



COMPUTER ARCHITECTURE

2 The evolution of computing machines

The evolution of computing machines and other devices for computation can be chronologically divided into five major groups:

- I. Period of mechanics from about 1600 →
 - Babbage: Analytical Machine
- II. Electro-mechanical computers from 1939 →
 - Zuse Z3, Harvard Mark
- III. First electronic computers 1945
 - ENIAC
- IV. Electronic stored program computers (1945 →)
 - EDVAC, the IAS
- V. The rapid development of computers after 1950

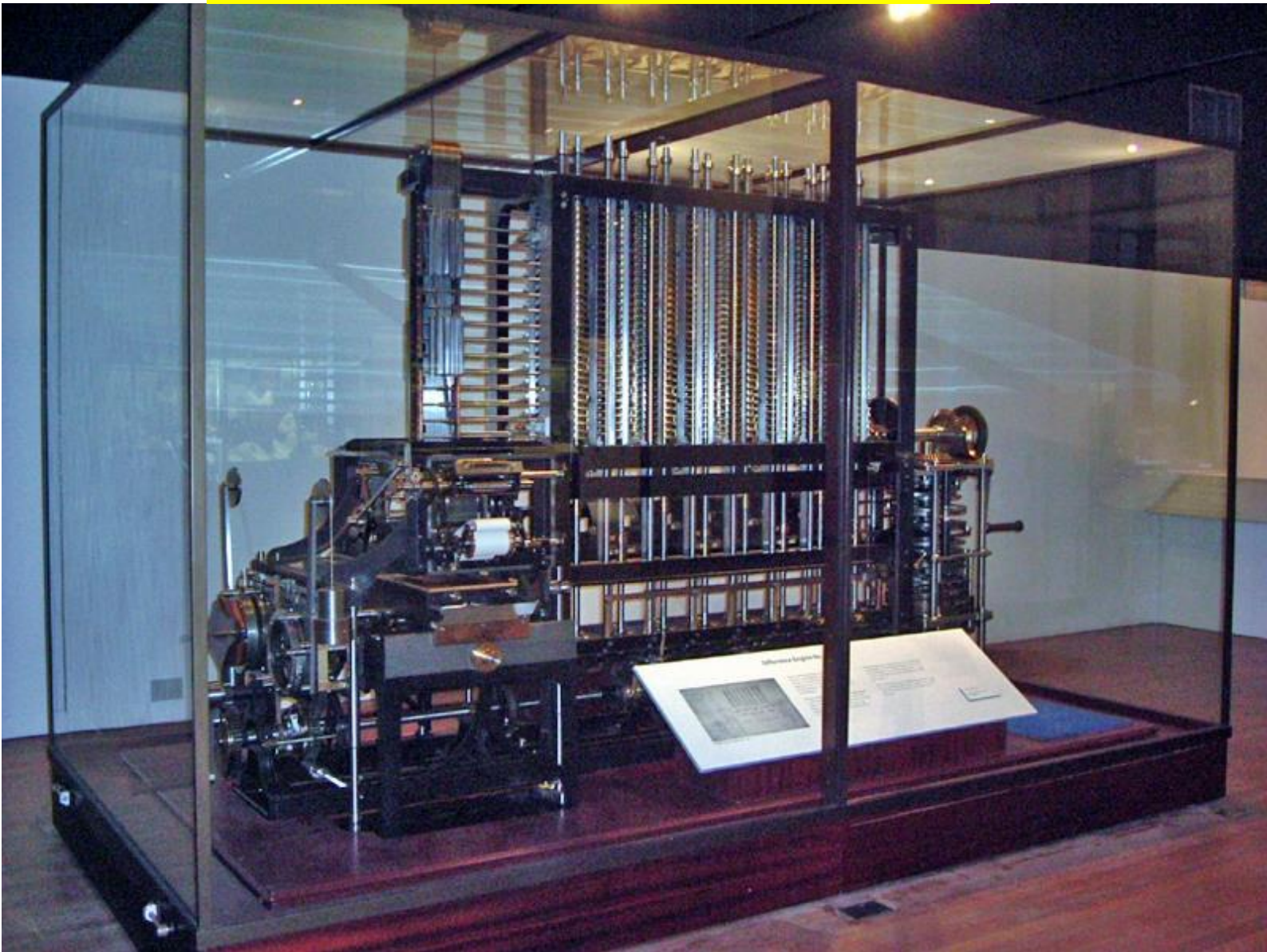
I. period of mechanics

- first calculators in the 17th century - mechanical, manually operated

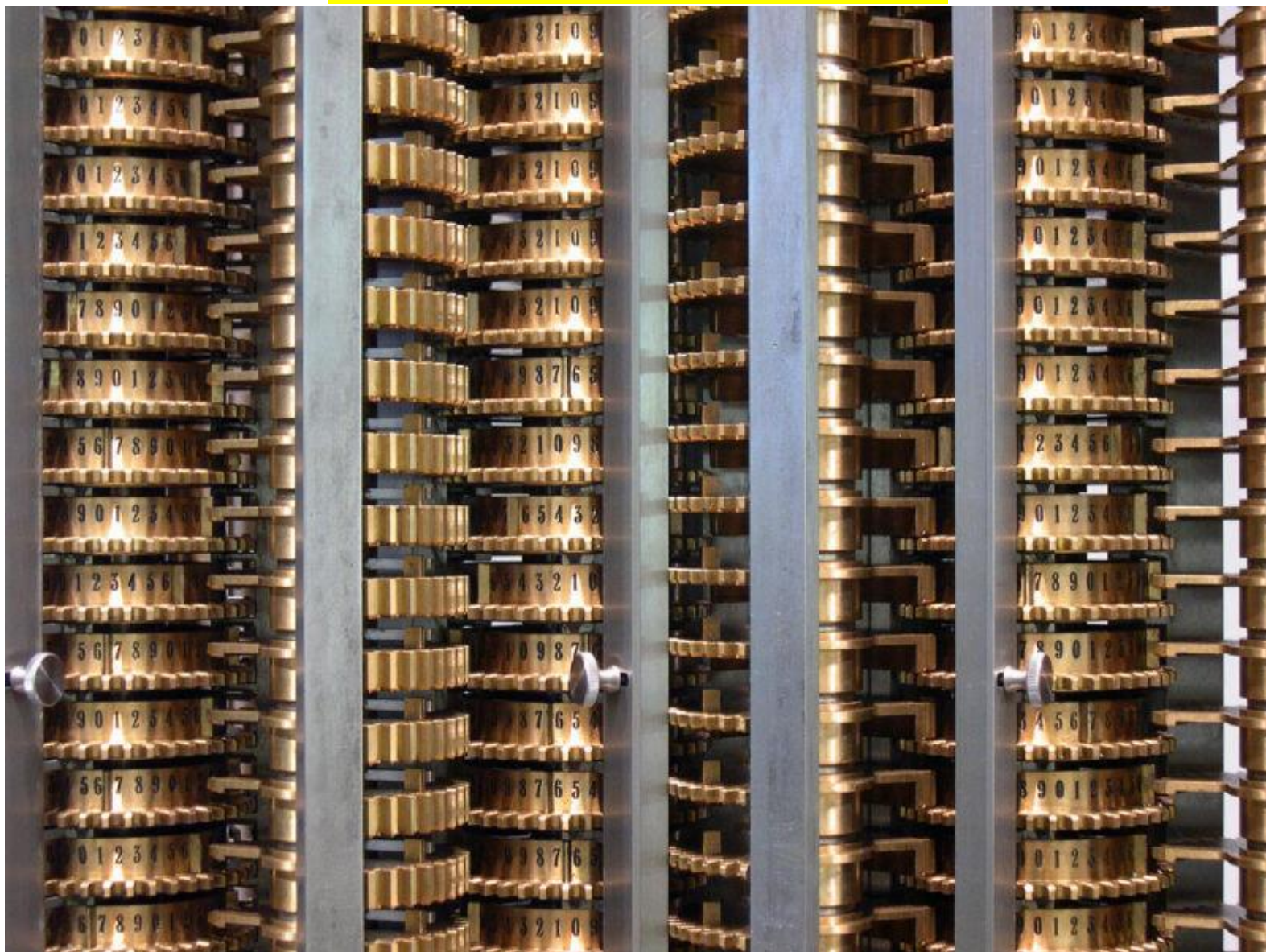
- Charles Babbage (1792 - 1871)
 - Differential machine (1823 - 1833)

 - **Analytical Machine (1834 - 1836)**
 - "The first real precursor of today's computers" ([Kodek])
 - It combines two important features:
 - Operation run by a program
 - It is designed to solve arbitrary problems
 - Never fully completed.

Differential machine 2 (London Science Museum)

