = 200 x  *(2 o.m.)*

- Multiplication of two *10* figure numbers, e.g., 5,678,912,343 x 9,876,543,217
  - by hand: *10* minutes
  - by computer: *100* nanosec *(10 o.m.)*
- *Predicting weather? (accurately)*

Exercise: The Super-Computer Game

Q: How fast is **the fastest computer** and **why?**

Vote on best answer (+50p each in team)

- Team work, first 5 minutes
  1. Form team of 2-3 persons
  2. Think about own experience
  3. Convince your team before proposing an answer
  4. Formulate an answer (!)

- Open discussion, next 5 minutes
  - Tell everyone the answer
  - I will nominate the team member who explains

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Top500 in November 2014

Q: How much in **Jun 2017**?

Q: How much is **33,862.7 Tera-FLOPS**, vs. your laptop's performance?

Traditional HPC

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	National University of Defense Technology China	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P NUDT	3120000	33862.7	54902.4	17808
2	DOE/SC/Oak Ridge National Laboratory United States	**Titan** - Cray XK7 , Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x Cray Inc.	560640	17590.0	27112.5	8209
3	DOE/NNSA/LLNL United States	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom IBM	1572864	17173.2	20132.7	7890
4	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect Fujitsu	705024	10510.0	11280.4	12660
5	DOE/SC/Argonne National Laboratory United States	**Mira** - BlueGene/Q, Power BQC 16C 1.60GHz, Custom IBM	786432	8586.6	10066.3	3945

Parallel computing: 195 cores/node!

Accelerated!

Accelerated!

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It Depends! Graph500 ≠ Top500 !

Graph processing

Rank	Machine	Installation Site	Number of nodes	Number of cores	Problem scale	GTEPS
1	K computer (Fujitsu - Custom supercomputer)	RIKEN, Japan	**65536**	524288	40	17,977
2	DOE/NNSA/LLNL Sequoia (IBM - BlueGene/Q, Power BQC 16C 1.60 GHz)	LLNL, USA	**65536**	1048576	40	16,599
3	DOE/SC/Argonne National Laboratory Mira (IBM - BlueGene/Q, Power BQC 16C 1.60 GHz)	ANL, USA	**49152**	786432	40	14,328
4	JUQUEEN (IBM - BlueGene/Q, Power BQC 16C 1.60 GHz)	FZJ, Germany	**16384**	262144	38	5,848
5	Fermi (IBM - BlueGene/Q, Power BQC 16C 1.60 GHz)	CINECA	**8192**	131072	37	2,567
6	Tianhe-2 (MilkyWay-2) (National University of Defense Technology - MPP)	Changsha, China	**8192**	196608	36	2,061
7	[illegible]	CNRS/IDRIS-GENCI	**4096**	65536	36	1,427
8	[illegible] 1.60 GHz)	[illegible]aresbury Laboratory, UK	**4096**	65536	36	1,427
9	DIRAC (IBM - BlueGene/Q, Power BQC 16C 1.60 GHz)	University of Edinburgh, UK	**4096**	65536	36	1,427
10	Zumbrota (IBM - BlueGene/Q, Power BQC 16C 1.60 GHz)	EDF R&D	**4096**	65536	36	1,427

Number 1 in Top500

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- Team work, first 5 minutes
  1. Form team of 2-3 persons
  2. Think about own experience
  3. Convince your team before proposing an answer
  4. Formulate an answer (!)

Always start with
“It depends”

- Open discussion, next 5 minutes
  - Tell everyone the answer
  - I will nominate the team member who explains

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Computer Technology Improvements

(Slide adapted from Andy Tanenbaum)

Computer Component	IBM PC	Apple MacBook Pro	Improvement Ratio

MIPS index: http://www.roylongbottom.org.uk/mips.htm

Computer Technology Improvements

(Slide adapted from Andy Tanenbaum)

Computer Component	IBM PC 	Apple MacBook Pro 	Improvement Ratio
CPU speed	.420 MIPS	~320,000 MIPS	800,000x

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Volume	1 m^3	.001 m^3	1,000x

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Compound improvement ratio ~ 10^{20} x better

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Main Memory	.625 MB	16 GB	>25,000x
External Storage	.360 MB	512 GB	>1,450,000x
Volume	1 m^3	.001 m^3	1,000x
Cost (2017 $)	8,000 $	3,250 $	~2.5x

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Computer Technology Improvements Applied to Transportation Industry

(Slide adapted from Andy Tanenbaum)

Source: http://www.kelbillet.com/blog/thalys-2/thalys-billets-train-paris-bruxelles-bas-prix-ete/

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Computer Component	Train Component	Improvement Ratio	Train AMS-Paris
CPU speed	Ride speed	800,000x	<1 s

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CPU speed	Ride speed	800,000x	<1 s
Main Memory	Passenger Capacity	>25,000x	7,900,000 people

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External Storage	Range	>1,450,000x	>18,000x Earth

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Cost (2017 $)	Ticket Cost	~2.5x	<15 $

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But 1:50 train rides would crash catastrophically

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But 1:50 train rides would crash catastrophically

Yet train engineers would say it's a great success!

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A History of Computer Invention

- The computer is not a single invention
- Ideas from *mathematics, physics, mechanical engineering,* and *electrical engineering*

Q: How different are the 1940s Zuse Z3 and the 2010s supercomputer?

