(A Brief) History of Computer Architectures

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based on slides from
Gerard J.M. Smit

Overview of Computer Technology

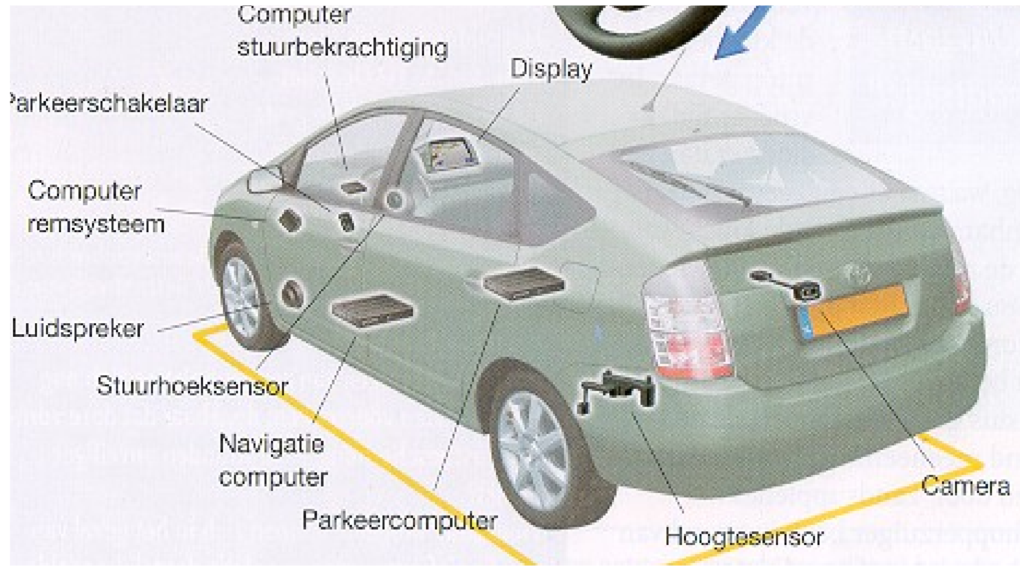
- Till 1938 Mechanical
- 1940s-50s Vacuum Tubes
- 1950s-60s Discrete Transistors
- 1960s-70s Discrete ICs (e.g., TTL)
- 1970s-present LSI and VLSI microprocessors
  Large Scale & Very Large Scale Integration
- 2000-present MPSoC
  Multi-Processor System on Chip

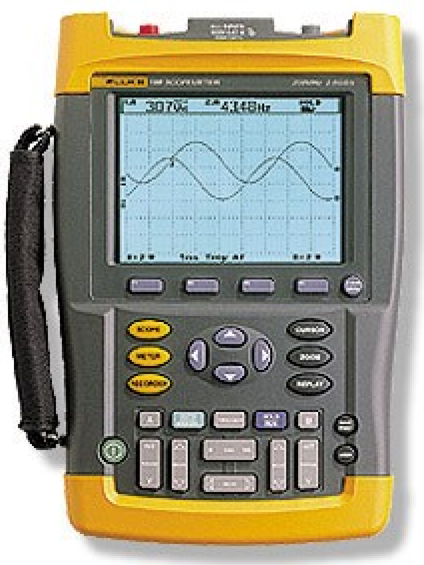
Embedded Computer Systems

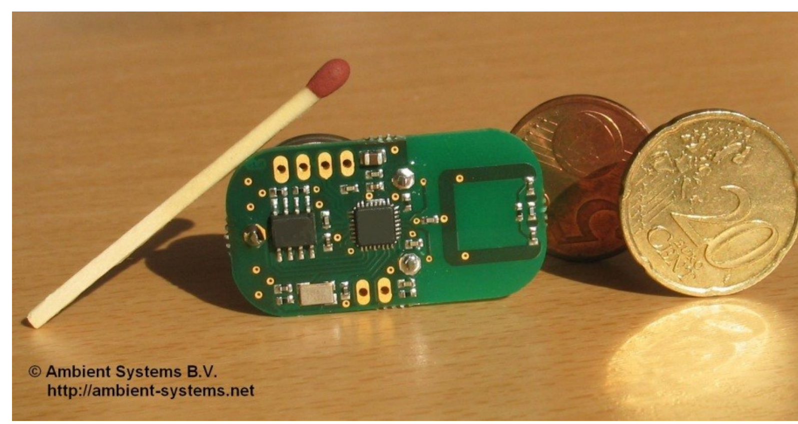
- Computer as part of larger system
  - Consumer electronics, appliances
  - Networking, telecommunications
  - Automotive / aircraft control

- What’s in the box
  - Microcontroller/Microprocessor
  - Memory: RAM, ROM, Flash
  - Special-purpose I/O (including analog stuff)
  - Communication (Bluetooth, WiFi, …)

Embedded Systems







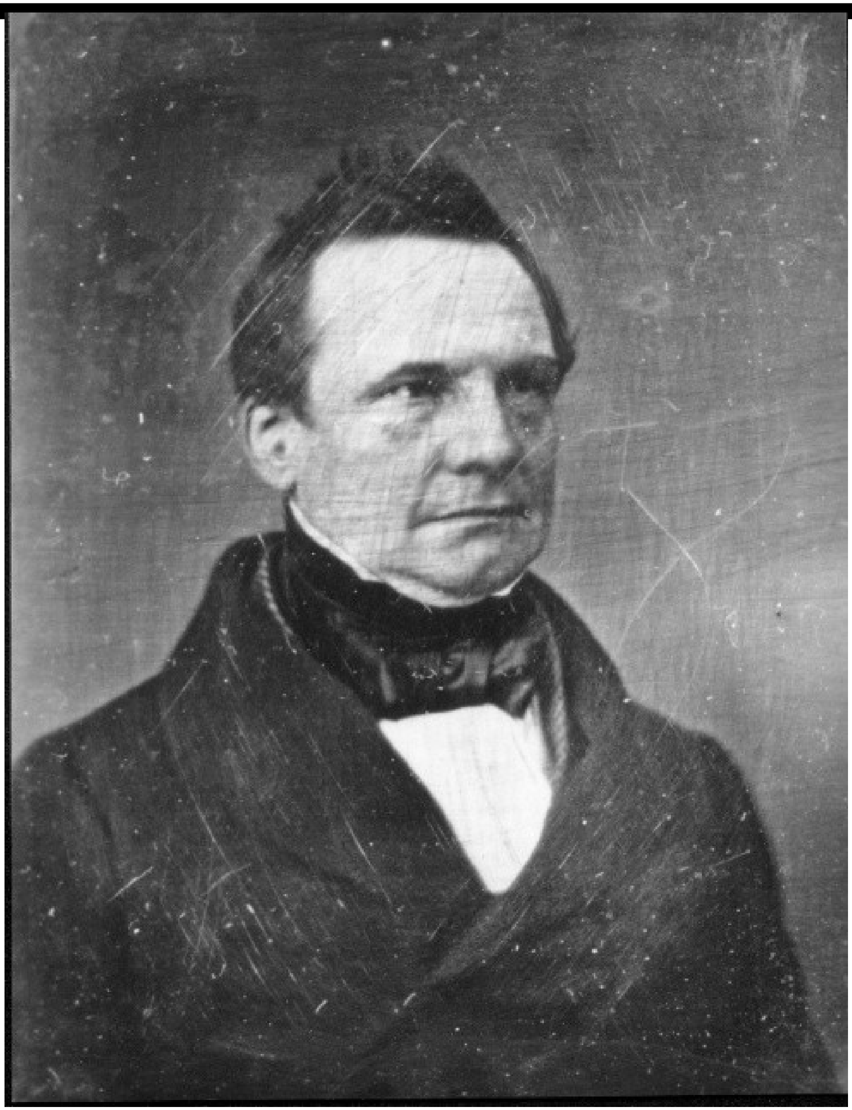
Mechanical Computers

1805 - Jacquard Loom

- First fully automated and programmable Loom (weaving machine)
- Used punch cards to "program" the pattern to be woven into cloth
- First "Embedded Computer"

Charles Babbage 1791-1871

Professor of Mathematics,
Cambridge University, 1827-1839



Charles Babbage

- ***Difference Engine*** **1823**
- ***Analytic Engine*** **1833**
  - **The forerunner of modern digital computer!**

Application

- Mathematical Tables – Astronomy
- Nautical Tables – Navy

(annoyed they contained human made computation errors)