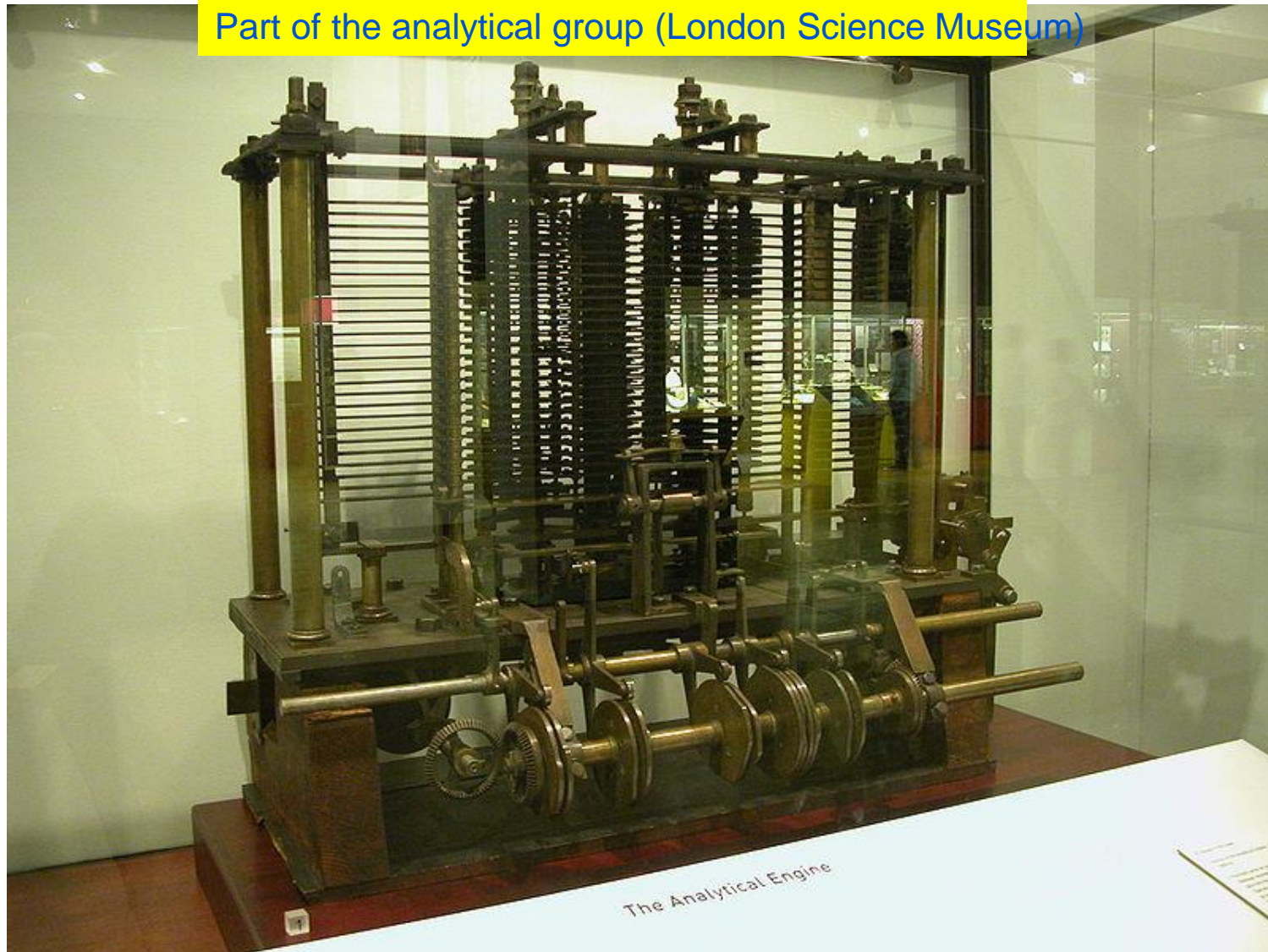


Differential machine 2 close-up picture



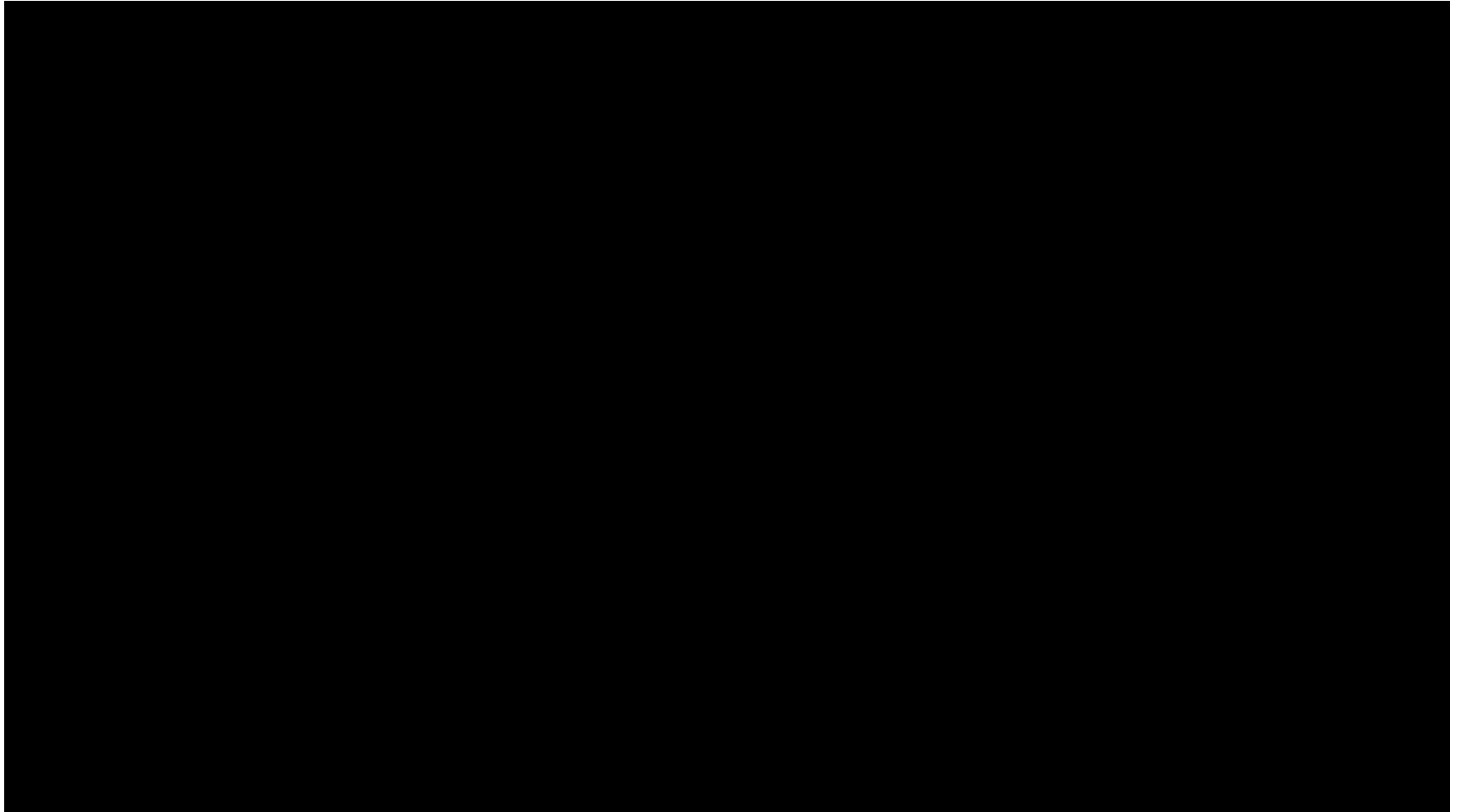
The development of computing machines - Period of mechanics

Part of the analytical group (London Science Museum)



Babbage: Analytical Machine

YT Video: [False Dawn: The Babbage Engine](https://www.youtube.com/watch?v=XSkGY6LchJs)



II. Electro-mechanical computers

- The development of electrical engineering has opened up new possibilities for the realization of computing machines
 - The drive the gears, **electric motors** are used (previously manually driven or by a steam engine)
 - In systems based on **punched cards** the presence or absence of holes is determined **electrically** and no longer mechanically
- Herman Hollerith: 1887 for the first time successfully used the device based on punched cards

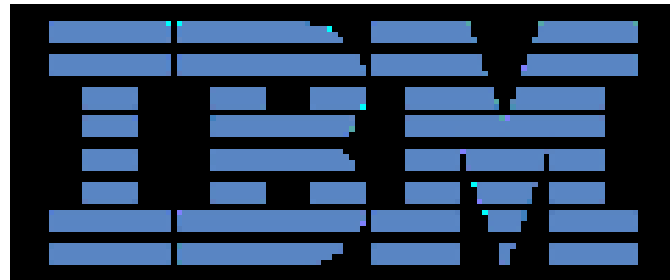
Hollerith machine used in the census
(Scott Beale's photostream)



- Hollerith has founded in 1896 Tabulating Machine Company. That was later joined with two more in 1924 and renamed in International Business machines Corporation - IBM