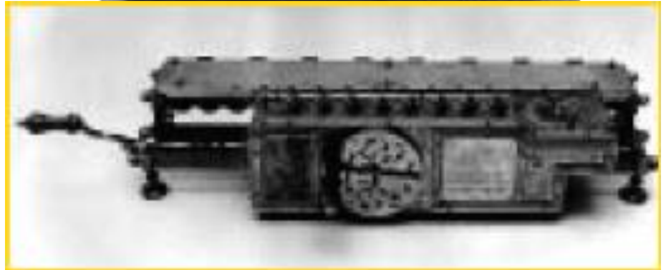
Outline

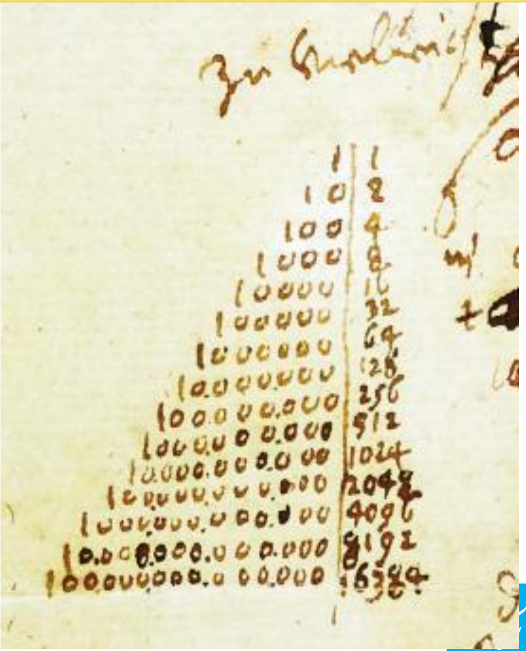
A History of Computer Architectures

1. **Pre-History (to 1930s)**
   - **Many approaches, first programmable devices**
2. 1st Generation: Electro-Mechanical (1930s-1950s)
3. 2nd Generation: Transistors (1955—1975)
4. 3rd Generation: Microprocessors (1960s—today)
5. 4^{th} Generation: Multi-Computing (1969—today)

Calculators

- Machines of Pascal and Leibnitz were mechanical calculators
  - No memory or program
  - Leibniz used binary system (1705)
  - A single operation at a time
  - Only simple operations (+,-,x,/)





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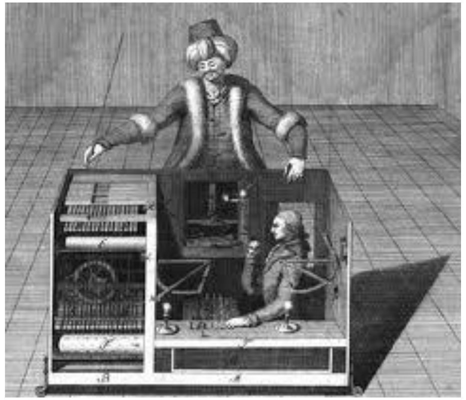
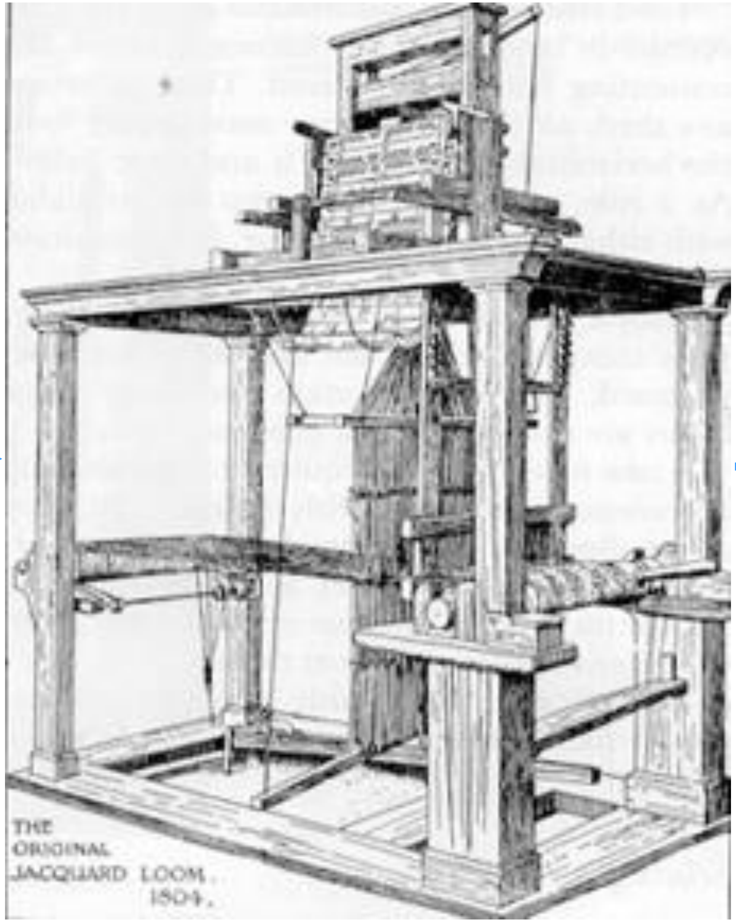
Programmable devices

- Devices that could execute a program in different areas:
- Mechanical Music Instruments
  - Bagdad, *9*-th Century
  - Carillons
- Chess / Mechanical Turk (1770)?
- Punch Cards for weaving machines
  - Jaquard (end *18*-th Century)



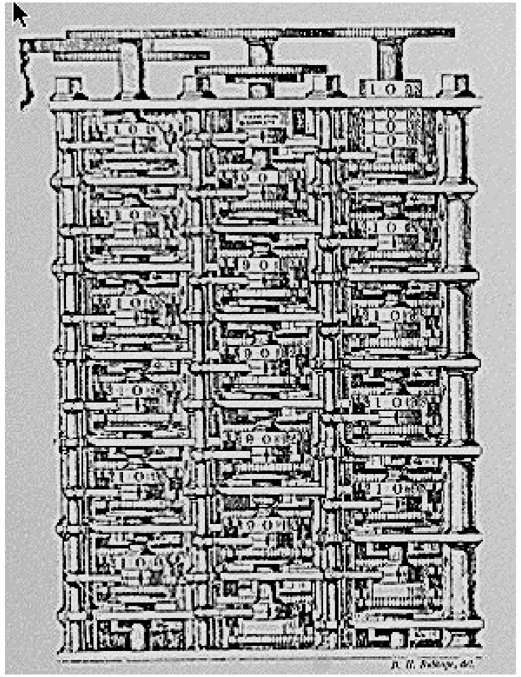
The Jaquard Loom (actually, Head, 1801)

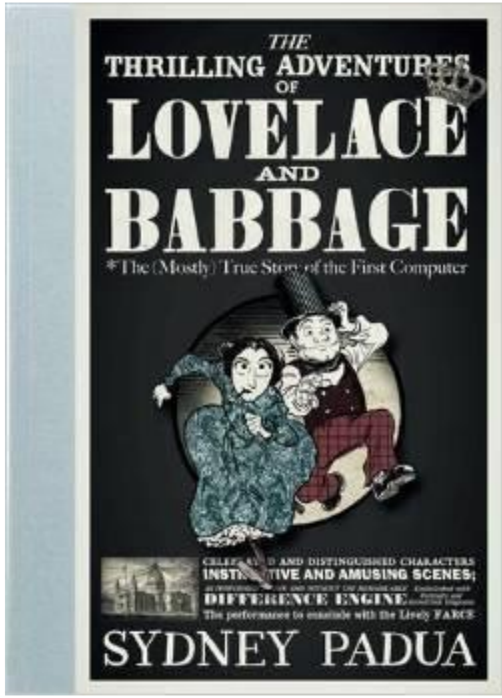
- Programmable



Difference Engine

(never built)