Background

- Any continuous function can be approximated by a polynomial --- *Weierstrass*

Technology

- mechanical - gears, Jacquard’s loom

Difference Engine

1823

- **Babbage's paper is published**

1834

- **The paper is read by Scheutz & his son in Sweden**

1842

- **Babbage gives up the idea of building it; he is onto Analytic Engine!**

1855

- **Scheutz displays his machine at the Paris World Fare**
- **Can compute any 6th degree polynomial**
- ***Speed:* 33 to 44 32-digit numbers per minute!**

Now the machine is at the Smithsonian

Analytic Engine

1833: Babbage's paper was published

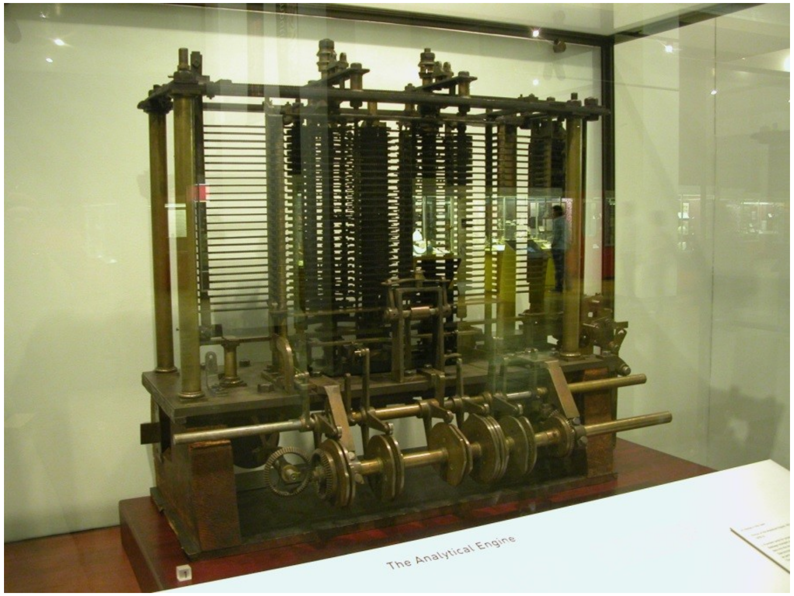
- ***conceived during a hick-up in the development of the difference engine***

Inspiration: *Jacquard Looms*

- **looms (weaving machines) were controlled by punched cards**
  - **The set of cards with fixed punched holes dictated the pattern of weave**
    ⇒ *program*
  - **The same set of cards could be used with different colored threads**
    ⇒ *numbers*

