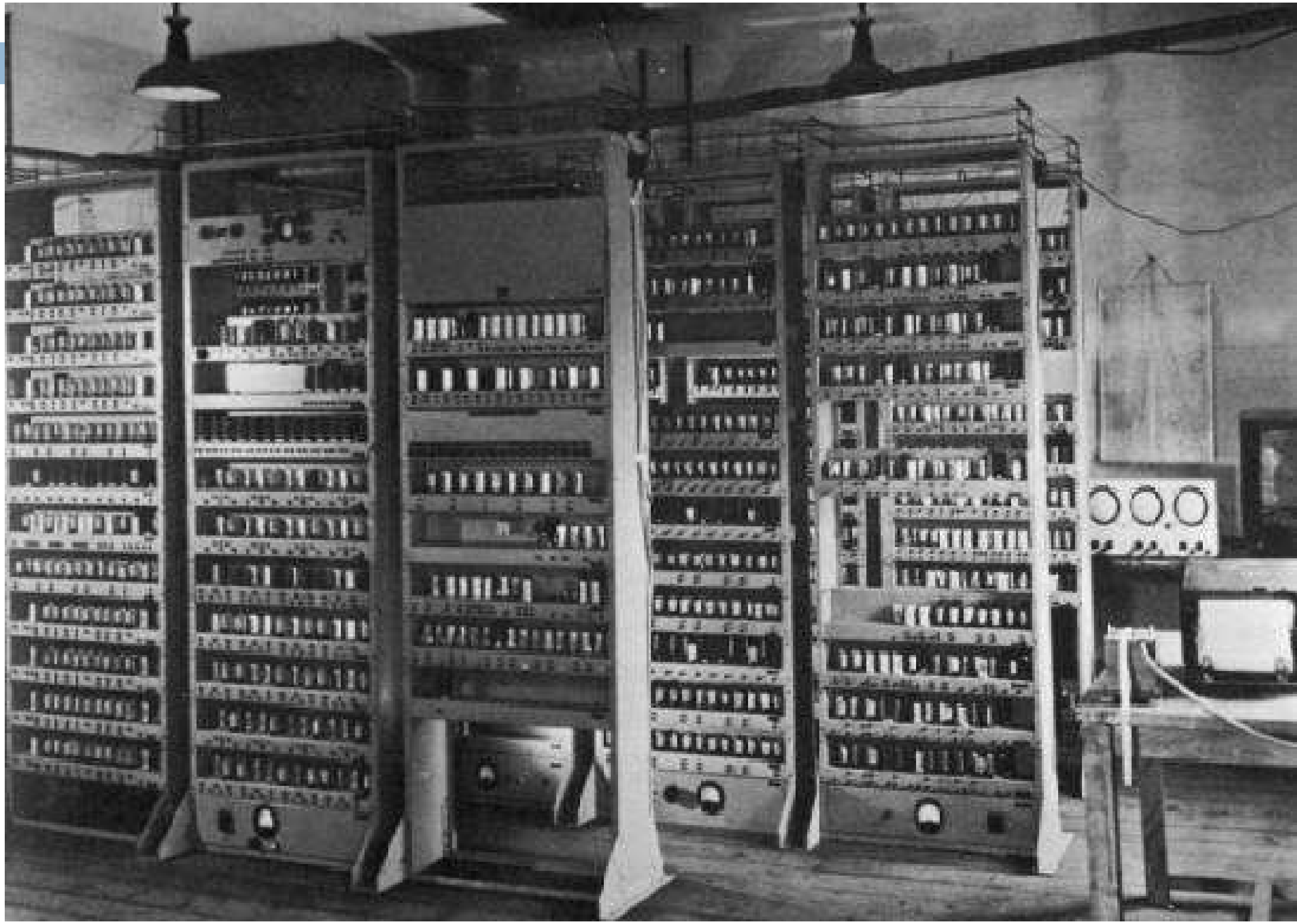
EC-252: COMPUTER ARCHITECTURE AND MICROPROCESSORS