Analytical Engine

- Arith. Unit
- Memory
- I/O
- Control (IF)
- Stored program

- Invented by Johann Helfrich von Müller (1786)
- Extended by Charles Babbage (1822)
- First algorithm proposed by Ada Lovelace (1840s)

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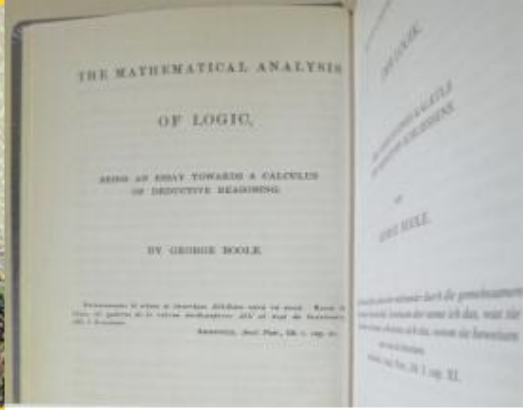
Mathematical Influence



- George Boole (*1854*) showed that logic could be reduced to a simple algebraic system
- Work remained a curiosity until rediscovered by Whitehead and Russell in Principia Mathematica (*1910-3*)
- Then, formal logic developed resulting in Gödel and the work of Alan Turing

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Analog Computers

- Analog computers predated digital computers
  - Slide rule
  - Mechanical integrators (Vannevar Bush, *1931*)
- First systems that enabled significant reduction of calculation times

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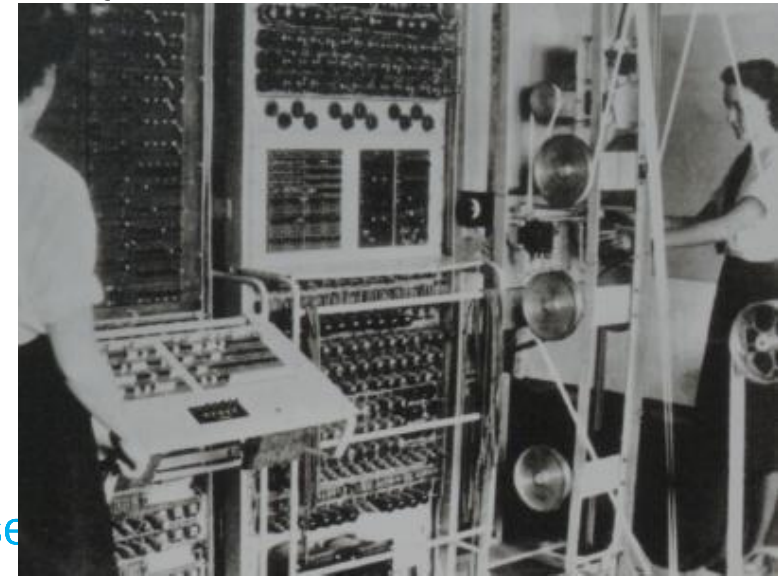
Spying—A Killer App for Computers Since the 1940s

- COLOSSUS, in the UK (1944)
  - App specific, fully electronic, storage, binary system
  - 5,000 characters processed per second, Lorenz cypher
  - Used during the D-Day, instrumental for VE-Day
- All records destroyed 1970s (natsec), so no IP claims possible



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Electro-Mechanical Devices
ASCC

"Only six electronic digital computers would be required to satisfy the computing needs of the entire United States."

- *1937-1944*, Howard Aiken builds the Automatic Sequence Controlled Calculator (ASCC)
  - First general-purpose digital computer
  - 750,000 components, 5 tons
- Goal: *100* times faster than by hand
- Reality: only *3-5* times faster, due to component failures

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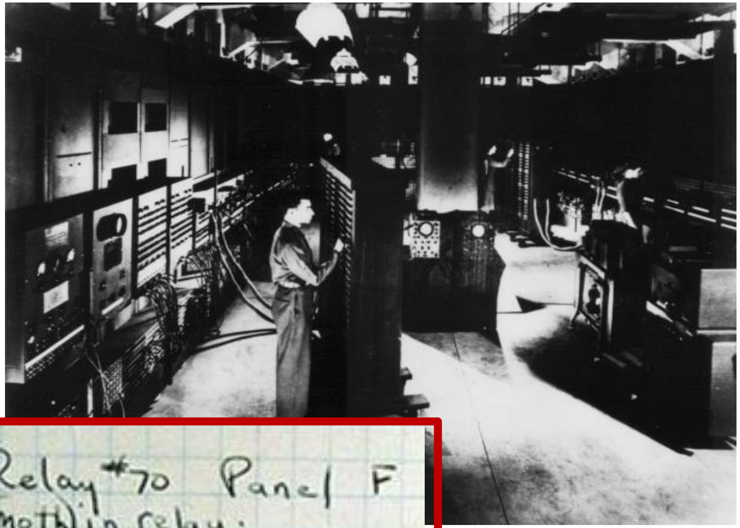
Electro-Mechanical Devices
ENIAC

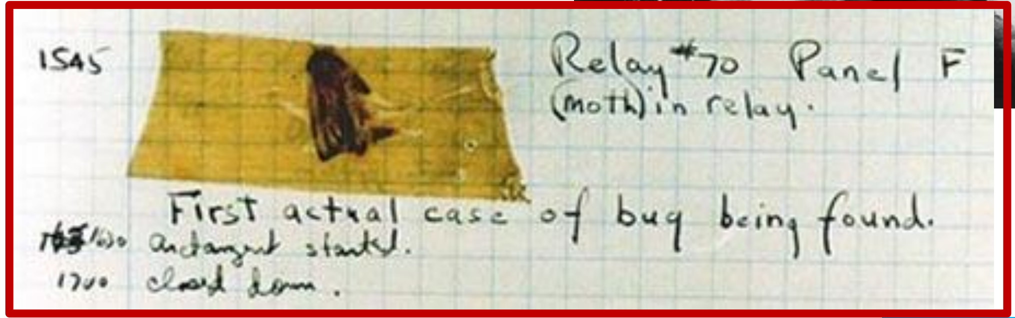
- *1943-1947*, John Mauchly and John Presper Eckert started building the Electronic Numerical Integrator and Calculator (ENIAC).
  - **First all-electronic computer (*)**
  - *18,000* tubes (*5-10*cm each), *150* kilowatt dissipation, *30* tons
  - Large office space
  - **1,000** bits of memory
  - From 20 hours to 20 seconds
- (*) The first computer IP lawsuit: vs John Atanasoff