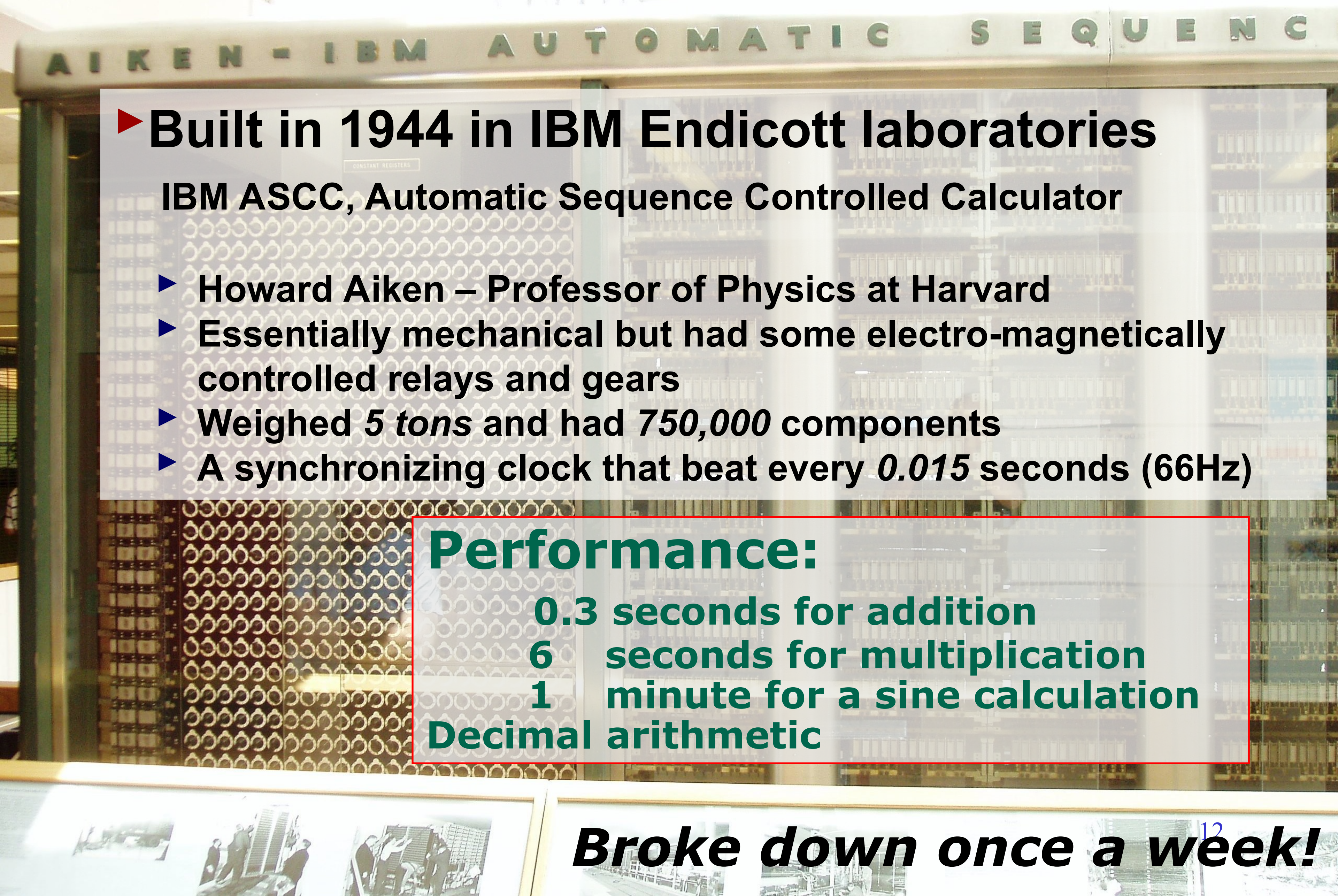
1871: Babbage dies

- **The machine remains unrealized.**



Electronic computers

1944 - Harvard Mark I



- **Built in 1944 in IBM Endicott laboratories**

  IBM ASCC, Automatic Sequence Controlled Calculator

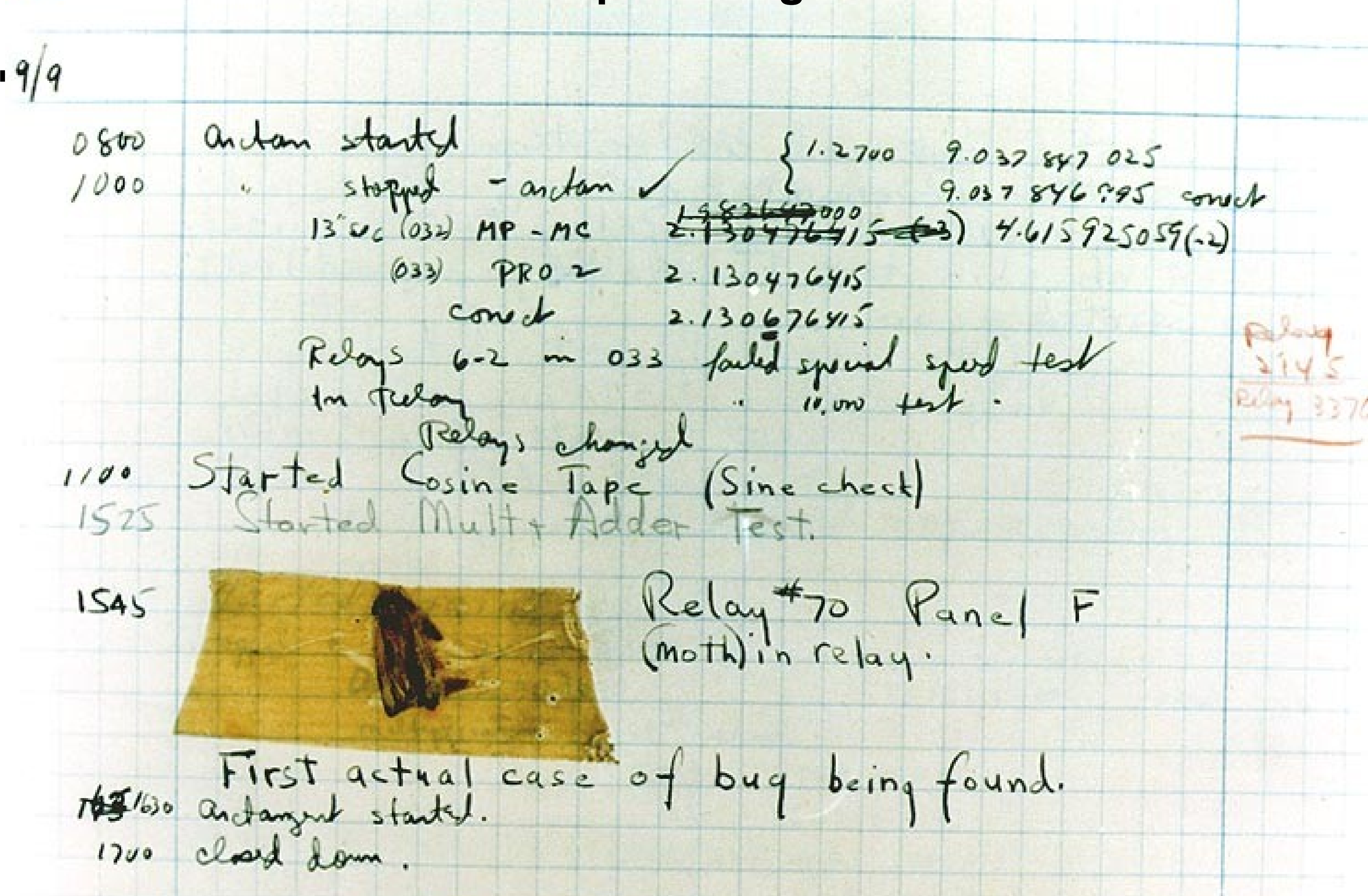
  - **Howard Aiken – Professor of Physics at Harvard**
  - **Essentially mechanical but had some electro-magnetically controlled relays and gears**
  - **Weighed *5 tons* and had *750,000* components**
  - **A synchronizing clock that beat every *0.015* seconds (66Hz)**

Performance:

0.3 seconds for addition
6 seconds for multiplication
1 minute for a sine calculation
Decimal arithmetic

Broke down once a week!

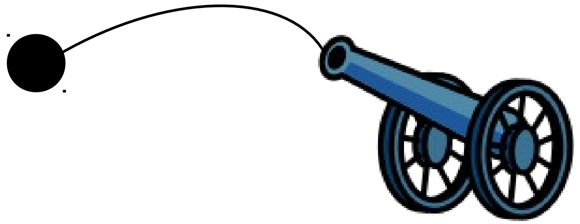
Programmer Harvard Mark I was Grace Hopper, who described the first computer bug



1945 - Electronic Numerical Integrator and Computer (ENIAC)

- ENIAC (1943-45) at the University of Pennsylvania
- The first, completely electronic, operational, general-purpose analytical calculator!
  - 30 tons, 72 square meters, 200KW
- Performance
  - Read in 120 cards per minute
  - Addition took 200 μs, Division 6 ms
  - 1000 times faster than Mark I
- Not very reliable!

WW-2 Effort

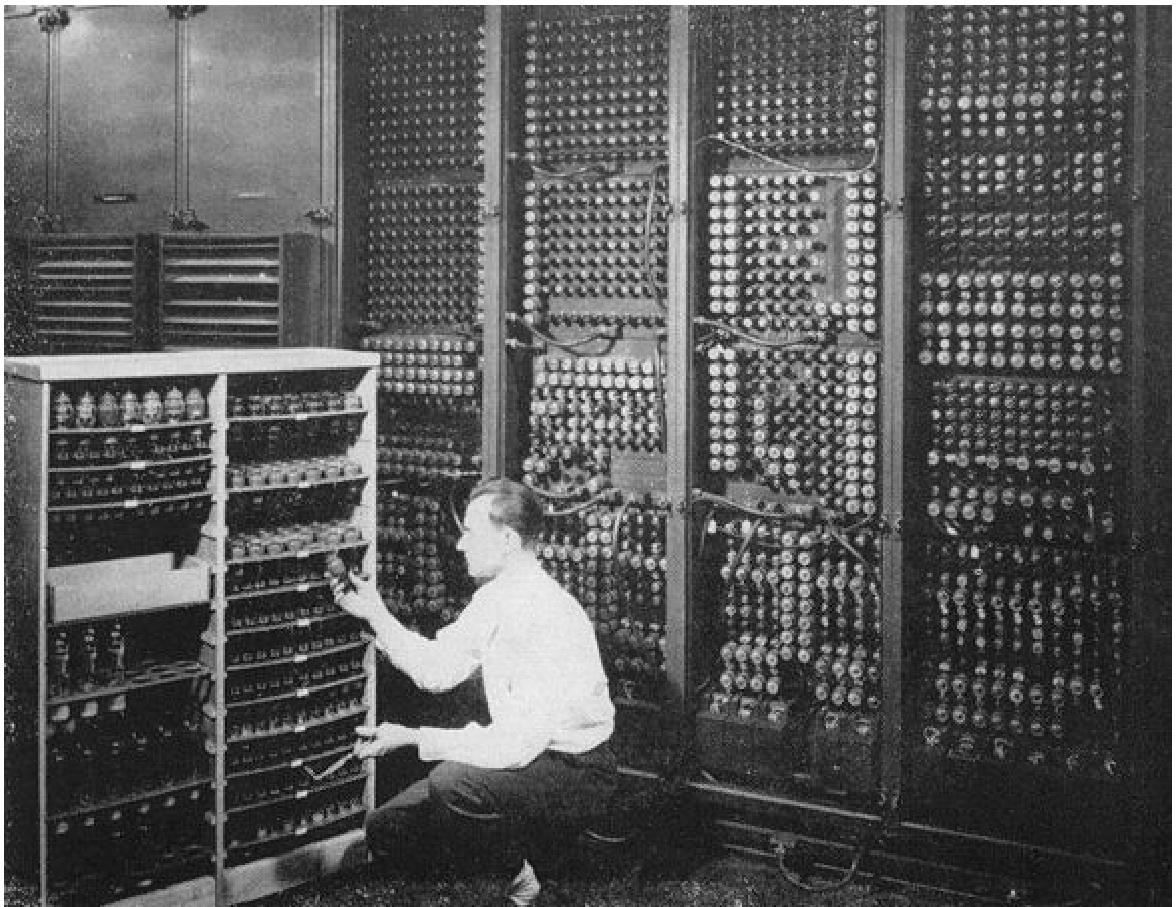


Application: Ballistic calculations
angle = f (location, tail wind, cross wind,
air density, temperature, weight of shell,
propellant charge, ...)

But also used to study the feasibility of the hydrogen bomb, the program consisted of 1 million cards

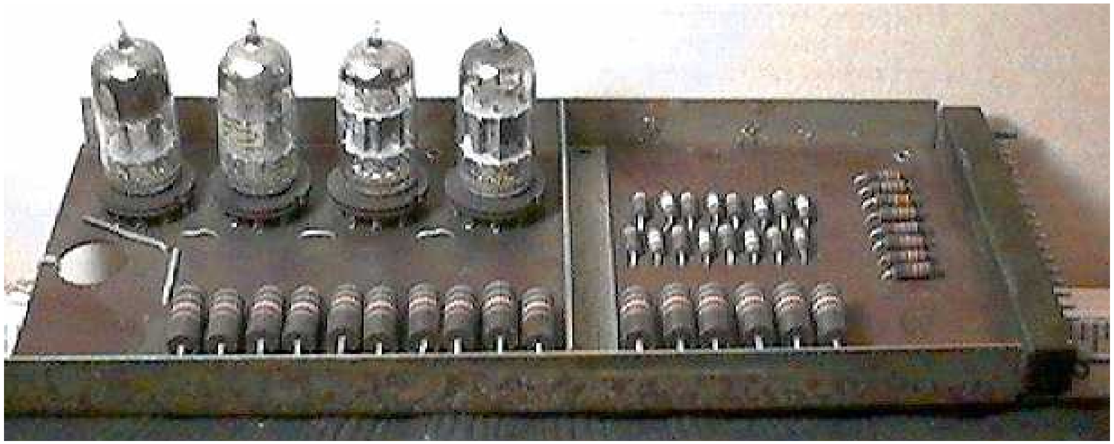
1940s-1960s ENIAC (14 feb 1946)