Vaskar Raychoudhury

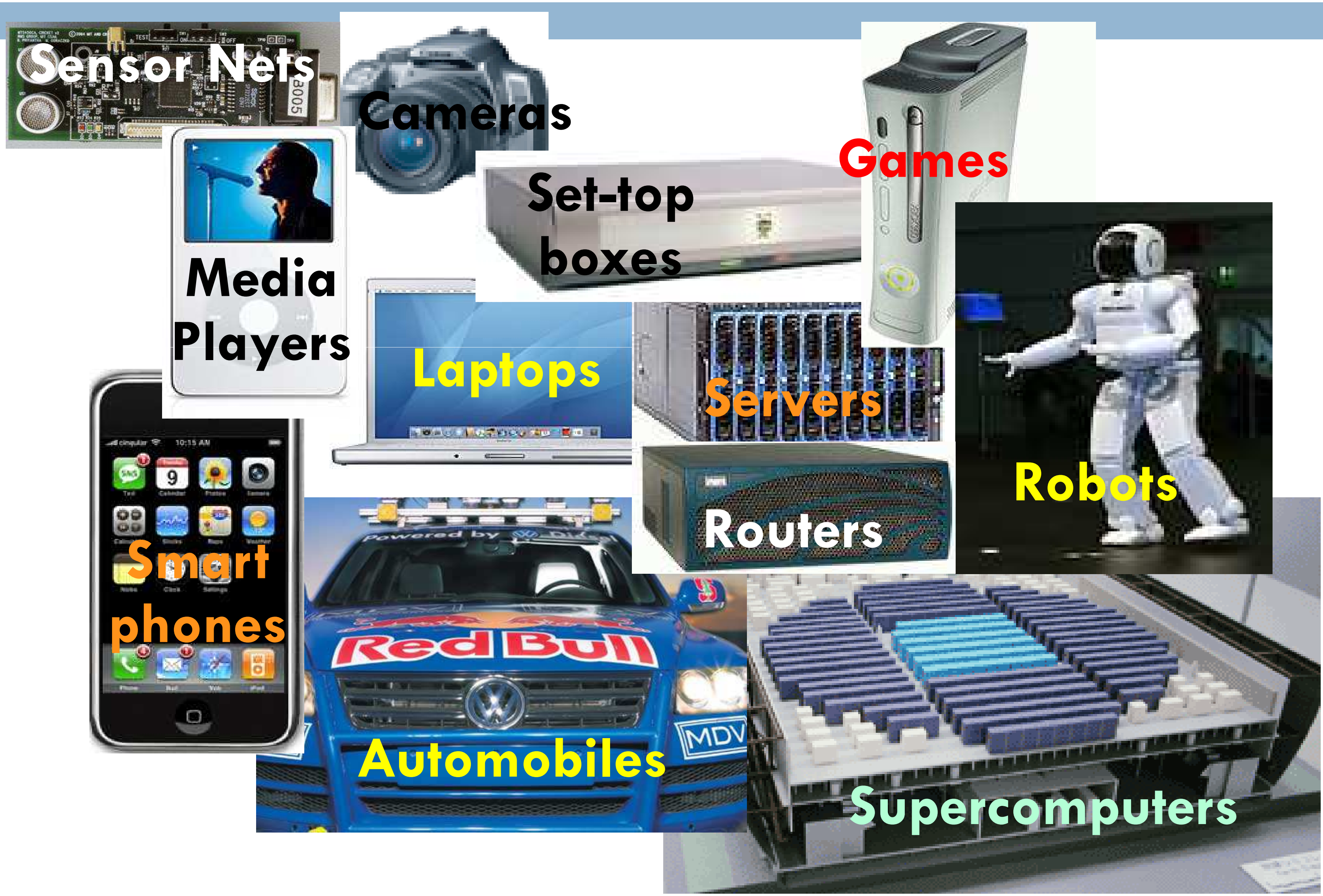
Indian Institute of Technology Roorkee

Computing Devices Then…



EDSAC, University of Cambridge, UK, 1949

Computing Devices Now



Computer Generations

- Zeroth Generation
  - Mechanical Computers (1642 – 1945)
- First Generation
  - Vacuum Tubes (1945 – 1955)
- Second Generation
  - Transistors (1955 – 1965)
- Third Generation
  - Integrated Circuits (1965 – 1980)
- Fourth Generation
  - Very Large Scale Integration (1980 – ?)