Electro-Mechanical Devices

Problems with ENIAC

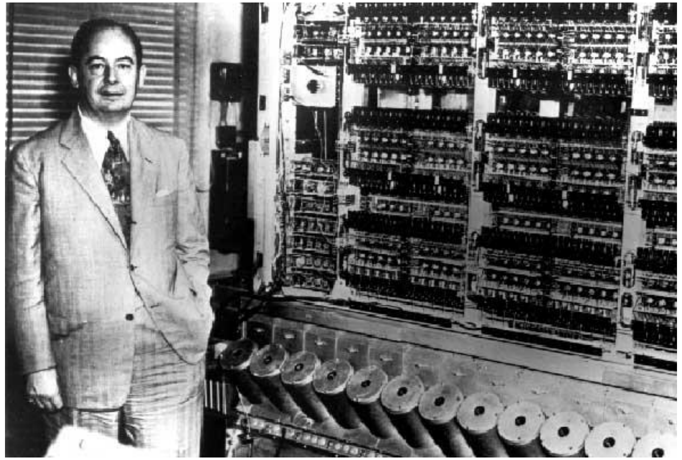
- Each time switched on: ~10 tubes failed
- Difficult to program
- Not very flexible
- Technologically too complex
- Memory too small
- Bugs

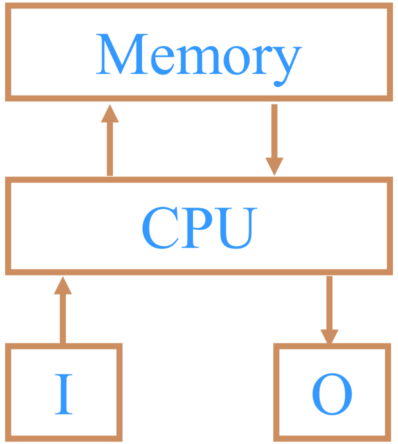




Electro-Mechanical Devices
EDVAC

- Problems analyzed by Mauchly + Eckert
- Proposed new design: Electronic Discrete Variable Automatic Computer (EDVAC)
- Basis of so-called *Von Neumann Architecture*





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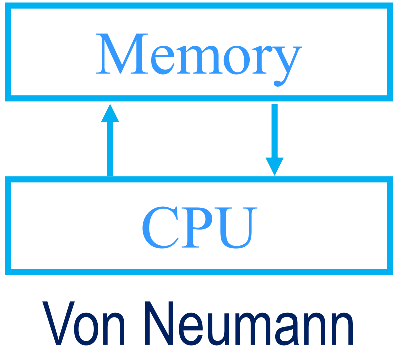
von Neumann or Harvard Architecture?

Von Neumann Architecture

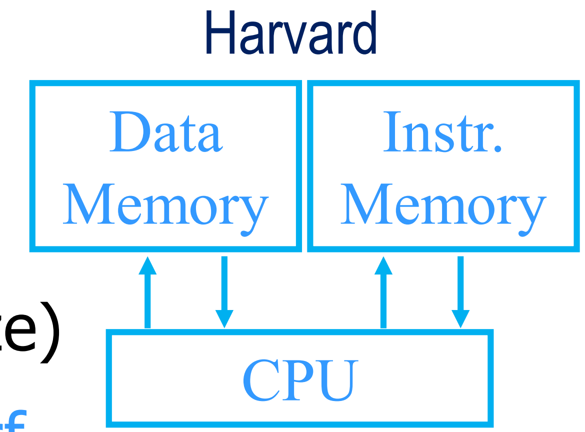
- Single Instruction and Data memory
- Single memory-CPU pathway = simple + bottleneck



Q: Which is used **today** and **why?**

Harvard Architecture

- Separate Instruction and Data memories (word size)
- Separate memory-CPU pathways = complex + perf.



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Transistors (1955—1975) and Microprocessors (1960s—today)

- Transistors
  - Reliable, Smaller, Less power
- U. Manchester (1953)/ Bell Labs (1948)
- DEC PDP-1 (1959)
  - Hacker culture, first game (Spacewar), text-ed, dbg
- Integrated Circuits
  - Enabled small, low-cost microprocessors
- MOS Tech (ATARI)
- Apple & Apple][
- Current technology
  - 1971 Intel 4004 @108KHz: 1st uproc.
- First supercomputer: Cray's CDC 6600, 10MFLOPS

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Devices in the Transistor and Microprocessor eras

- The first monitor (1951) — US Army's display system, part of WHIRLWIND

- The first mouse (1968) — Doug Engelbart's "X-Y Position Indicator for a Display System"

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The IBM Personal Computer

- Released in the 1980s
  - The blueprint for today's PCs
  - Changed the market
- Open standards and friendliness to third-party hardware and software developers

Q: How much is third-party hardware allowed **today? (e.g., by Apple)**
Q: How much is third-party software allowed **today? (e.g., in App Stores of Apple, Google, Microsoft)**

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Moore’s and Rock’s Laws

Also read: http://spectrum.ieee.org/semiconductors/materials/5-commandments/

Source: http://www.accelerating.org/acc2003/moores_law.htm

- Moore’s Law (# of transistors/chip): density of silicon chip 2x every 1.5 (2) years
- Rock’s Law (cost to produce chips): cost of equipment to produce chips 2x every 4 years ($12k in 1968, $14M in 2012’s 193-nm wavelength stepper)

1: http://www.nytimes.com/2012/01/13/science/smaller-magnetic-materials-push-boundaries-of-nanotechnology.html
2: http://www.nytimes.com/2012/02/20/science/physicists-create-a-working-transistor-from-a-single-atom.html