14 multiplications per second



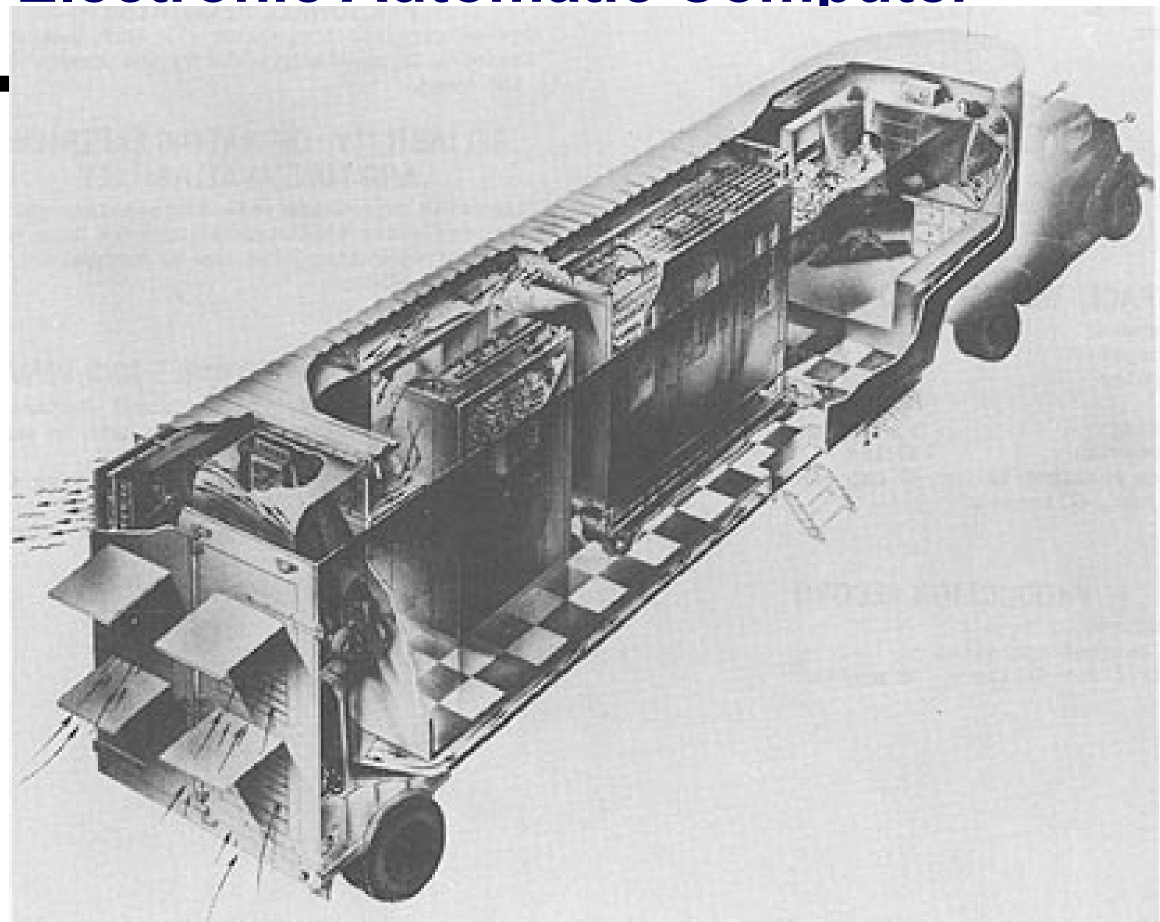
Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

1951 – UNIVAC (I)



One of the machines (5th) built was used by CBS to predict the result of the 1952 presidential election. With a sample of just 1% of the voting population it famously predicted an Eisenhower landslide while the conventional wisdom favoured Stevenson.

1954 - DYSEAC, first mobile computer!
Second Standards Electronic Automatic Computer



- Carried in two tractor trailers, 12 tons + 8 tons
- Built for US Army Signal Corps

900 vacuum tubes and 24,500 crystal diodes.
It had a memory of 512 words of 45 bits each (plus one parity bit),

[Courtesy Mark Smotherman]

1949 – EDVAC
Electronic Discrete Variable Automatic Computer

- First Draft of a report on EDVAC was published in 1945
- ENIAC's programming system was external
  - Sequences of instructions were executed independently of the results of the calculation
  - Human intervention required to take instructions "out of order"
- Eckert, Mauchly, John von Neumann and others designed EDVAC (1949) to solve this problem
  - Solution was the *stored program computer*

$\Rightarrow$ "***program can be manipulated as data***"

Stored Program Computer

Program = A sequence of instructions

How to control instruction sequencing?

manual control	**calculators**
automatic control	
external (paper tape)	**Harvard Mark I , 1944**
	Zuse's Z1, WW2
internal	
plug board	**ENIAC 1946**
read-only memory	**ENIAC 1948**
read-write memory	**EDVAC 1947 *(concept)***

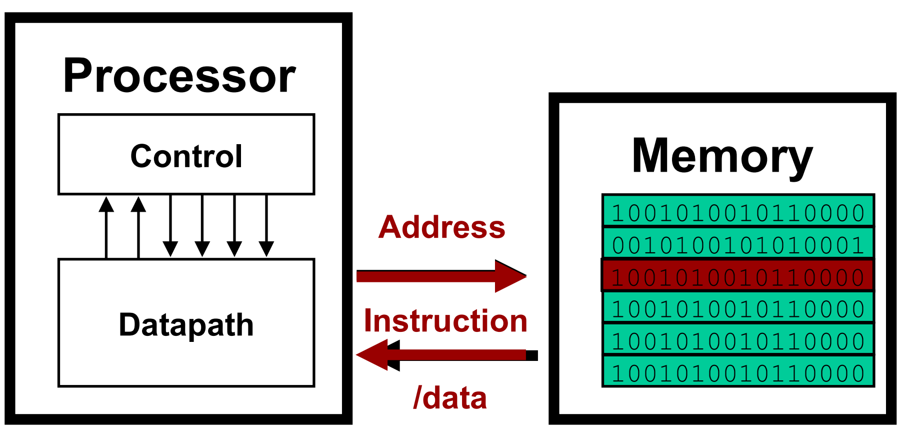
- **The same storage can be used to store program and data**

Computer System Operation
(von Neuman processor)

- Executing Programs - the "fetch/decode/execute" cycle
  - Processor **fetches** instruction from memory
  - Processor **decodes** instruction (which instruction?)
  - Processor **executes** "machine language" instruction

next instr

Load Data
Perform Calculation
Store Results



Dominant Problem: *Reliability*

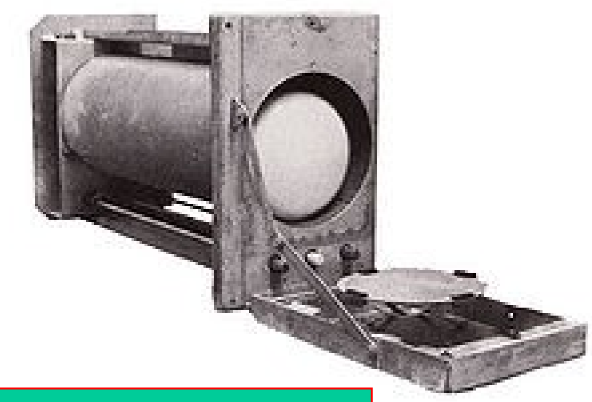
Mean time between failures (MTBF)

MIT's Whirlwind with an MTBF of 20 min. was perhaps the most reliable machine !