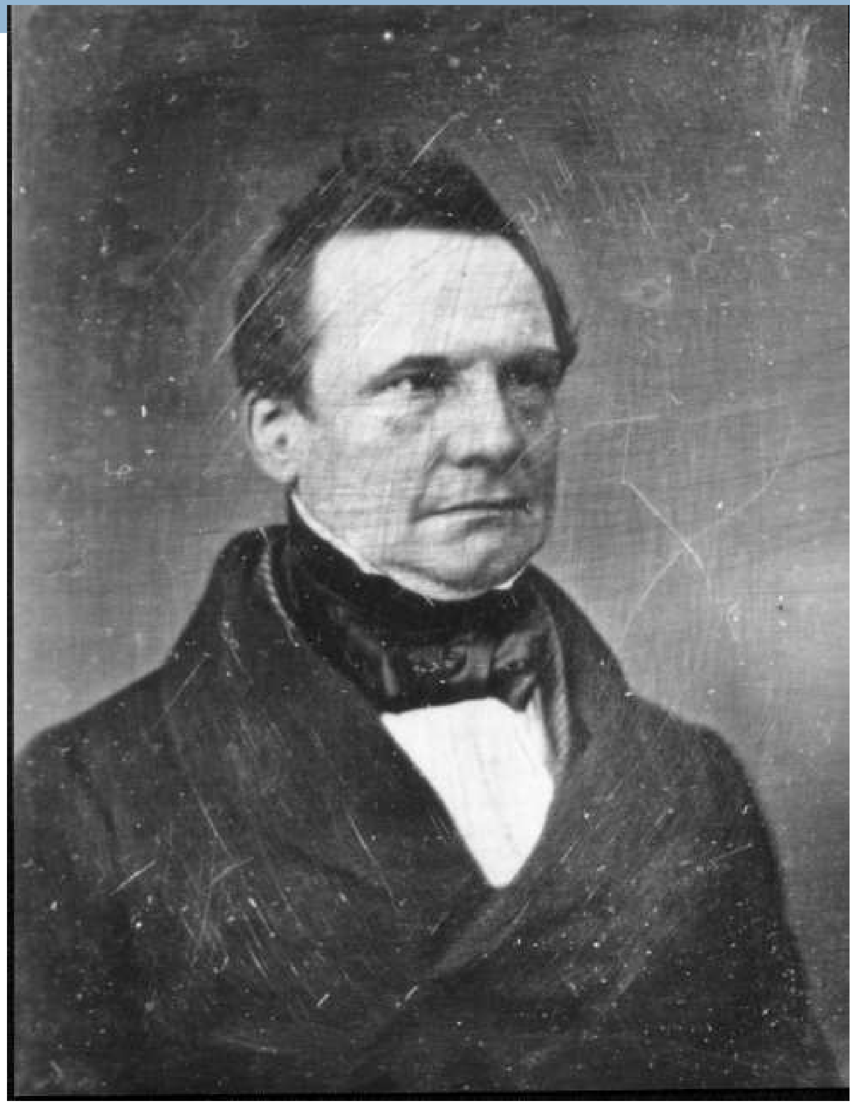
Computer Architecture: A Little History

Why worry about old ideas?

- Helps to illustrate the design process, and explains why certain decisions were taken
- Because future technologies might be as constrained as older ones
- Those who ignore history are doomed to repeat it
  - Every mistake made in mainframe design was also made in minicomputers, then microcomputers, where next?