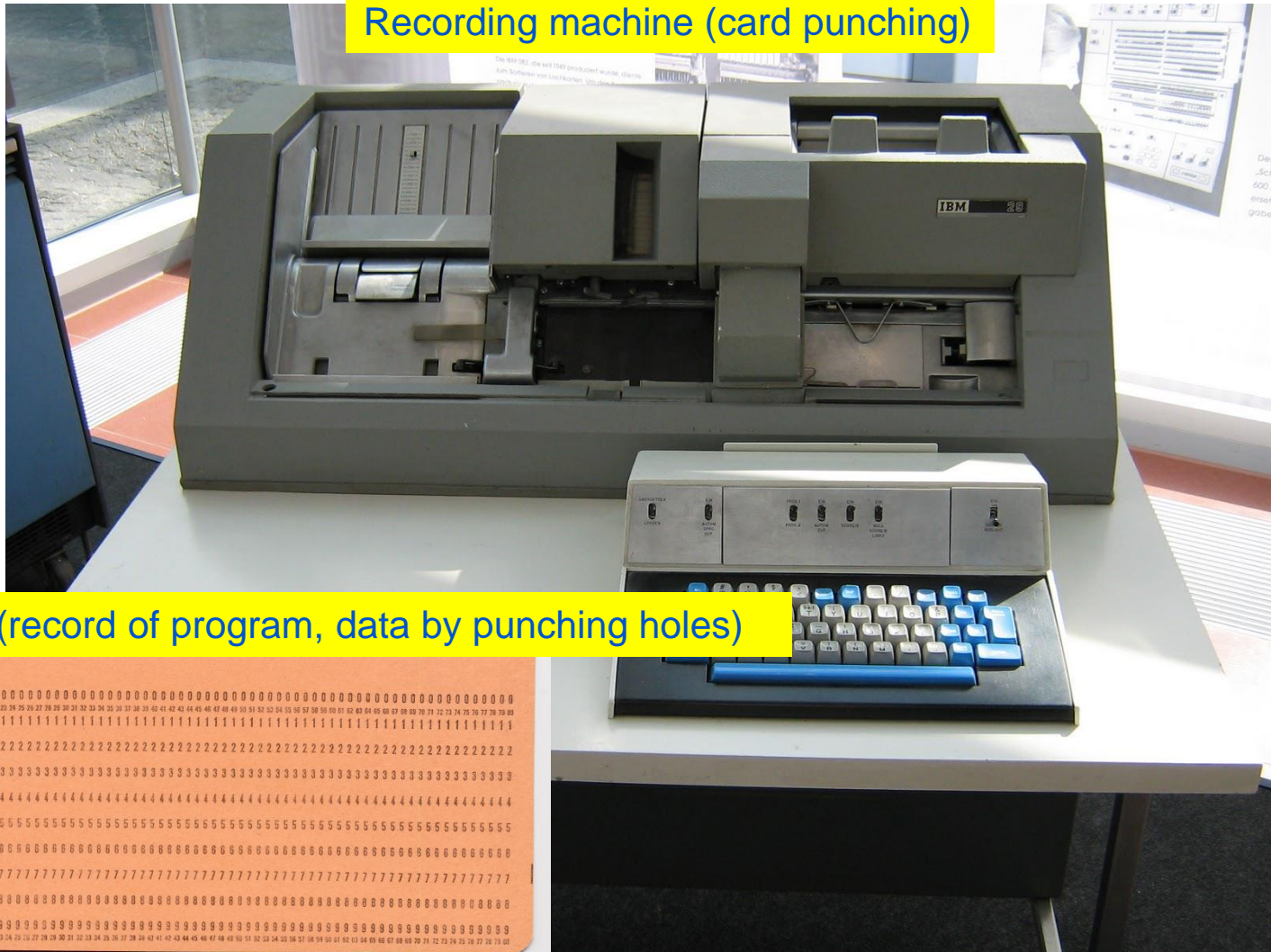
first logo of IBM company



logo used since 1972

The development of computing machines - Electromechanical machines

Recording machine (card punching)



Punched card (record of program, data by punching holes)

A machine for punching cards and card

■ Konrad Zuse (1910 - 1996):

□ **Z1** (1938)

- first working machine of Babbage's kind, although he did not know for Babbage's work - completely mechanical

□ **Z2**

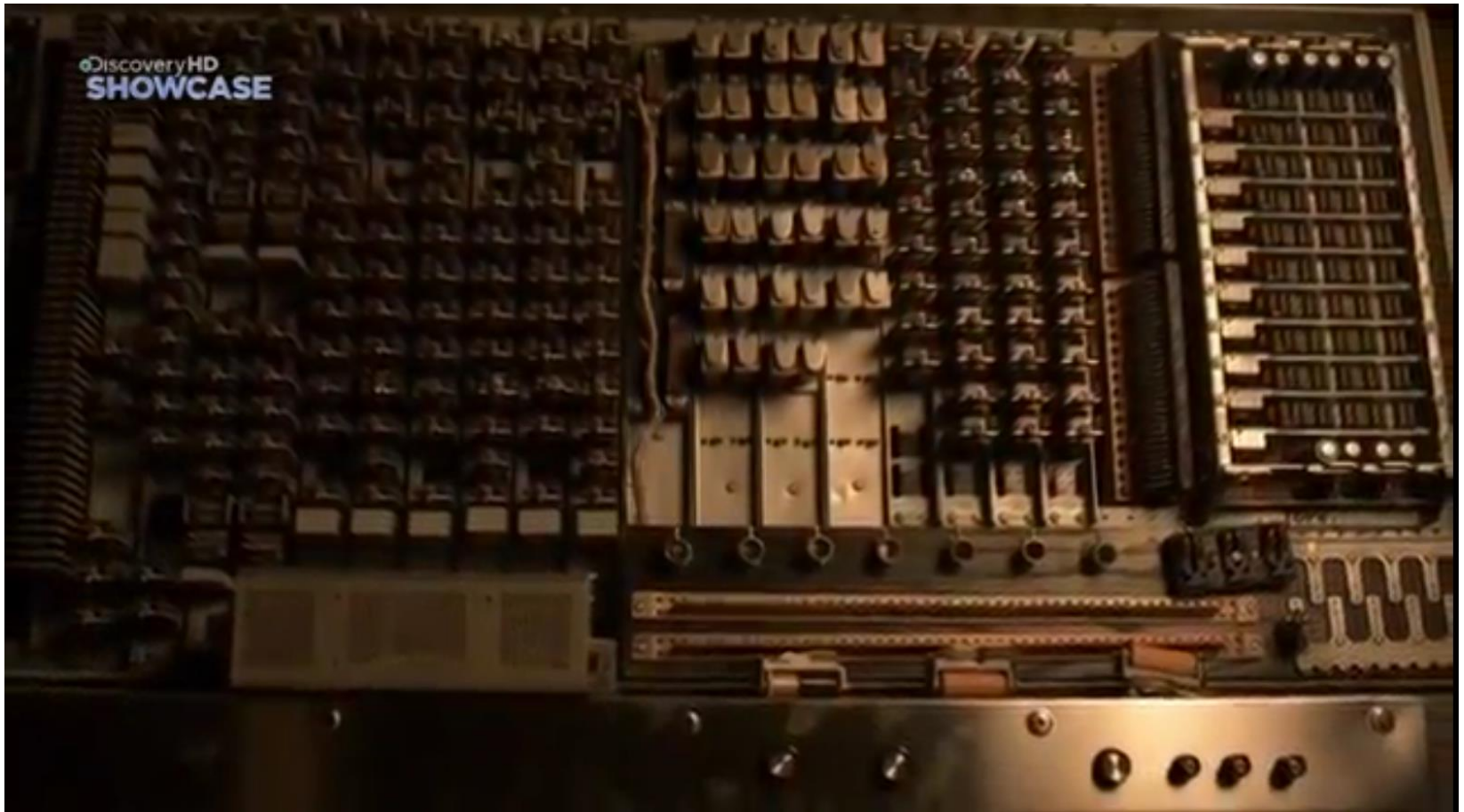
- arithmetical unit built with telephone relays, mechanical memory of the Z1 - unfinished