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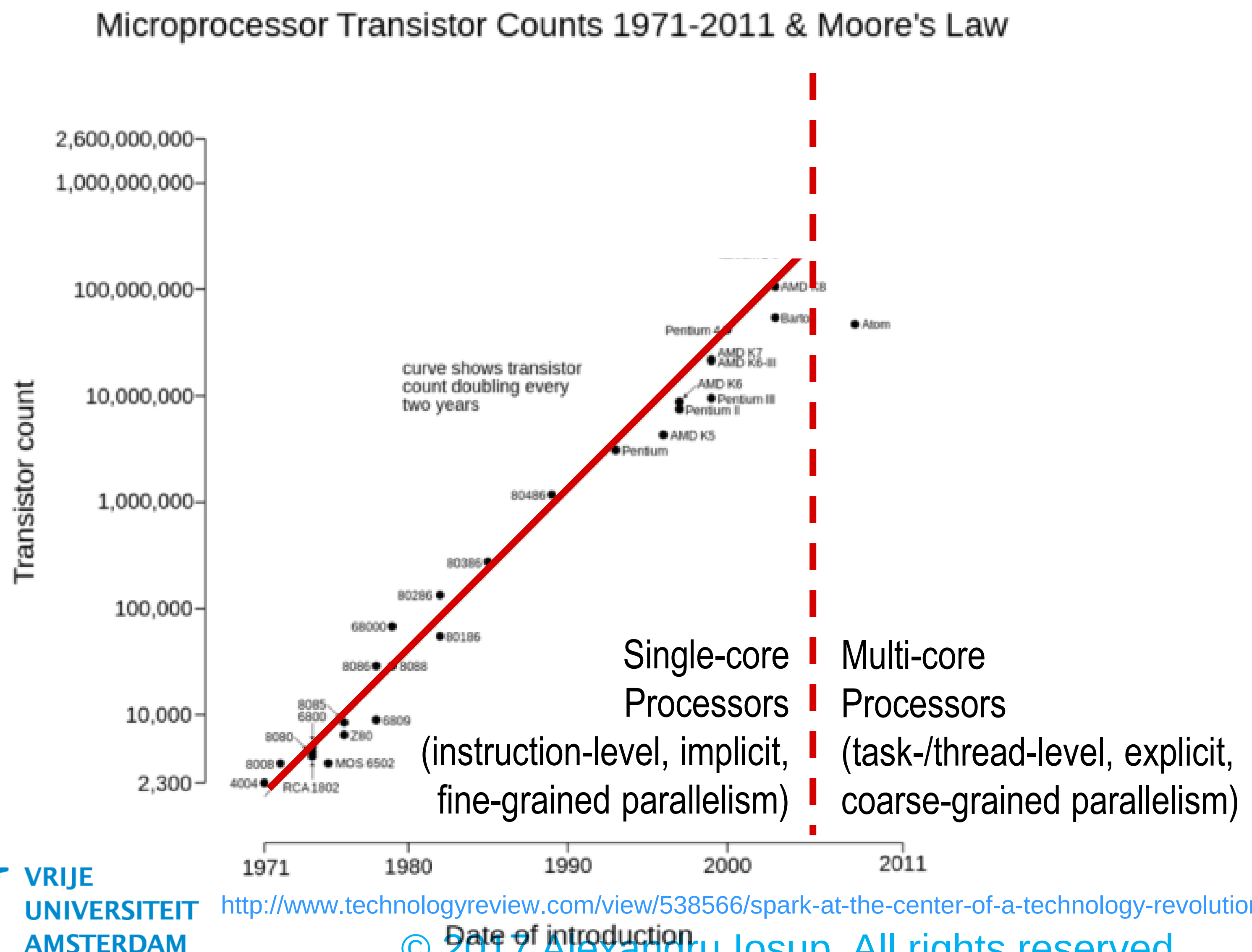
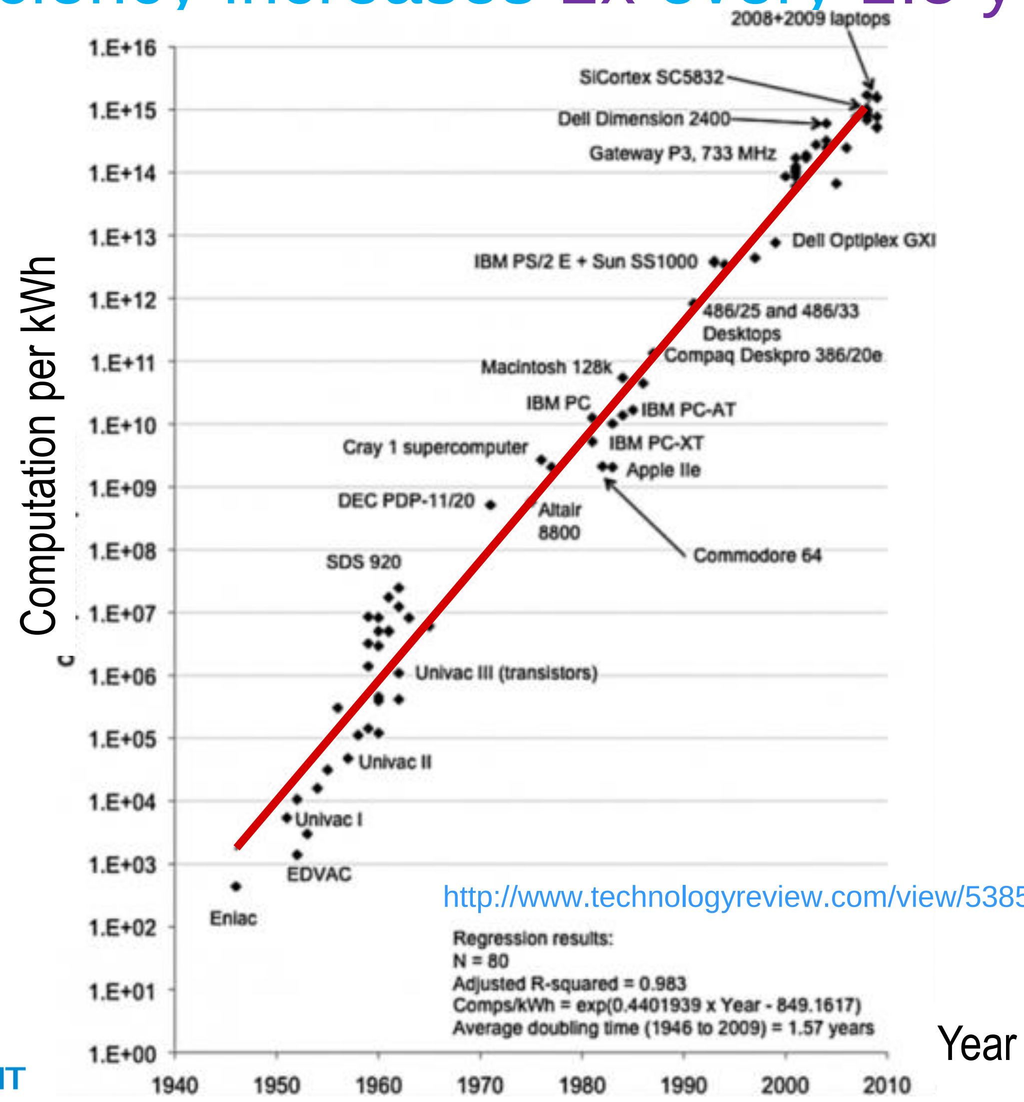
Is Moore's Law Dead? Maybe Just Not Needed…



http://www.technologyreview.com/view/538566/spark-at-the-center-of-a-technology-revolution/