Charles Babbage 1791-1871

Lucasian 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*

Background

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

Technology

- *mechanical - gears, Jacquard's loom, simple calculators*

Difference Engine

1823

- Babbage's paper is published

1834

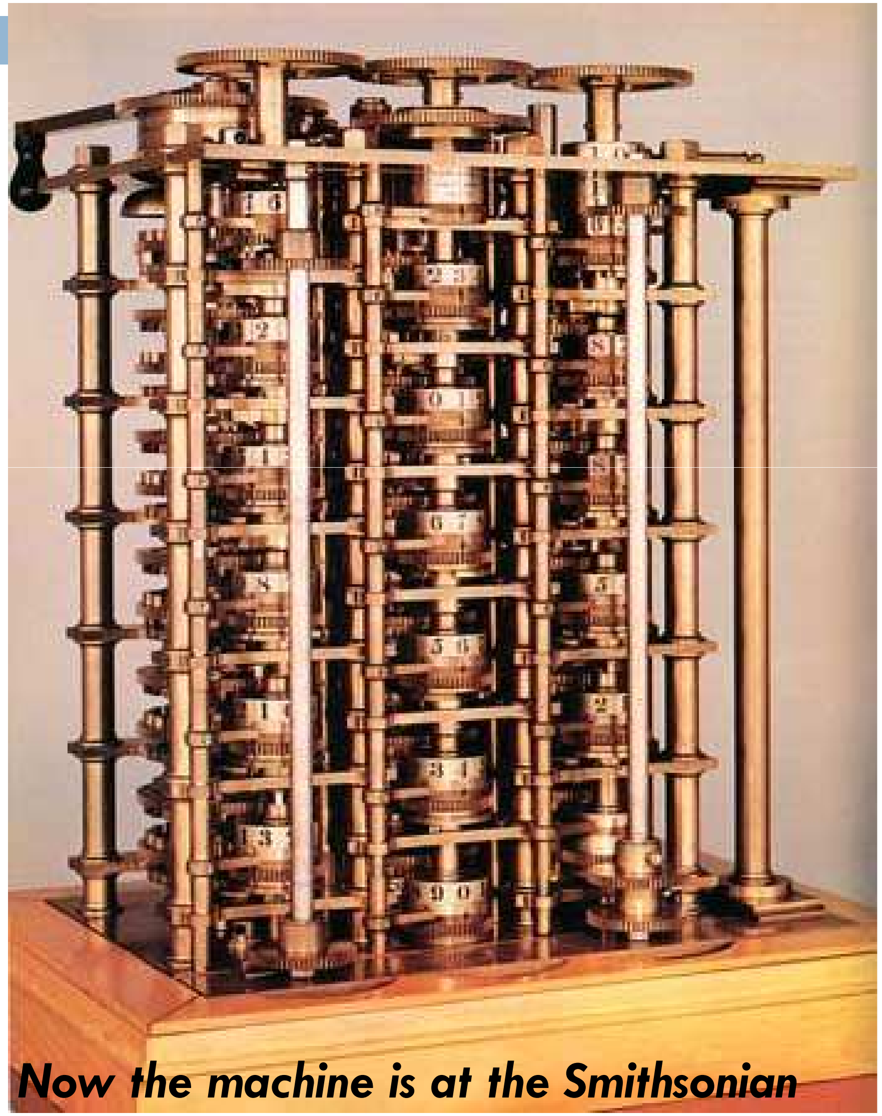
- The paper is read by Scheutz & his son in Sweden

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 hiatus in the development of the difference engine*

Inspiration: *Jacquard Looms*

- looms 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.

It is not clear if the analytic engine could be built even today using only mechanical technology

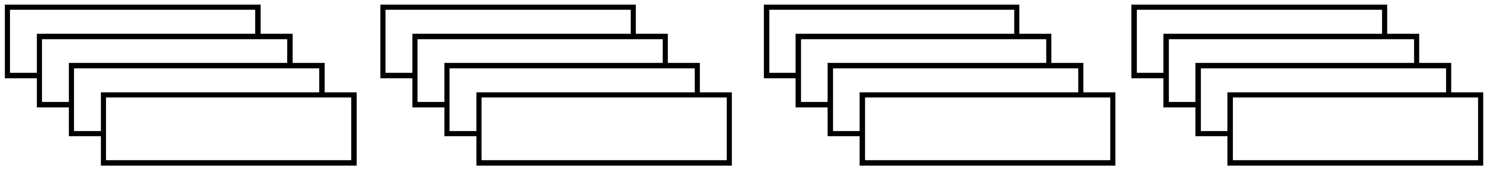
Analytic Engine

The first conception of a general-purpose computer

1. The *store* in which all variables to be operated upon, as well as all those quantities which have arisen from the results of the operations are placed.
2. The *mill* into which the quantities about to be operated upon are always brought.

