Computer Architecture (Fall 2022)

Introduction

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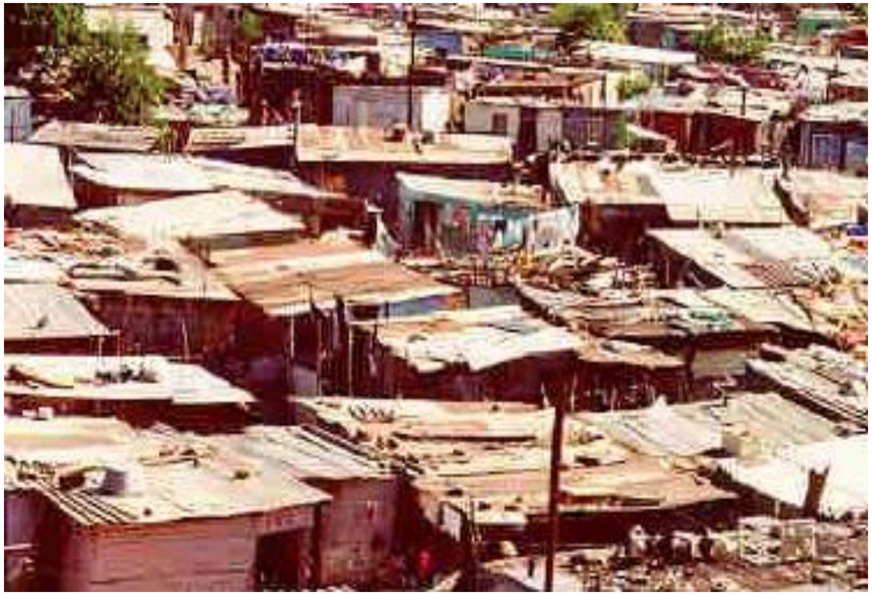
What is C&A?

- Computer architecture – The conceptual design and fundamental operational structure of a computer system.
  - CPU and Instruction Set
  - Access mode to memory
  - Components and their interconnection
  - …