Reasons for unreliability:

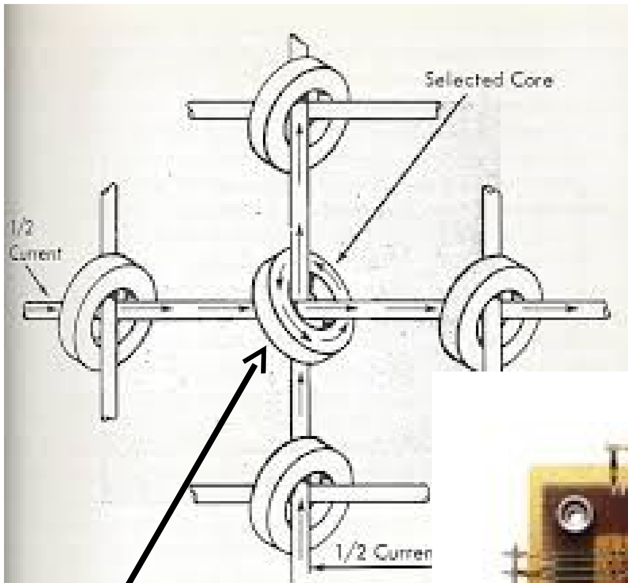
1. Vacuum Tubes

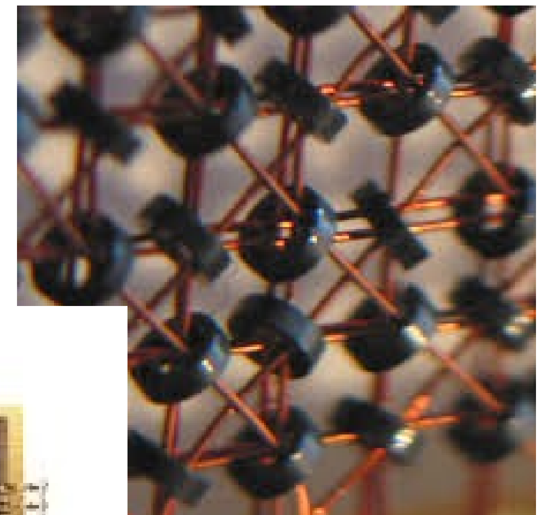
2. Storage medium
   - acoustic delay lines
   - mercury delay lines
   - Williams tubes

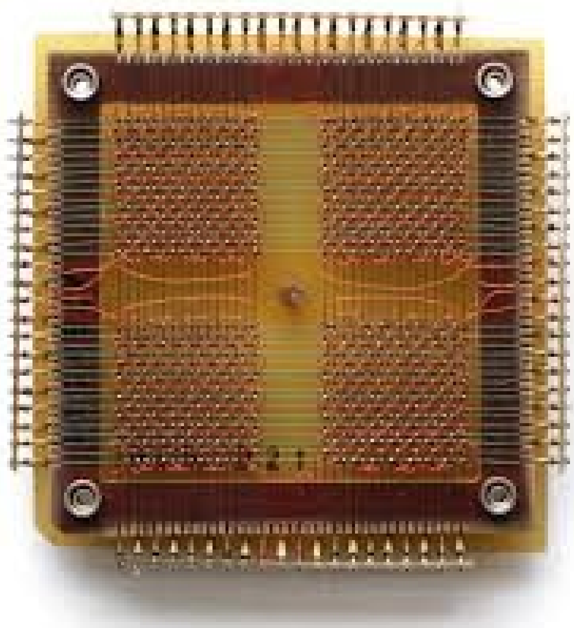


Reliability solved in part by invention of Core memory by J. Forrester 1954 at MIT for Whirlwind project

Core memory







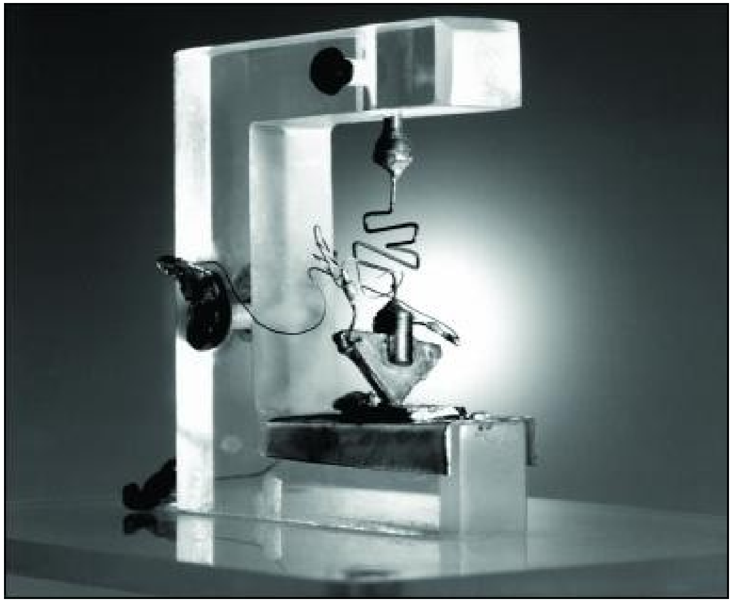
Magnetic ring-core memory

Solutions to reliability problems

- **Memory**
  - **Core memory**
    - **Store bits in magnetic material**
  - **Solid state memory**
    - **Memory in chips (RAM, ROM, Flash)**
  - **Large memories**
    - **Disk**
    - **Tape**
- **Logic**
  - **Transistors**
  - **Integrated circuits**

Invention of the bipolar transistor

Bardeen, Shockley, and Brattain at Bell Labs - Brattain and Bardeen invented the bipolar transistor in 1947. Later got the Nobel prize.



The first germanium bipolar transistor.

Texas Instruments First IC

12 September 1958: Jack Kilby's original integrated circuit

Integrated Circuits: SSI

Small Scale Integration (Germanium, Silicon)

- Early to mid 1960s
- Contained transistors numbering in the tens.
- Crucial to early aerospace projects that needed lightweight digital computers
  - U.S. Air Force Minuteman missile - forced IC technology into mass-production
  - NASA Apollo flight computer - led and motivated the IC technology

General purpose computers

Compatibility Problem at IBM

By early 60's, *IBM had 4 incompatible lines of computers!*

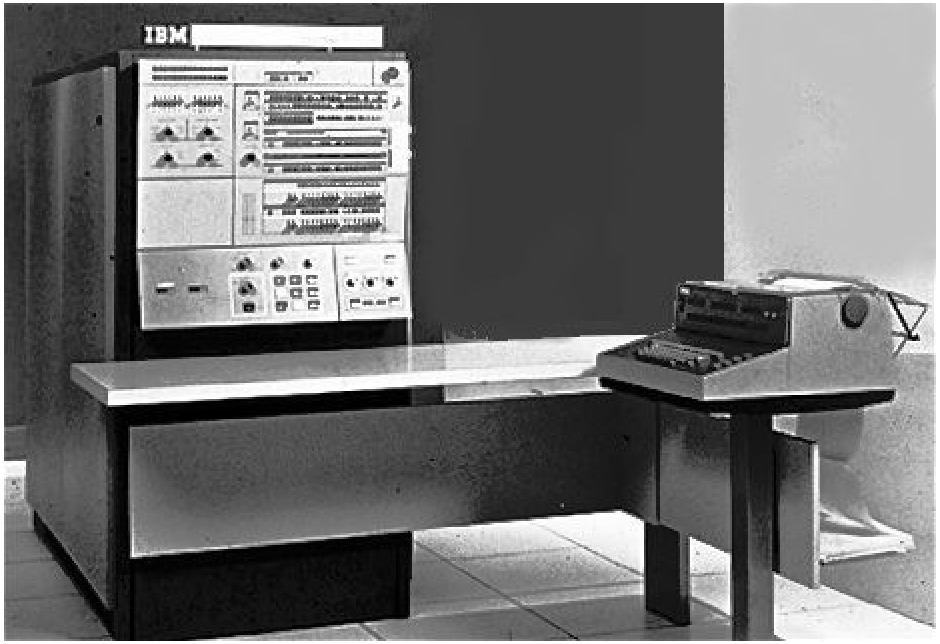
Each system had its own

- Instruction set
- I/O system and Secondary Storage:
  magnetic tapes, drums and disks
- assemblers, compilers, libraries,...
- market niche
  business, scientific, real time, ...

⇒ *IBM 360*

IBM 360

Amdahl, Blaauw and Brooks, 1964



IBM 360 - 1960s (Transistors)

Revolutionary design:

Different implementations for the same ISA (Instruction Set Architecture)

Instruction set completely hides differences of underlying hardware. For a programmer there is no difference.