The *program*

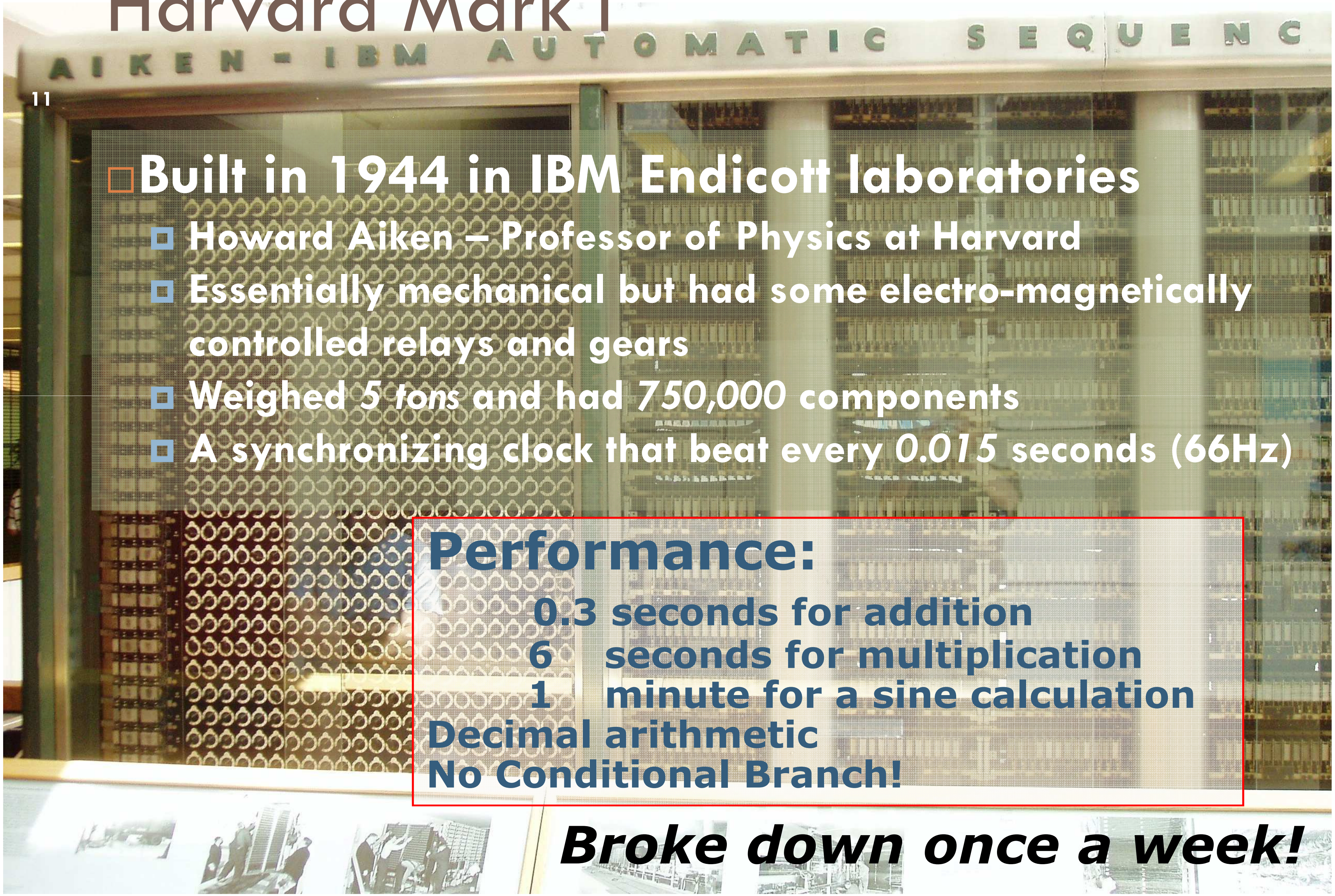
Operation variable1 variable2 variable3



An operation in the *mill* required feeding two punched cards and producing a new punched card for the *store*.

An operation to alter the sequence was also provided!

Harvard Mark I



- Built in 1944 in IBM Endicott laboratories
  - 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
No Conditional Branch!