□ **Z3** (1941)

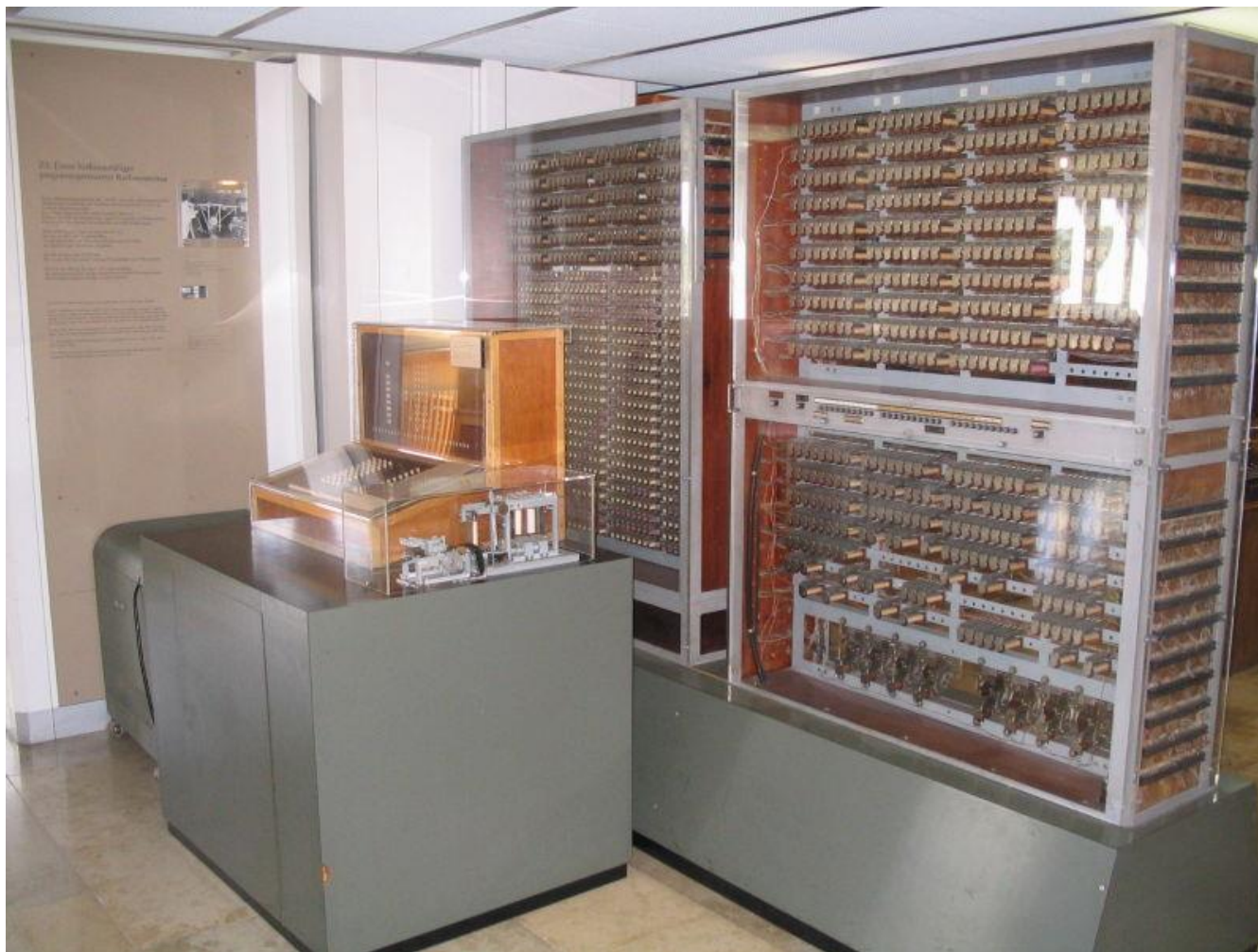
- first working **program guided electro-mechanical general purpose computer**
- used binary-based (not decimal-based) arithmetic
 - **2600 telephone relays**
 - relay memory consisting of **64 22-bit words**
 - 8-bit instructions stored **on a perforated tape**

Z3 in the Technical Museum Munich

Computer History - Z3



Z3 in the Technical Museum Munich



- Harvard **MARK I** completed in 1943 in the US, the machine **equivalent to Babbage's analytical machine**
 - Howard Aiken - physicist at Harvard University - unlike Zuse, he knew Babbage's work
- Followed by **MARK II, III and IV**
- Harvard Mark I and Zuse Z3 are similar machines:
 - Z3 - binary arithmetics
 - Harvard Mark I - decimal arithmetics
 - In both: **storage of instructions on a punched tape**

III. First electronic computers

- Relays replaced by electronic Tubes - switching time $5 \sim \mu\text{s}$
- The first attempt using tubes instead of relays was an analog computer (John Atanasoff, Iowa State University)
- Machines for the decryption of messages developed during World War 2 in Britain
- **ENIAC** (J. Mauchly and Eckert J., University of Pennsylvania - Moore School of Electrical Engineering)

- **ENIAC** (Electronic Numerical integrator and Calculator)
 - completed in 1945
 - ~ 500 to 1000 times faster than Mark I
 - The physical dimensions of 30m x 3m x 1m
 - 18,000 tubes, 150 relays, 140kW
 - Programming using switches (> 6000 switches) and connecting cables



IV. Electronic Stored program Computers

- Author of the idea of stored program computer is probably an American mathematician of Hungarian origin - John von Neumann (1903 - 1957)
- the idea **von Neumann** first published in 1945 in the proposal for a new electronic computer **EDVAC** (Electronic Discrete Variable Computer)