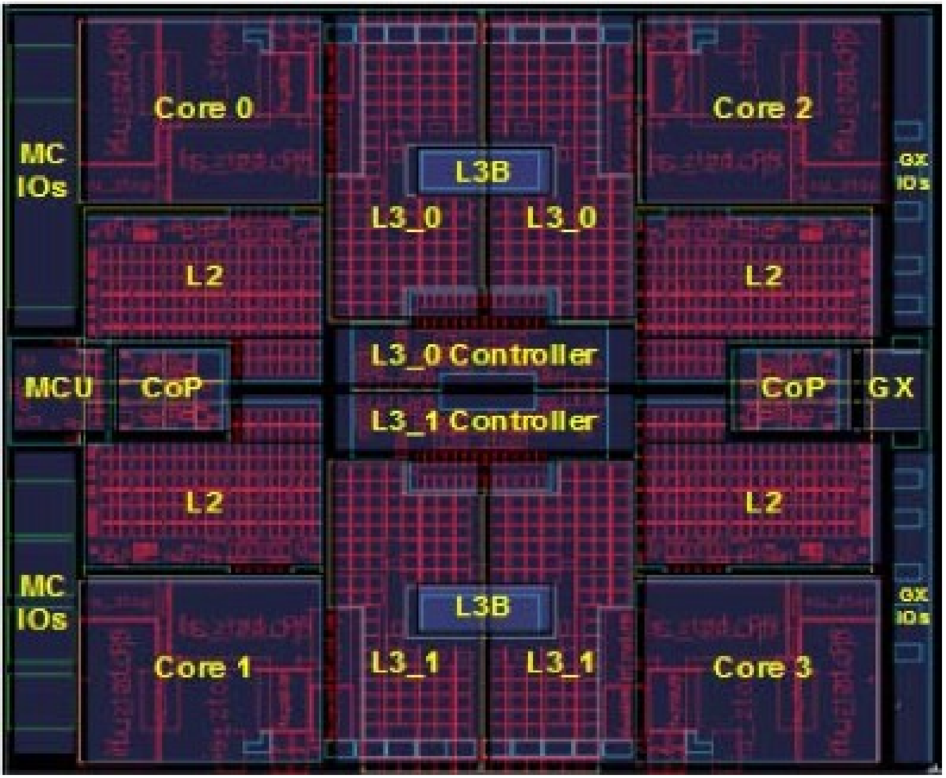
IBM 360: *A General-Purpose Register (GPR) Machine*

- Processor State
  - 16 General-Purpose 32-bit Registers
    - *may be used as index and base register*
    - *Register 0 has some special properties*
  - 4 Floating Point 64-bit Registers
  - A Program Status Word (PSW)
    - *PC, Condition codes, Control flags*
- A 32-bit machine with 24-bit addresses
  - But no instruction contains a 24-bit address!
- Data Formats
  - 8-bit bytes, 16-bit half-words, 32-bit words, 64-bit double-words

The IBM 360 is why bytes are 8-bits long today!

With minor modifications it still survives today!

IBM 360: 47 years later…
The zSeries z11 Microprocessor



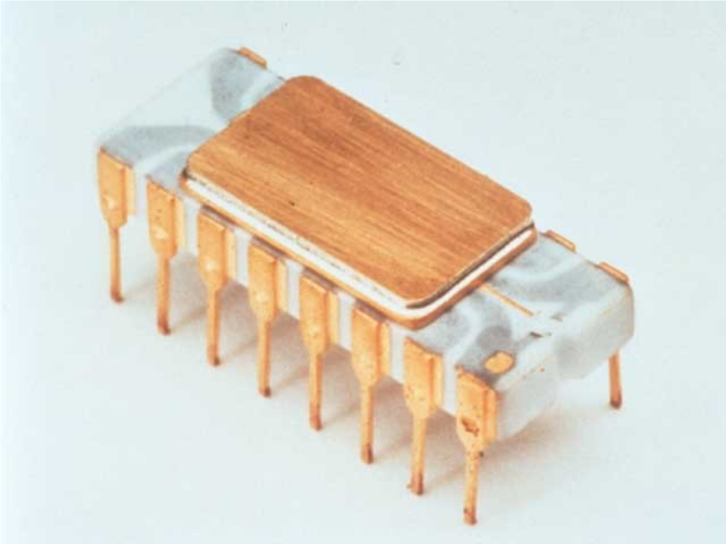
[IBM, HotChips, 2010]

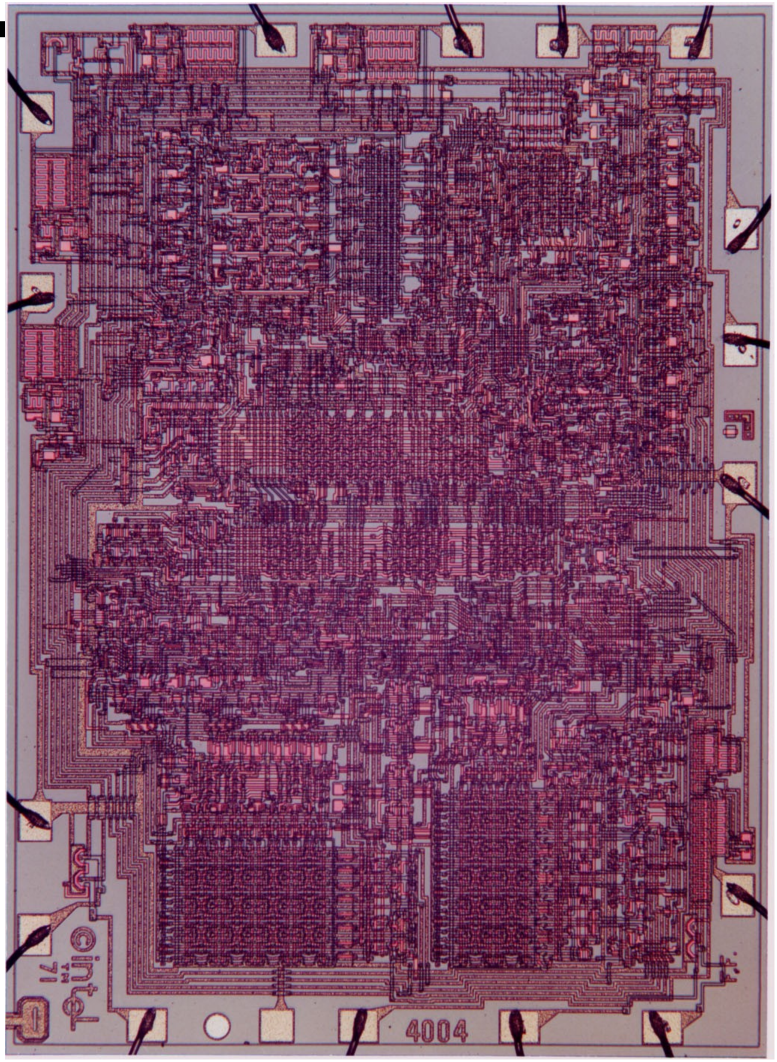
- 5.2 GHz in IBM 45nm PD-SOI CMOS technology
- 1.4 billion transistors in 512 mm^2
- 64-bit virtual addressing
  - original S/360 was 24-bit, and S/370 was 31-bit extension
- Quad-core design
- Three-issue out-of-order superscalar pipeline
- Out-of-order memory accesses
- Redundant datapaths
  - every instruction performed in two parallel datapaths and results compared
- 64KB L1 I-cache, 128KB L1 D-cache on-chip
- 1.5MB private L2 unified cache per core, on-chip
- On-Chip 24MB eDRAM L3 cache
- Scales to 96-core multiprocessor with 768MB of shared L4 eDRAM

Single chip microprocessors

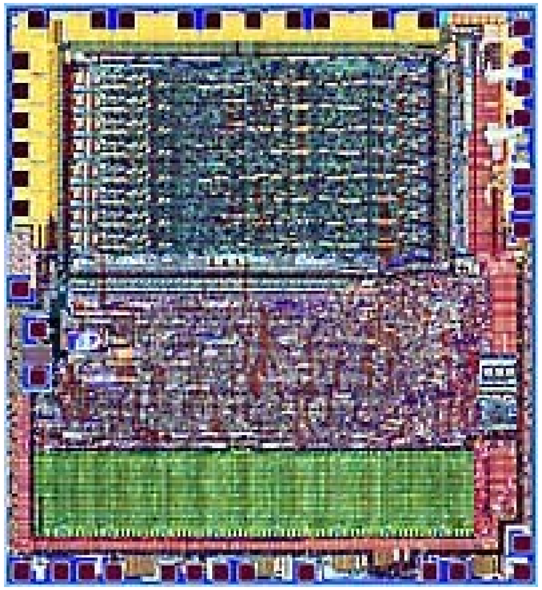
1971 – Intel 4004 Microprocessor

- Worlds first microprocessor with 2,300 transistors, had the same processing power as the 3,000 cubic-foot ENIAC
- 4 bits, 108 kHz
- Originally designed for Busicom (Japanese company)for a new calculator.