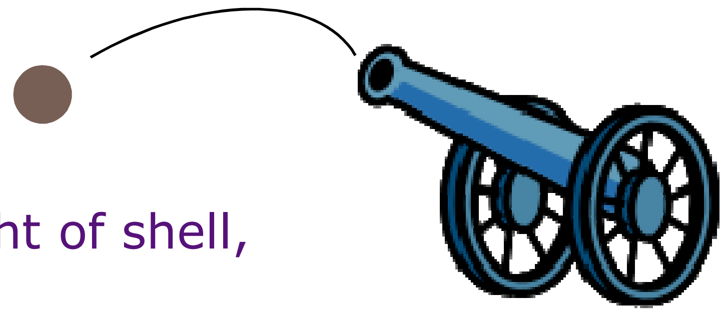
Broke down once a week!

Electronic Numerical Integrator and Computer (ENIAC)

- Inspired by Atanasoff and Berry, Eckert and Mauchly designed and built 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 ms, 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, ...)

Electronic Discrete Variable Automatic Computer (EDVAC)

- 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 (1944) to solve this problem
  - Solution was the *stored program computer*

    $\Rightarrow$ "*program can be manipulated as data*"
- *First Draft of a report* on EDVAC was published in 1945, but just had von Neumann's signature!
  - In 1973 the court of Minneapolis attributed the honor of *inventing the computer* to John Atanasoff

Stored Program Computer

Program = A sequence of instructions

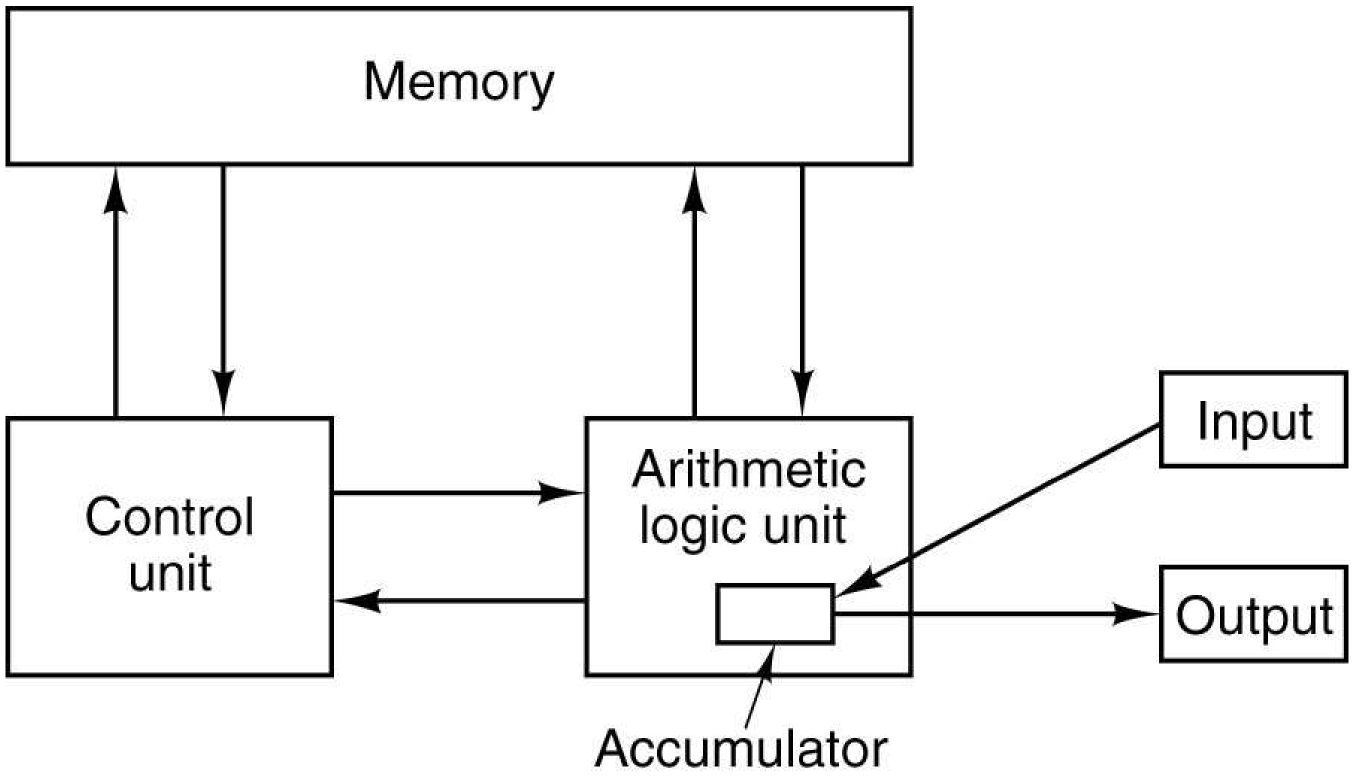
How to control instruction sequencing?