Habitat '67, by Moshe Safdie, at Montreal, Canada, 1967 © Artifice, Inc

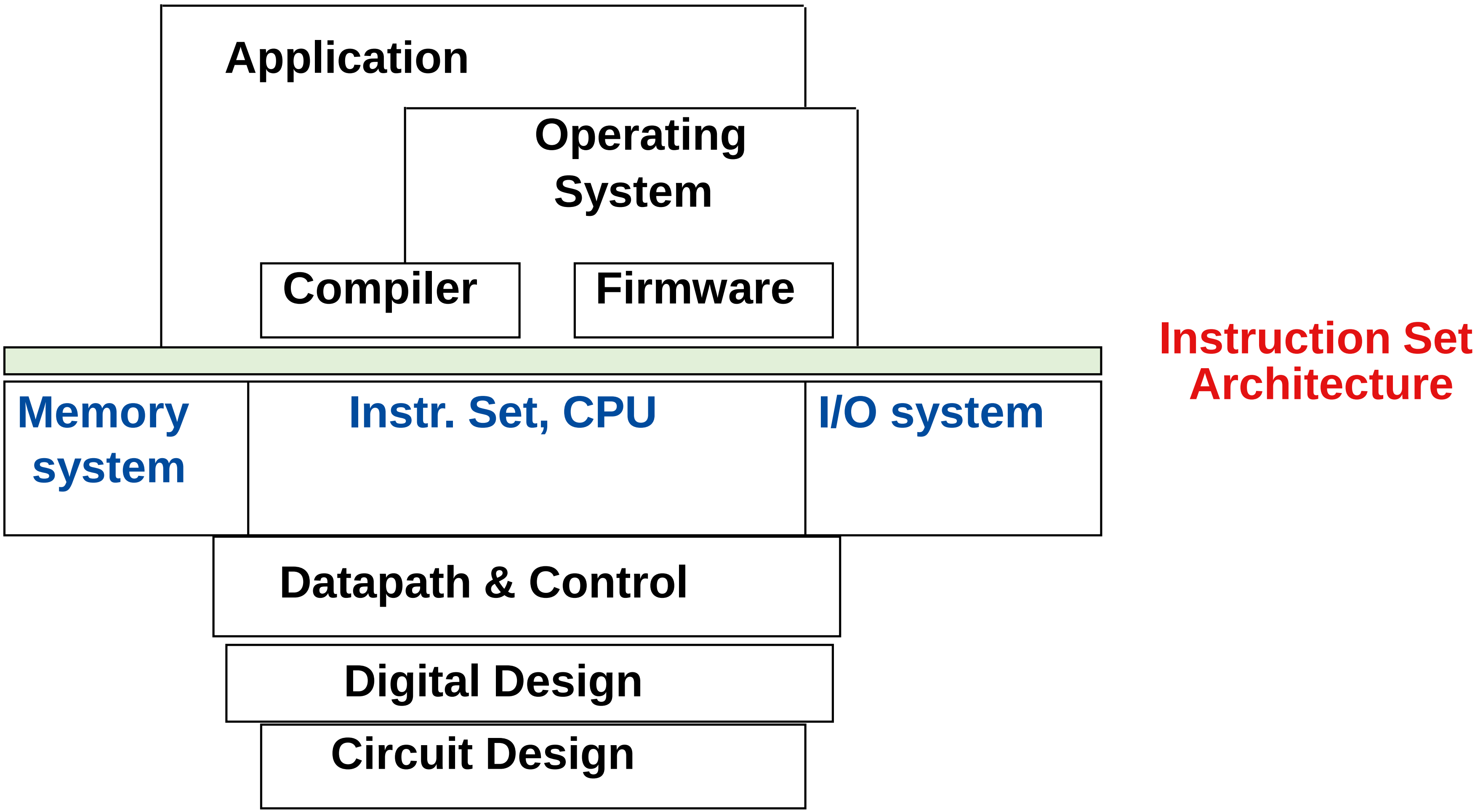


[Sangiovanni-Vincentelli Vincentelli 04]

What is C&A?

- Computer Architecture is those aspects of the instruction set available to programmers, independent of the hardware on which the instruction set was implemented.
- The term computer architecture was first used in 1964 by Gene Amdahl, G. Anne Blaauw, and Frederick Brooks, Jr., the designers of the IBM System/360.
- The IBM/360 was a family of computers all with the same architecture, but with a variety of organizations(implementations).

What is C&A? » Where "C&A" are?



02 What is C&A?

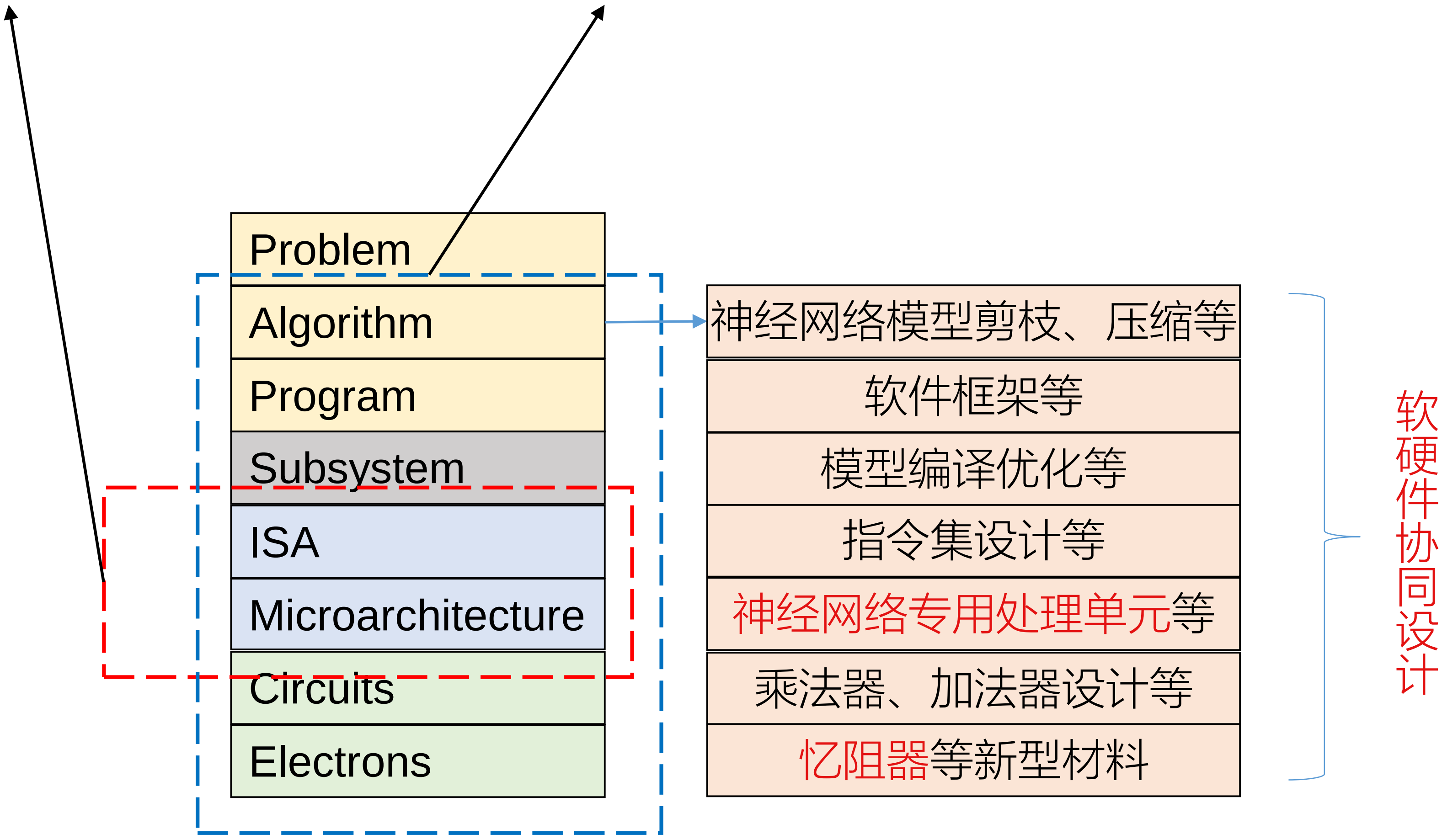
- "Old" view of computer architecture:
  - Instruction Set Architecture (ISA) design
  - i.e. decisions regarding:
    - registers, memory addressing, addressing modes, instruction operands, available operations, control flow instructions, instruction encoding