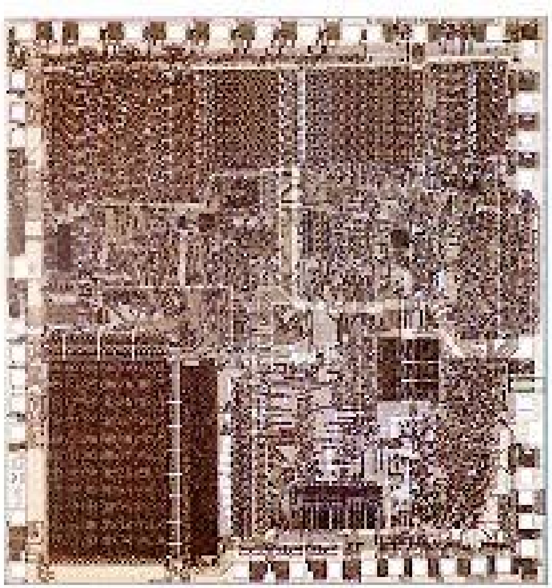
Computer History - 1970s



MOS Technologies 6502
8 bits data, 16 bits address, 2 MHz

Apple II Computer

Computer History - 1980s



Intel 8088
8 bits, 29000 transistors, 4.77MHz
(LSI Microprocessor)

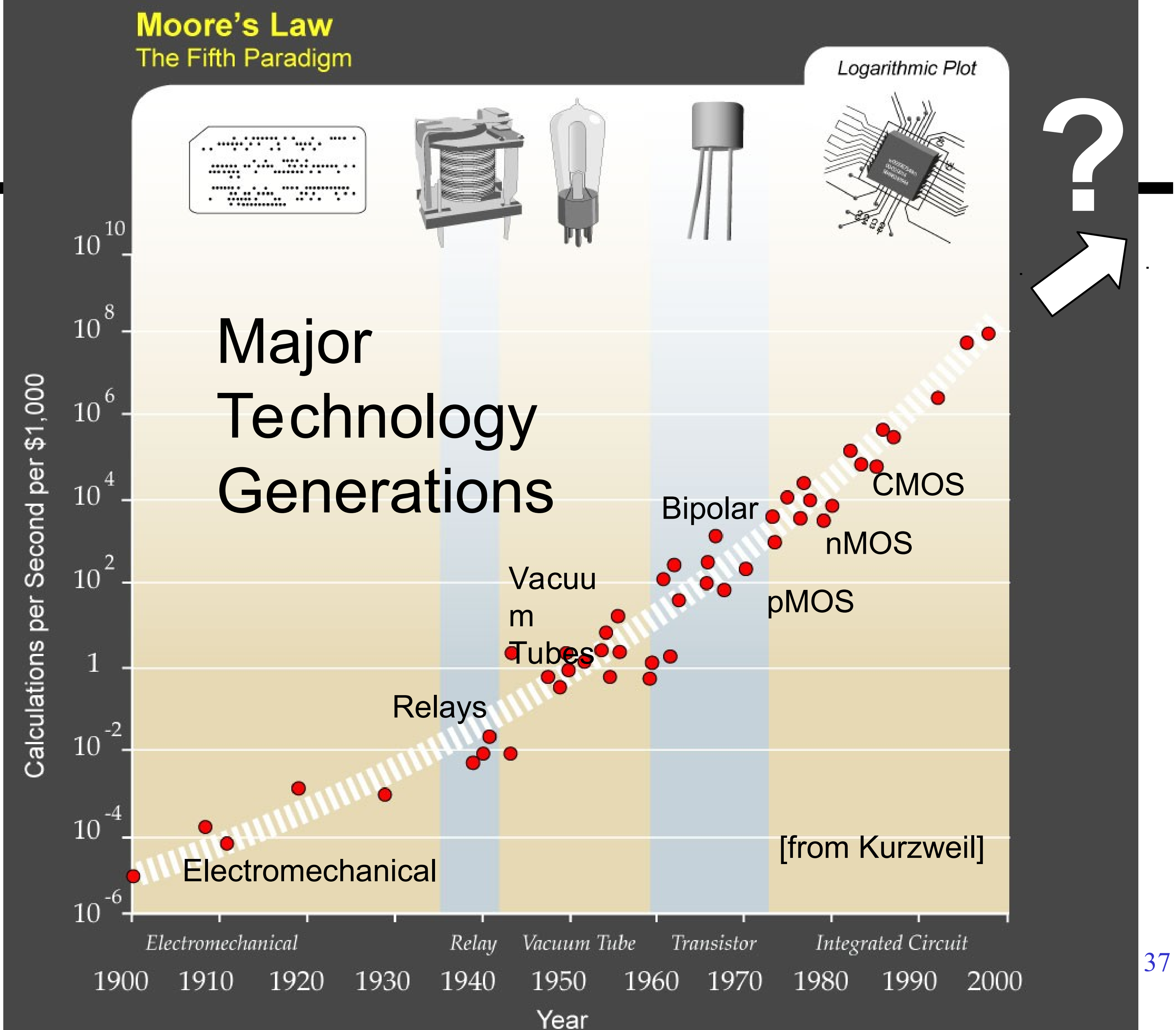
Original IBM PC

Images:
Intel Corporation www.intel.com
pcbiography members.tripod.com/pcmuseum

VLSI Trends: Moore's Law

- In 1965, Gordon Moore predicted that transistors would continue to shrink, allowing:
  - Doubled transistor density every 18-24 months
  - Doubled performance every 18-24 months
- History shows that Moore is right
- But, is the end in sight?
  - Physical limitations
  - Economic limitations

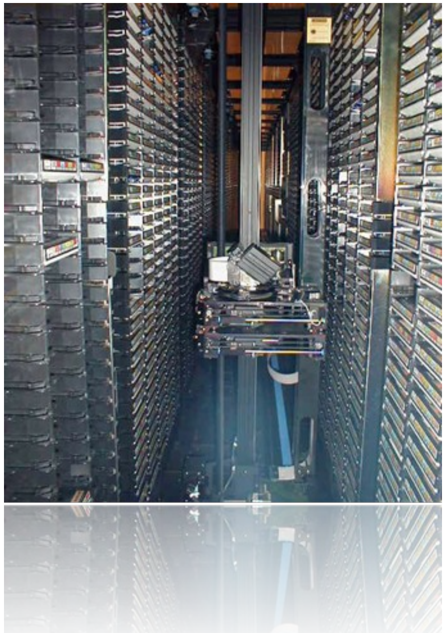
Gordon Moore
Intel Co-Founder and Chairmain Emeritus
Image source: Intel Corporation www.intel.com

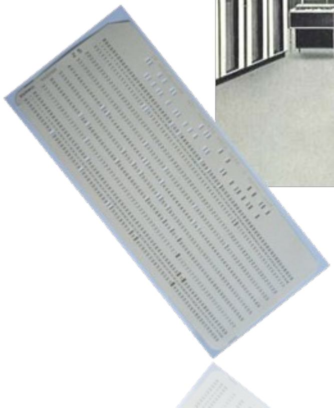

Moore's Law
The Fifth Paradigm
Logarithmic Plot
?
Major Technology Generations
Calculations per Second per $1,000
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
1
10^{-2}
10^{-4}
10^{-6}
CMOS
Bipolar
nMOS
pMOS
Vacuu m Tubes
Relays
Electromechanical
[from Kurzweil]
Electromechanical
Relay
Vacuum Tube
Transistor
Integrated Circuit
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year

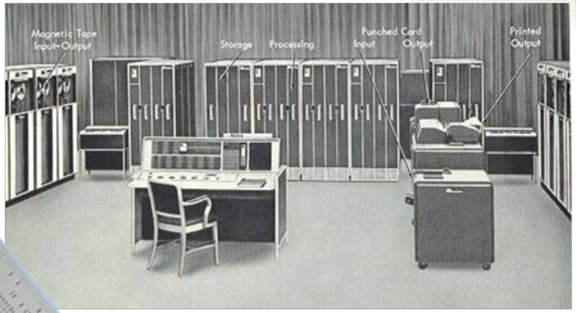
Trends

Trends Modern Computers

- **1960s: Batch computing**
  - **Mainframe Era**
  - **One computer, many users**
  - **Data storage: punch cards or magnetic tape**







Trends Modern Computers

- 1980s: Personal computing
  - PC/desktop Era
  - One computer, one user
  - System and user eye to eye