First Draft of a Report
on the EDVAC

by

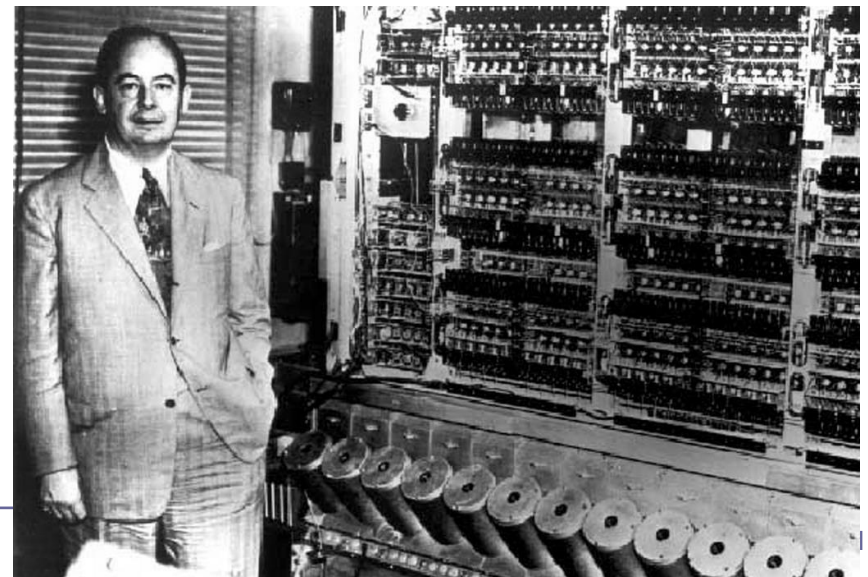
John von Neumann

Moore School of Electrical Engineering
University of Pennsylvania

June 30, 1945

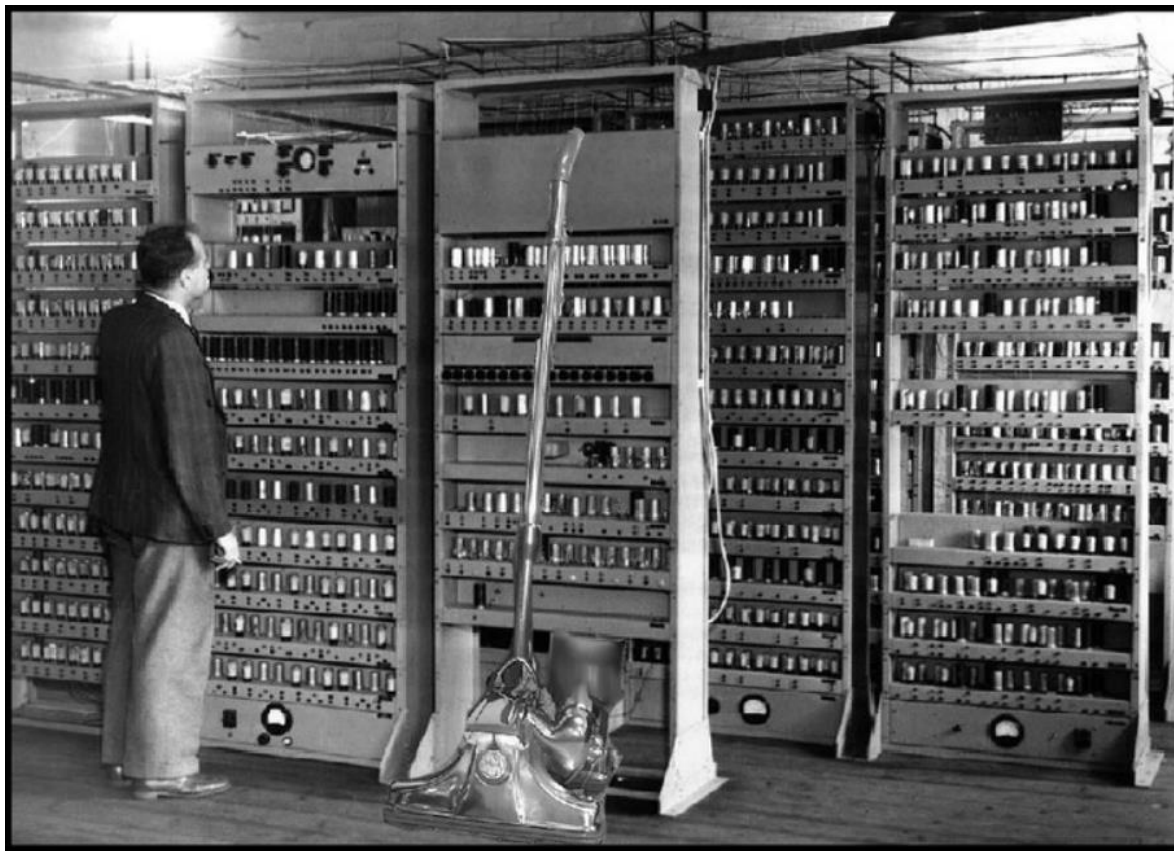
IAS and John von Neumann (Institute for Advanced Studies)

- EDSAC, EDVAC, IAS



- EDVAC (Electronic Discrete variable Computer)

- Completed in 1951 - the basis is the idea of a program stored in the memory



- EDSAC (Electronic Delay Storage Automatic Calculator)

- Completed in 1949 in Cambridge, England - the first operational stored-program computer – just before of EDVAC
- Introduction of the rule that is still followed nowadays :

If the instruction doesn't require otherwise (JUMP, GOTO instruction), instructions are read and executed in ascending address order

- IAS (acronym for Institute for Advanced Study)

- Parallel machine, approx. 10-times faster than ENIAC (EDVAC and EDSAC operated in serial order - a bit-by-bit)
- Random access memory
- Program Counter - register that contains the address of the next instruction

V. The rapid development of computers after 1950

- Development was more in a technological than architectural sense
- Since 1955, the tubes began to fade and were replaced by transistors
 - that are smaller, faster, more reliable
- Appearance of microprocessors 1971
- Personal computer IBM PC in 1980
- First ARM processor 1985 (RISC idea)
- First publication on RISC-V ISA 2011

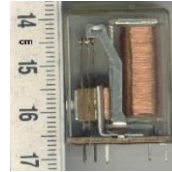
Prefixes for units of measurement

Abbreviation	Name	Value	Exponent (scientific notation)
p	pico	0,000 000 000 001	10^{-12}
n	nano	0,000 000 001	10^{-9}
μ	micro	0,000 001	10^{-6}
m	milli	0,001	10^{-3}
K	kilo	1 000	10^3
M	mega	1 000 000	10^6
G	giga	1 000 000 000	10^9
T	tera	1 000 000 000 000	10^{12}