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

EDSAC 1950 Maurice Wilkes

Von Neumann Machine



The original Von Neumann machine.

Compatibility Problem at IBM

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

701	=>	7094
650	=>	7074
702	=>	7080
1401	=>	7010

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, ...

$\Rightarrow$ *IBM 360*

IBM 360

- IBM introduced a single product line, the System/360 (IC-based) to replace the 7094 and the 1401 product lines
- It was the initial offering of the IBM product line

Property	Model 30	Model 40	Model 50	Model 65
Relative performance	1	3.5	10	21
Cycle time (in billionths of a sec)	1000	625	500	250
Maximum memory (bytes)	65,536	262,144	262,144	524,288
Bytes fetched per cycle	1	2	4	16
Maximum number of data channels	3	3	4	6

IBM 360 : Design Premises

Amdahl, Blaauw and Brooks, 1964

- The design must lend itself to *growth and successor machines*
- General method for connecting I/O devices
- Total performance - answers per month rather than bits per microsecond => *programming aids*
- Machine must be capable of *supervising itself* without manual intervention
- Built-in *hardware fault checking* and locating aids to reduce down time
- Simple to assemble systems with redundant I/O devices, memories etc. for *fault tolerance*
- Some problems required floating-point larger than 36 bits

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!

IBM 360: Initial Implementations

	Model 30 . . .	Model 70
Storage	8K - 64 KB	256K - 512 KB
Datapath	8-bit	64-bit
Circuit Delay	30 nsec/level	5 nsec/level
Local Store	Main Store	Transistor Registers
Control Store	Read only 1µsec	Conventional circuits

IBM 360 instruction set architecture (ISA) completely hid the underlying technological differences between various models.

Milestone: The first true ISA designed as portable hardware-software interface!

With minor modifications it still survives today!

Milestones in Computer Architecture (1)

Year	Name	Made by	Comments
1834	Analytical Engine	Babbage	First attempt to build a digital computer
1936	Z1	Zuse	First working relay calculating machine
1943	COLOSSUS	British gov't	First electronic computer
1944	Mark I	Aiken	First American general-purpose computer
1946	ENIAC I	Eckert/Mauchley	Modern computer history starts here
1949	EDSAC	Wilkes	First stored-program computer
1951	Whirlwind I	M.I.T.	First real-time computer
1952	IAS	Von Neumann	Most current machines use this design
1960	PDP-1	DEC	First minicomputer (50 sold)
1961	1401	IBM	Enormously popular small business machine
1962	7094	IBM	Dominated scientific computing in the early 1960s
1963	B5000	Burroughs	First machine designed for a high-level language
1964	360	IBM	First product line designed as a family

Some milestones in the development of the modern digital computer.

Milestones in Computer Architecture (2)

Year	Name	Made by	Comments
1965	PDP-8	DEC	First mass-market minicomputer (50,000 sold)
1970	PDP-11	DEC	Dominated minicomputers in the 1970s
1974	8080	Intel	First general-purpose 8-bit computer on a chip
1974	CRAY-1	Cray	First vector supercomputer
1978	VAX	DEC	First 32-bit superminicomputer
1981	IBM PC	IBM	Started the modern personal computer era
1981	Osborne-1	Osborne	First portable computer
1983	Lisa	Apple	First personal computer with a GUI
1985	386	Intel	First 32-bit ancestor of the Pentium line
1985	MIPS	MIPS	First commercial RISC machine
1987	SPARC	Sun	First SPARC-based RISC workstation
1990	RS6000	IBM	First superscalar machine
1992	Alpha	DEC	First 64-bit personal computer
1993	Newton	Apple	First palmtop computer

Some milestones in the development of the modern digital computer.