Koomey's Law (Computation/Energy)

Energy efficiency increases 2x every 1.5 years



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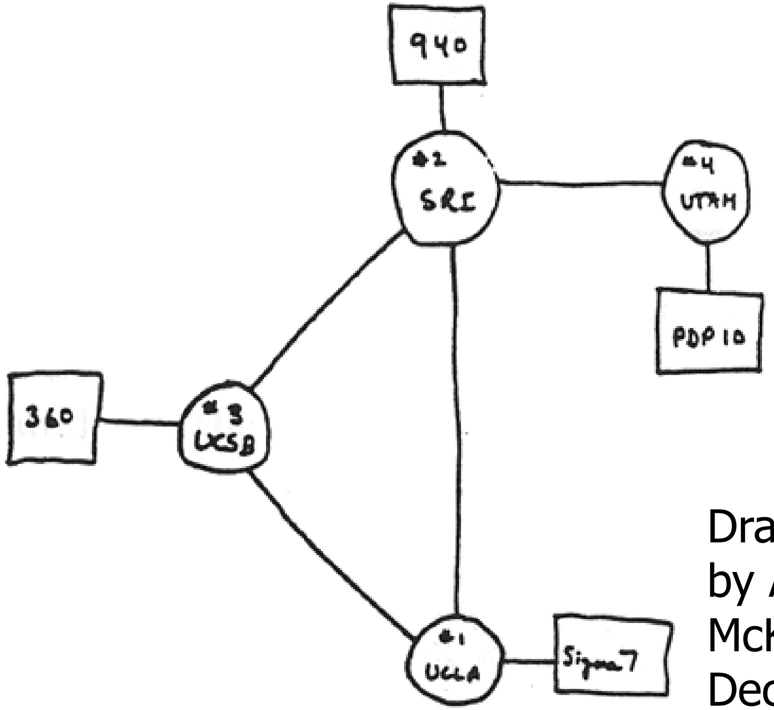
The Internet: Early History

- 1965-1969 ARPANET
  - Leonard Kleinrock develops the Queueing Theory (theoretical properties of the Internet)
  - 4 computers at UC Santa Barbara, UC Los Angeles, U. of Utah, Stanford Research Inst.
- 1972 ARPANET public + Email
- 1974 TCP/IP at Stanford
- 1982 ARPANET + TCP/IP = the (early) Internet