Trends Modern Computers

- **1990s: World Wide Web**
  - **One user, network of computers**
  - **Wider data access**
  - **Data sharing**
  - **Search engines**

  - **Moving towards:**
    - **Everywhere and anytime data access**

  - **But still:**
    System and user eye to eye

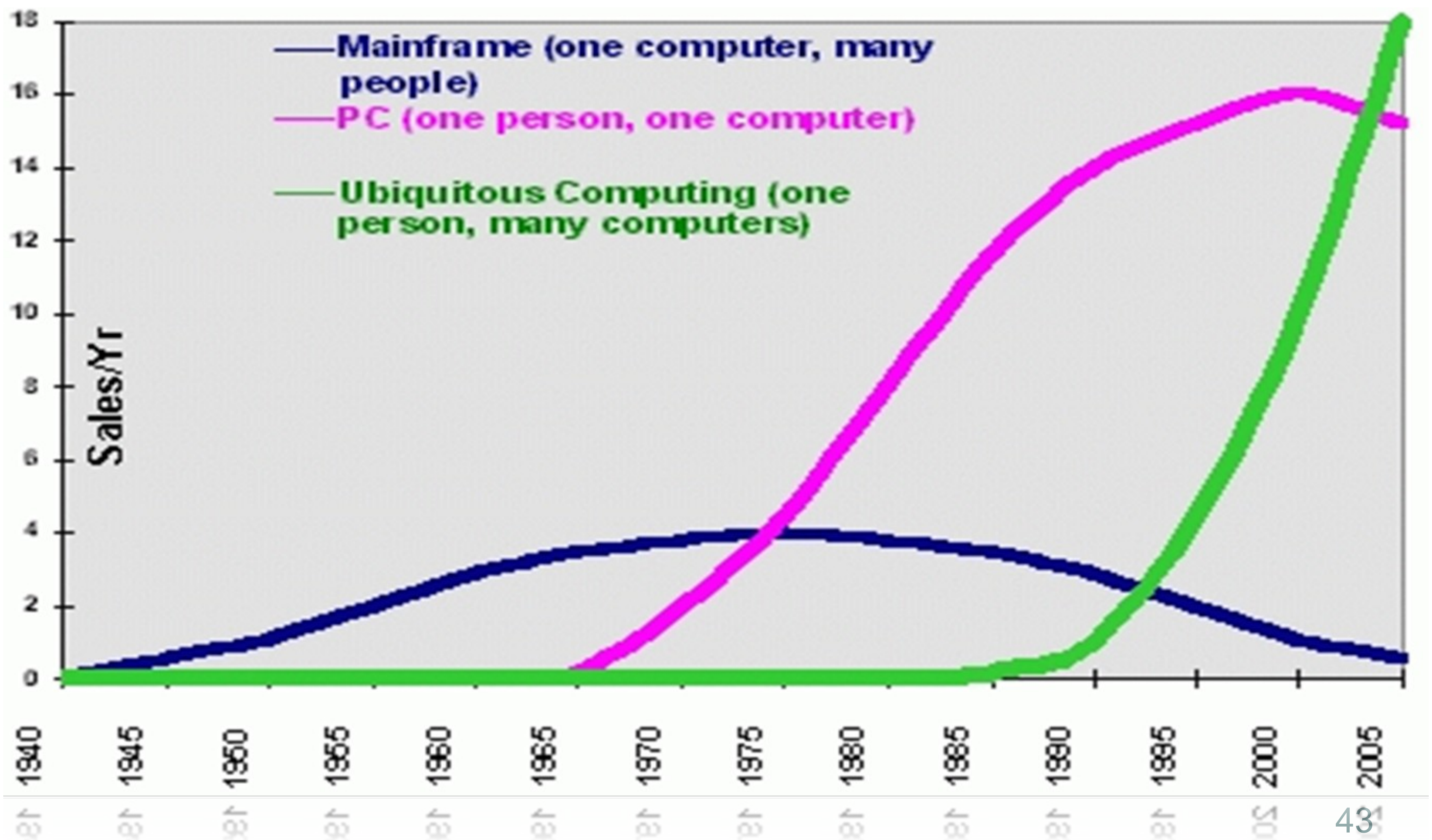
Trends Modern Computers

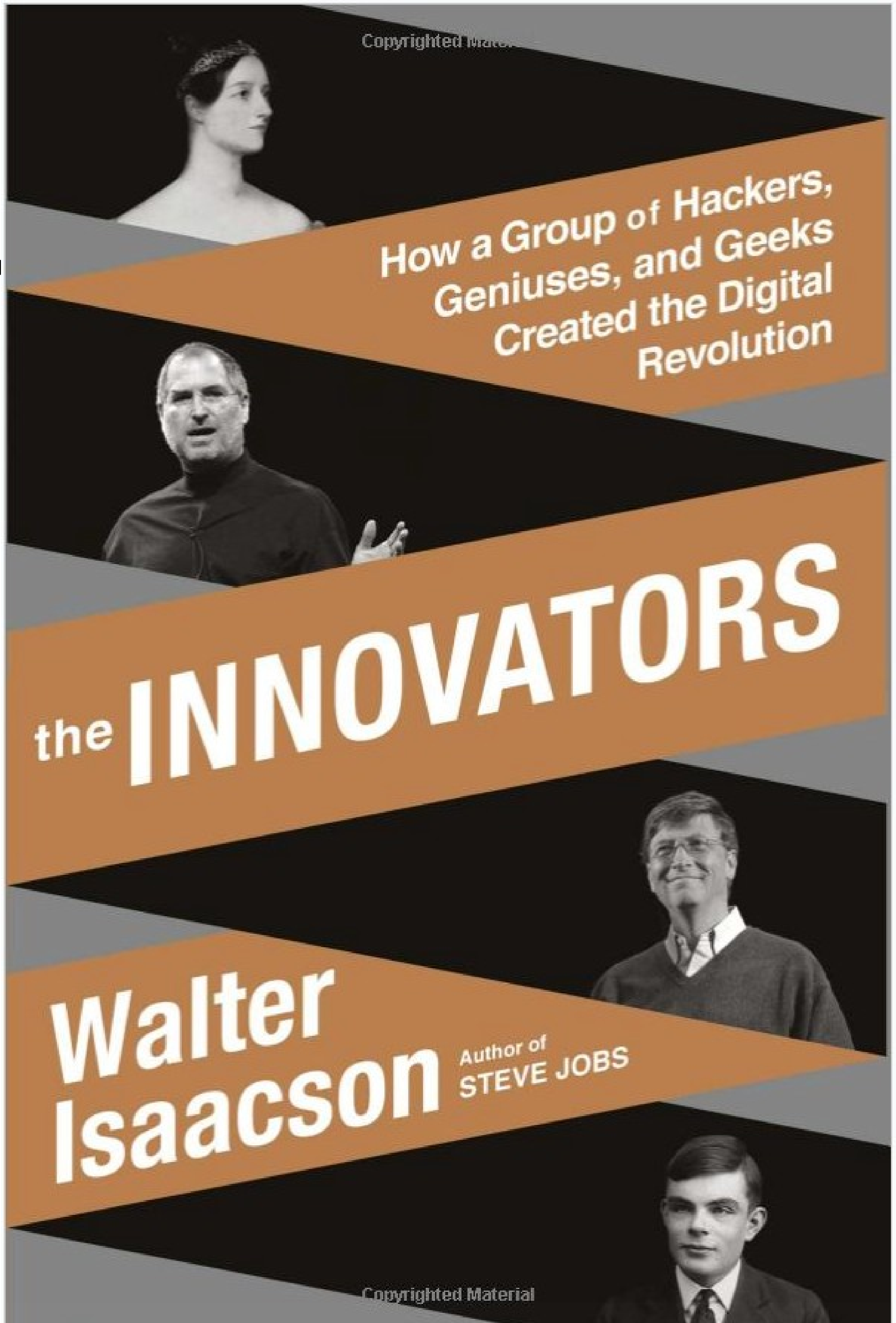
- **2000s: Paradigm shift**
  - **Small, cheap devices**
  - **Light**
  - **Wireless**
  - **Processing power**
  - **Everywhere, anytime**

- **Moore = less!**

- **Smaller size:**
  - disappearing computer
  - Internet of Things

Marc Weiser's Prediction: Three Waves of Computing





Book

The Innovators:

How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution

History of Computer Architectures

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based on slides from
Gerard J.M. Smit