Realization of switches as the basic building block - summary:

- Electro-mechanical switch

- 1939: Relay,



switching time

1-10ms

- Electrical switch

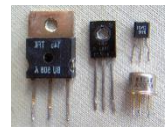
- 1945-1955: Vacuum tube,



switching time

~ 5 μ s

- 1955: Transistors → ,



switching time

~10ns

- 1958: Integrated circuit - chip,

switching time

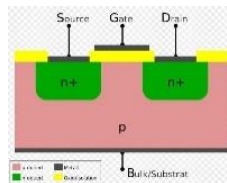
2-10ns

- 1980: VLSI integrated circuit

switching time

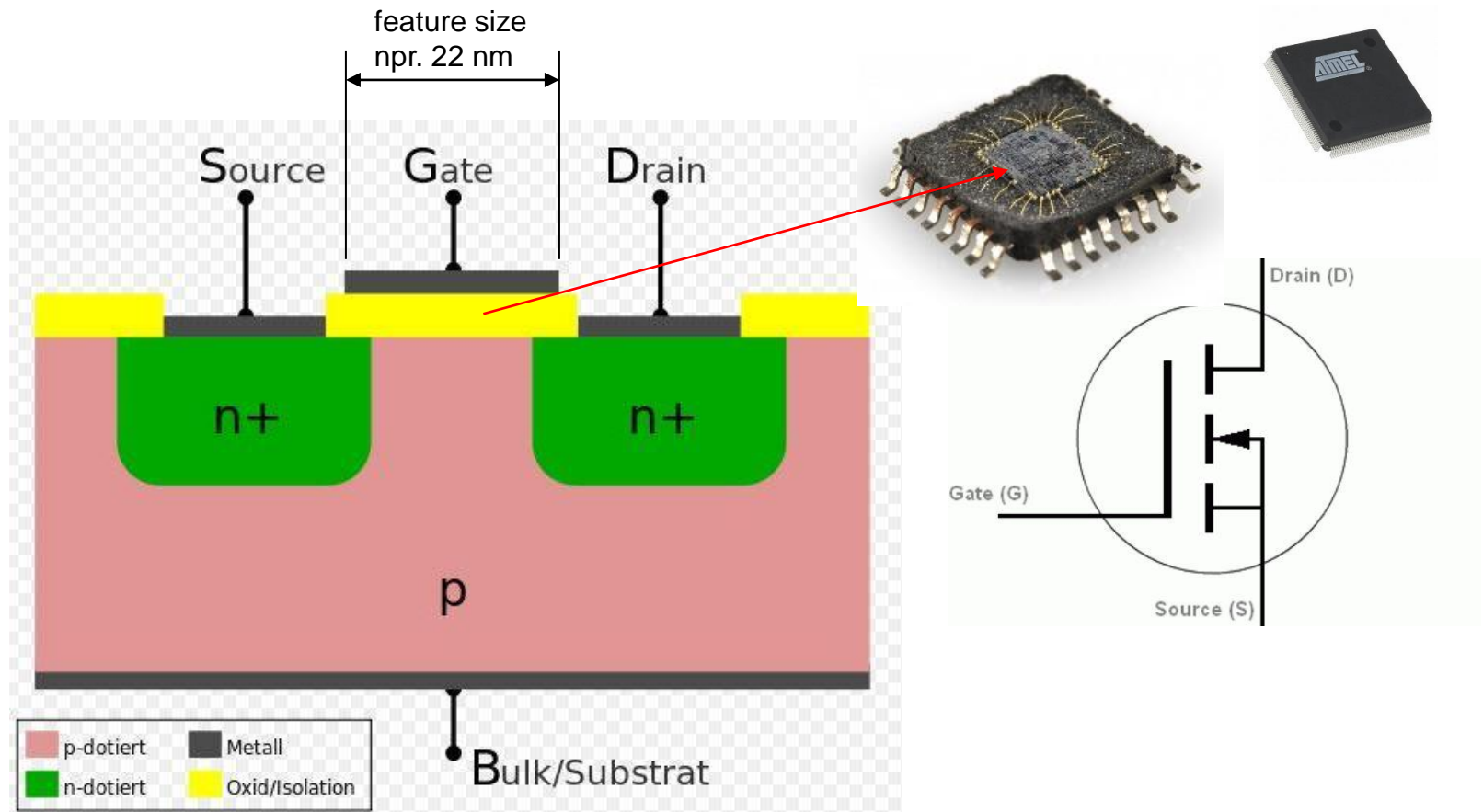
< 0.1ns

- Very Large Scale Integration



Stacked nanosheet FET

Transistors as a part of the integrated circuit VLSI



V. The rapid development of computers after 1950

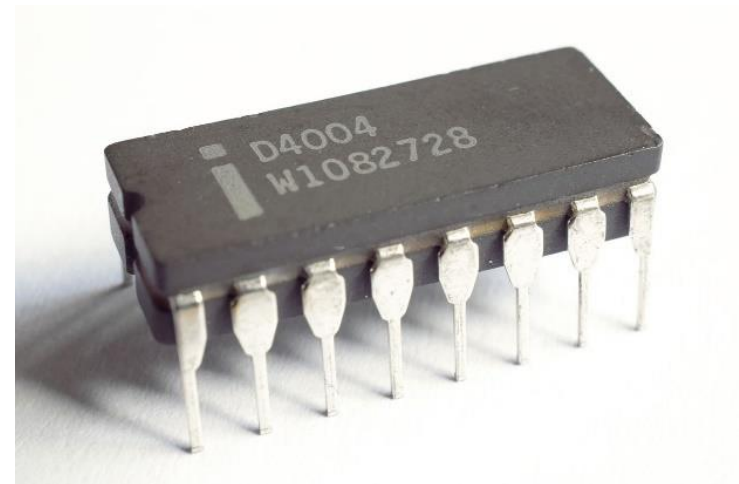
Milestones:

- I. Appearance of **microprocessors** 1971
- II. Personal computer **IBM PC** in 1980
- III. First **ARM** processor 1985
- IV. First publication on **RISC-V ISA** 2011