Drawing by Alex McKenzie, Dec 1969

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The Internet Today

net, ca, us

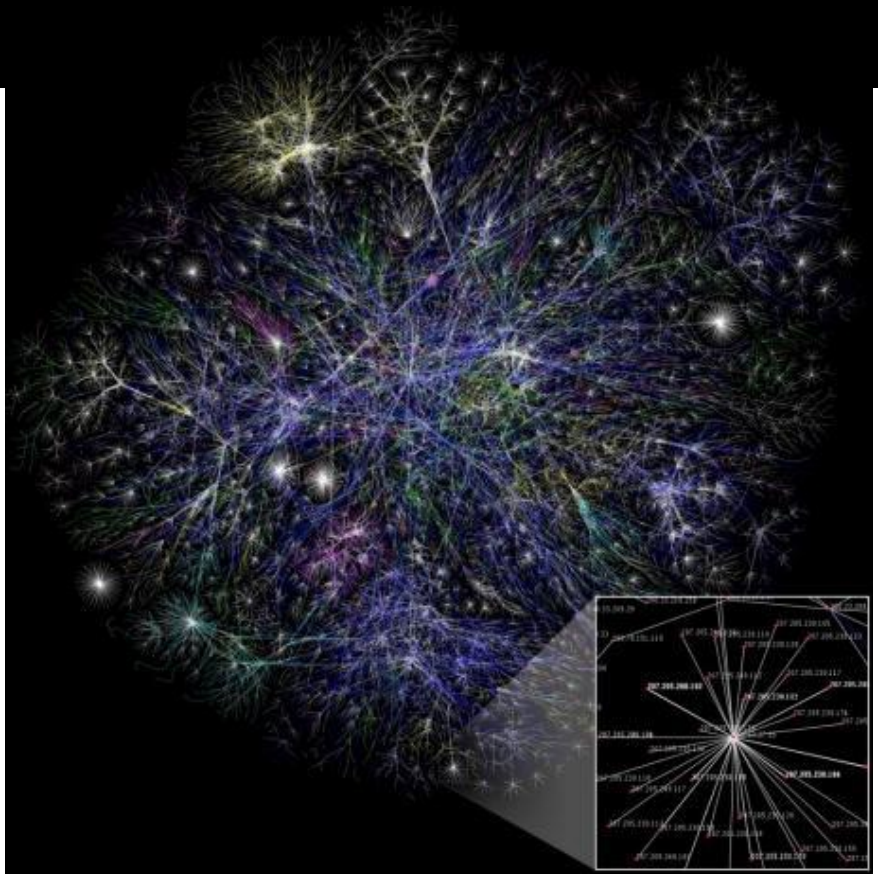
com, org

mil, gov, edu

asia

de, uk, it, fr, pl

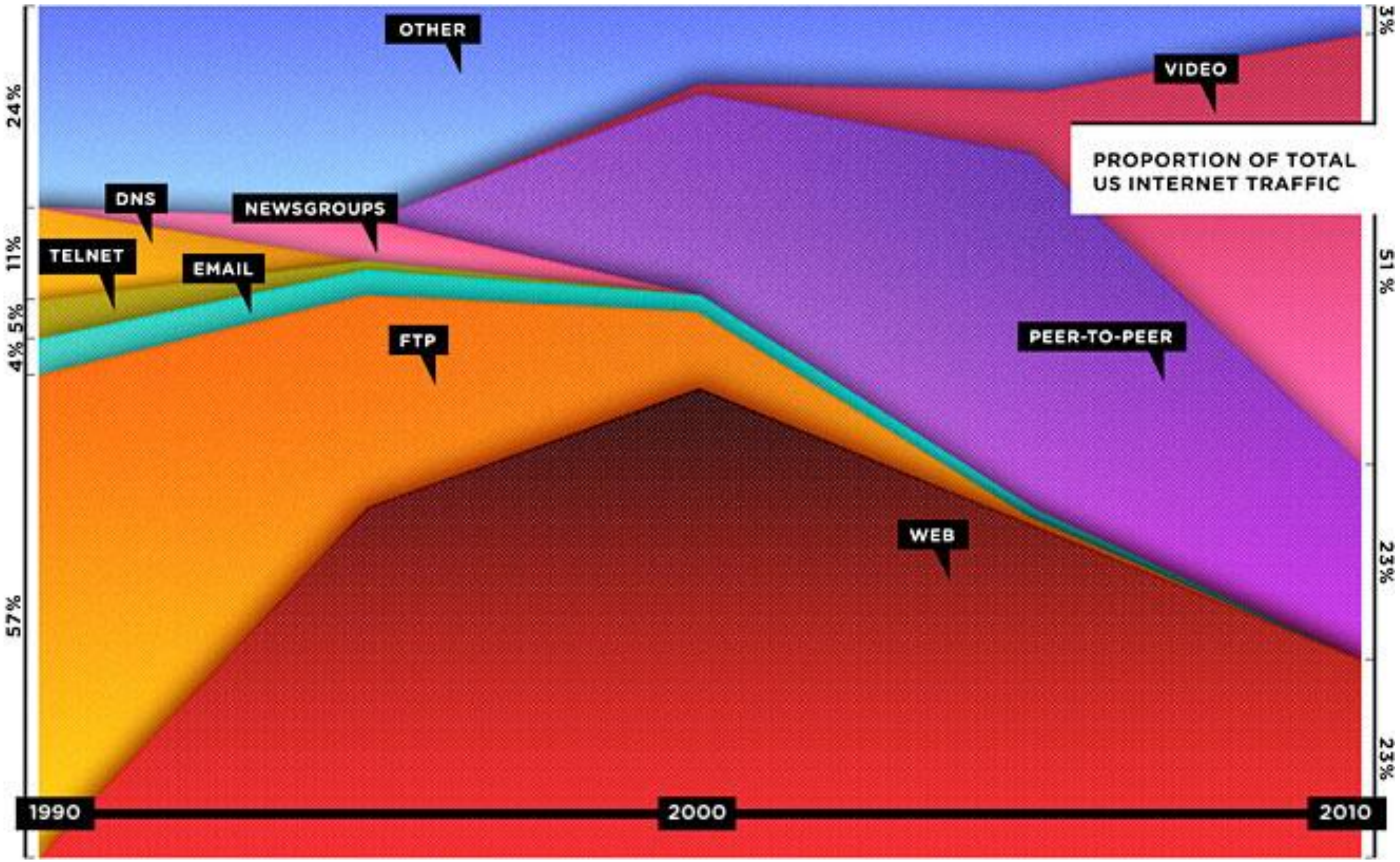
br, kr, nl



Source: http://www.opte.org/maps/

Internet-Based Applications

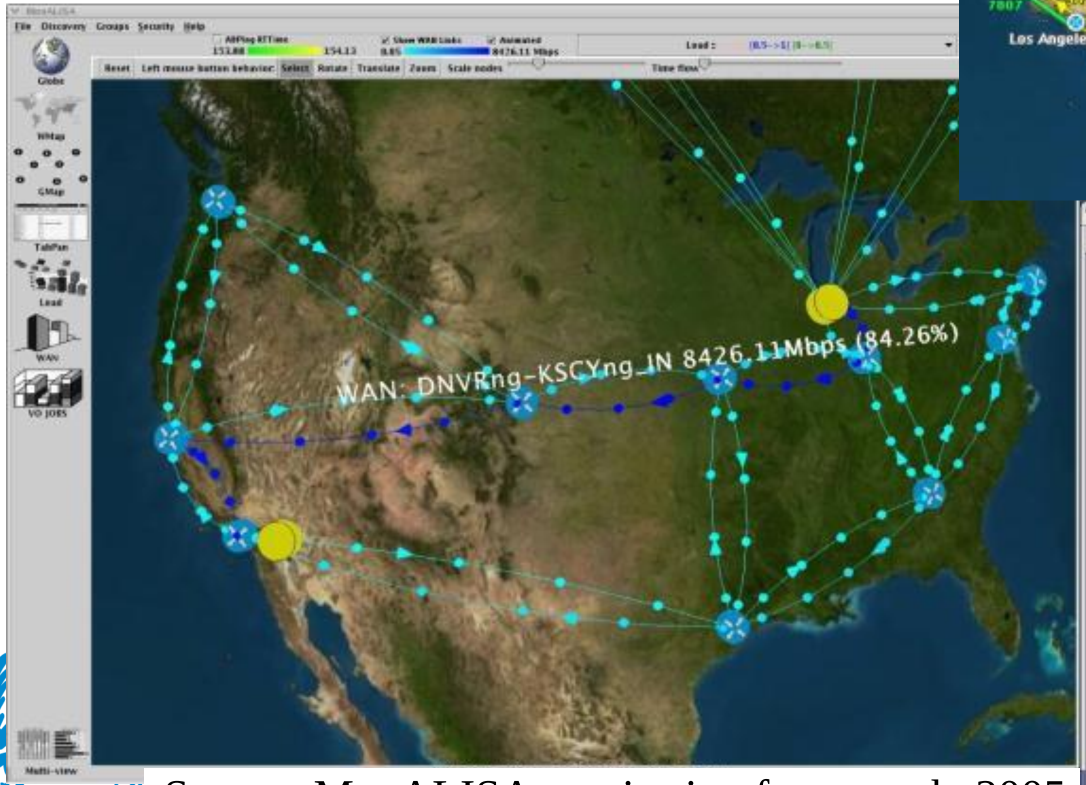
- Metcalfe's Law: usefulness of a network ~ n^2, n objects/users