Milestone I: Microprocessors' appearance in 1971

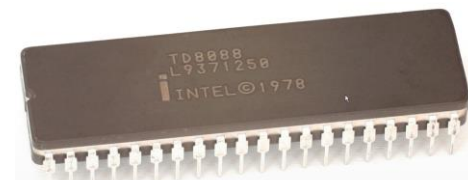
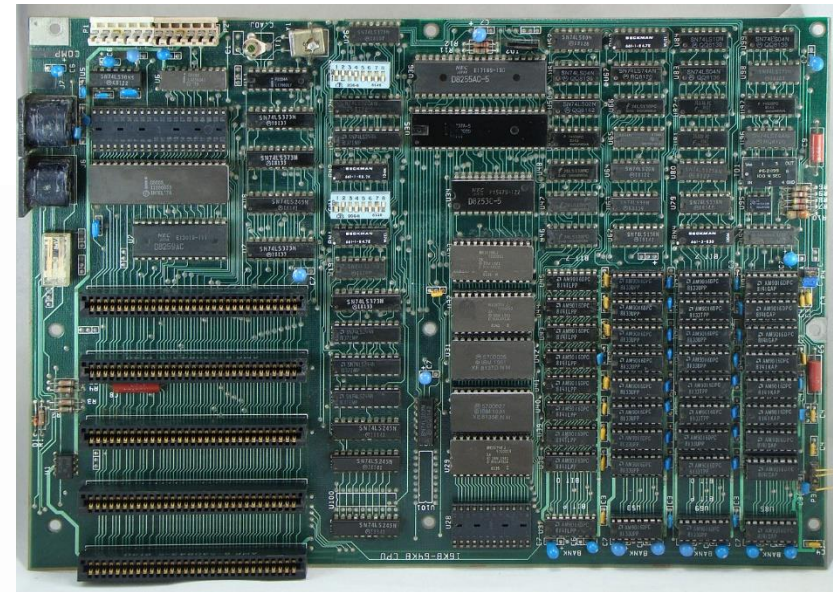
■ First microprocessor on one chip - Intel 4004 (1971)

- 2.250 transistors on board 3,2 x 4,2 mm
- feature size 10 μm = 10×10^{-6} m = 0,00001 m,
 - Human hair diameter approx. 100 μm)
- 16 pins
- Instruction execution in 10,8 μs (= 0,0000108 s) or 21,6 μs
- Power 1,0 W
- Price (projected in current time) \$26



Milestone II: Personal Computer IBM PC / XT Year 1983

- The Intel CPU 8088, clock frequency 4.77 MHz
 - x86 architecture (1st generation)
- Memory: from 128 KB to 640 KB
- One or two floppy disk units 5.25 "
- Hard disk with a capacity of 10 MB



Intel 8088

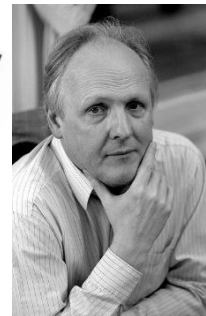
Milestone III : First ARM processor 1985

- ❑ 25000 transistors
- ❑ El. consumption 1W
- ❑ Implementation of RISC idea

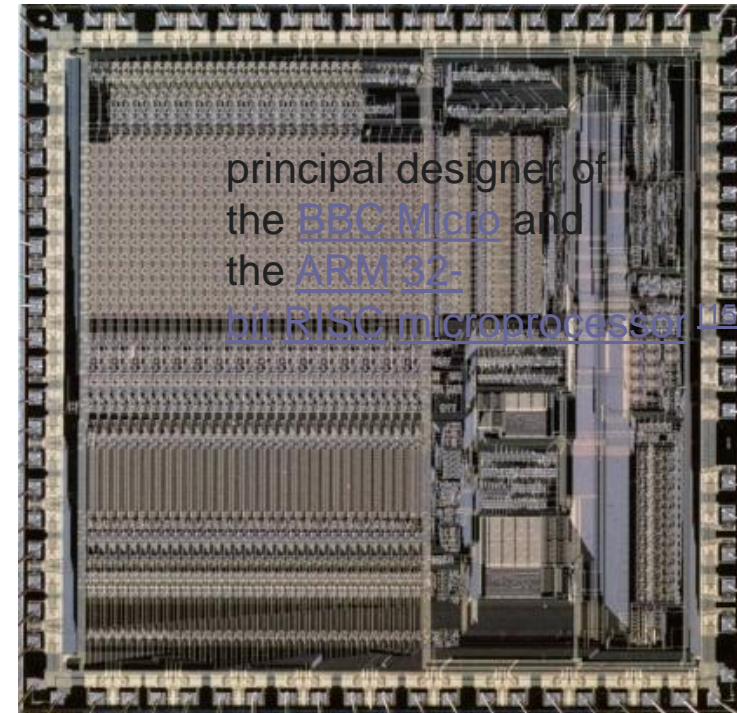


[Online simulation:](http://visual6502.org/sim/varm/armgl.html)

<http://visual6502.org/sim/varm/armgl.html>

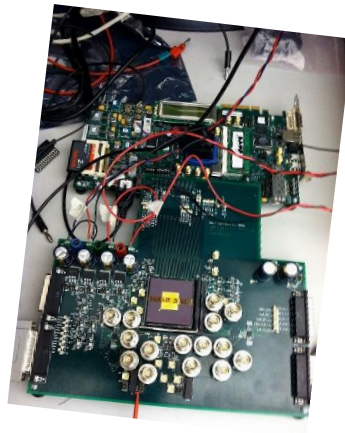


Steve Furber
principal designer of
the BBC Micro and
the ARM 32-
bit RISC microprocessor.^[15]



Milestone IV : First publication RISC-V ISA (2011)

- Truly opened idea, realization (BSD)



RISC-V is an open standard Instruction Set Architecture (ISA) enabling a new era of processor innovation through open collaboration

RISC-V enables the community to share technical investment, contribute to the strategic future, create more rapidly, enjoy unprecedented design freedom, and substantially reduce the cost of innovation

The RISC-V Instruction Set Manual, Volume I: Base User-Level ISA

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Electrical Engineering and Computer Sciences
University of California at Berkeley

Technical Report No. UCB/EECS-2011-62
<http://www.eecs.berkeley.edu/Pubs/TechRpts/2011/EECS-2011-62.html>

May 13, 2011

<https://riscv.org/about/history/>

IBM computer in 1130 - the first digital computer at the University of Ljubljana in 1971