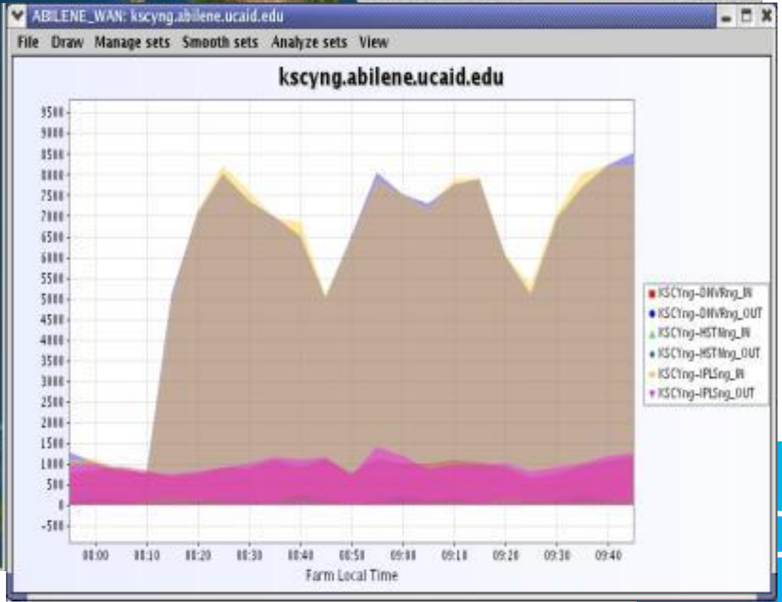


 http://meetings.ripe.net/ripe-48/presentations/ripe48-ipv6-lsr.pdf

ABILENE: Backbone Research Network

- TCP/IP Land Speed Record
- ~ 7 Gb/s in single TCP stream from Geneva to Caltech

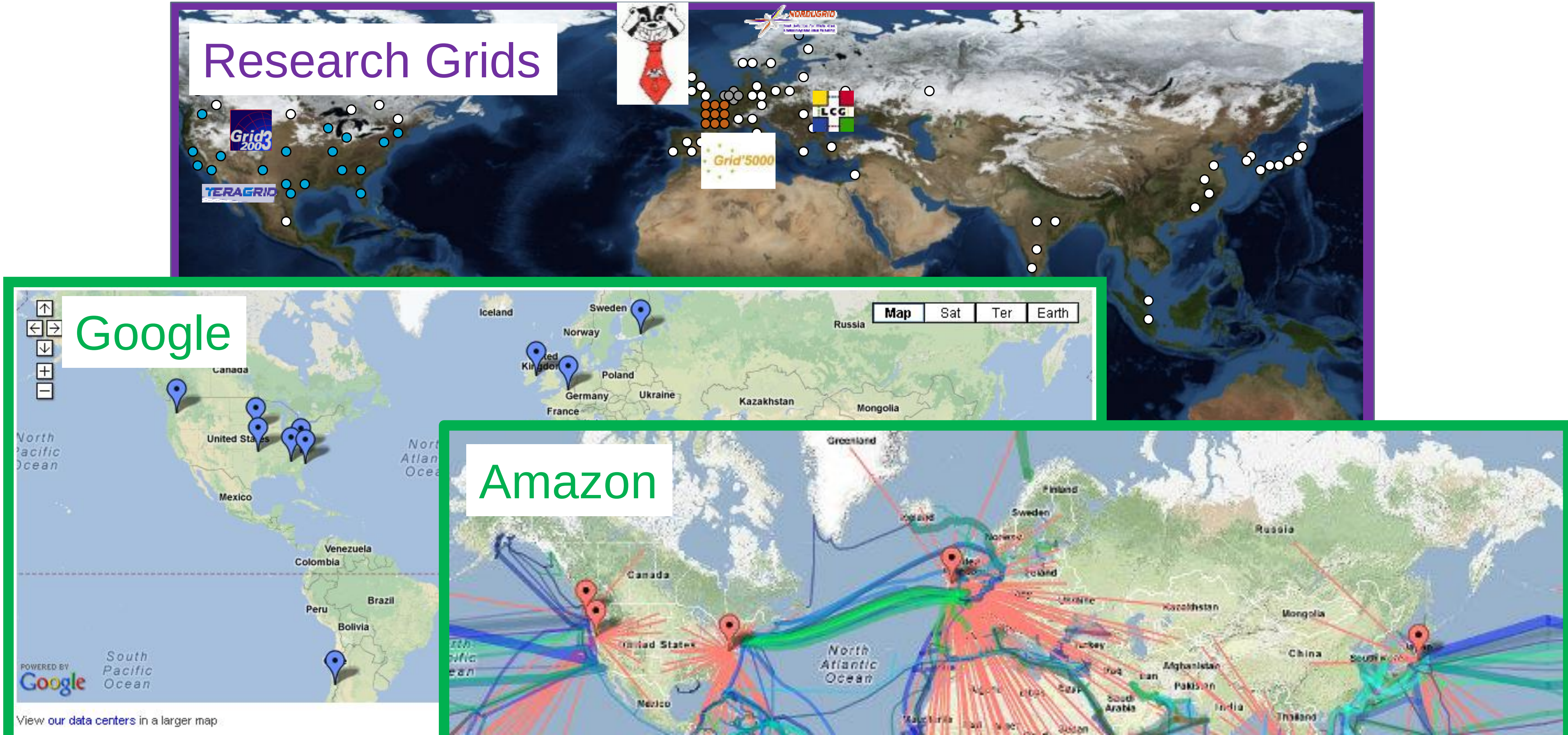




Source: MonALISA monitoring framework, 2005

Multi-computing

Grids (‘00s) and Cloud/Datacenter Computing (‘10s)



A Computer In Your Pocket (or Hand)

- Not tech, apps + mobility
- Internet everywhere (?)
- PC killers (?!)
- iPhone and relatives (2007—)
  - Initially music device++
- iPad and relatives (2010—)
  - Small format
  - High resolution

Source: http://www.imore.com/history-iphone-2g + http://www.imore.com/history-ipad-2010

Take-Home Message

1. Digital Computers are not a single invention
   - Math, Mechanical Engineering, Electrical Engineering
2. Empirical laws of computing
   - Are Moore’s and Rock’s Laws still valid?
   - Koomey’s Law for energy efficiency
   - Metcalfe’s Law for network usefulness
3. Evolutionary trends
   - The von Neumann and/or Harvard architectures?
   - Single and/or distributed computers?
   - PC+/-Mobile computing? Always connected?