- "Real" computer architecture:
  - Specific requirements of the target machine
  - Design to maximize performance within constraints: cost, power, and availability
  - Includes ISA, microarchitecture, hardware

Where “C&A” are?

Narrow Defination

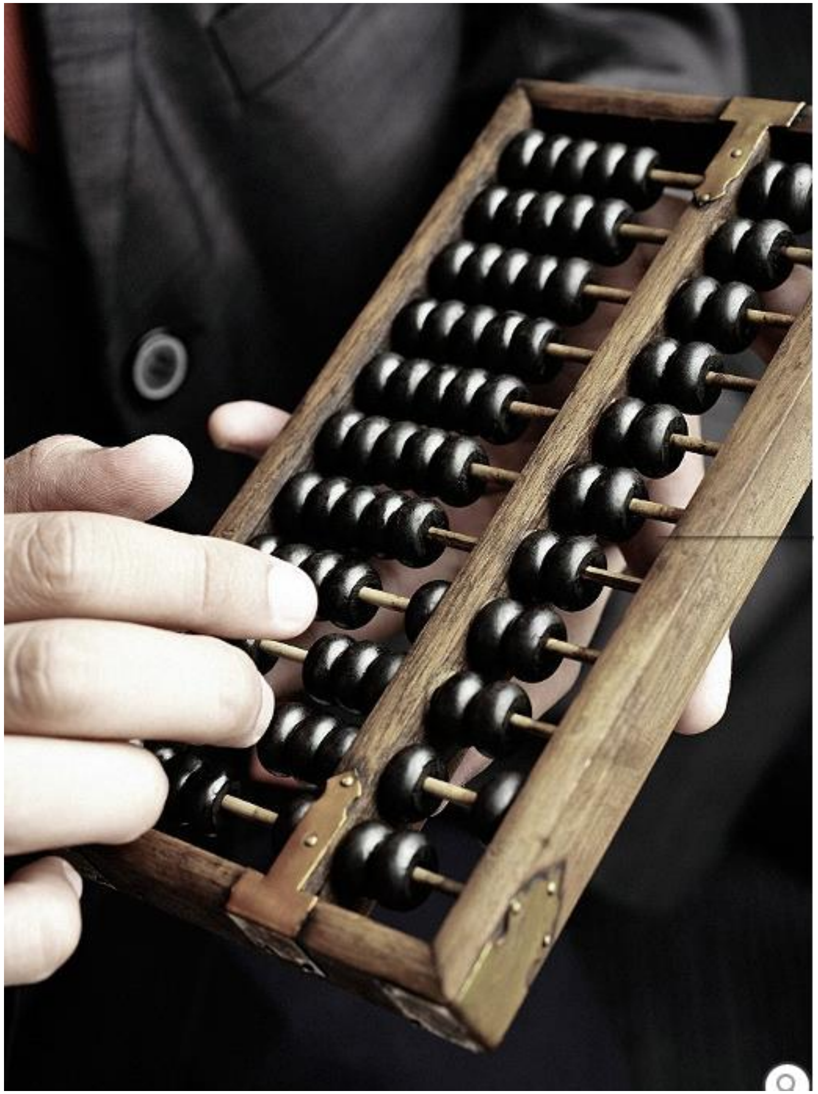
Broad Defination



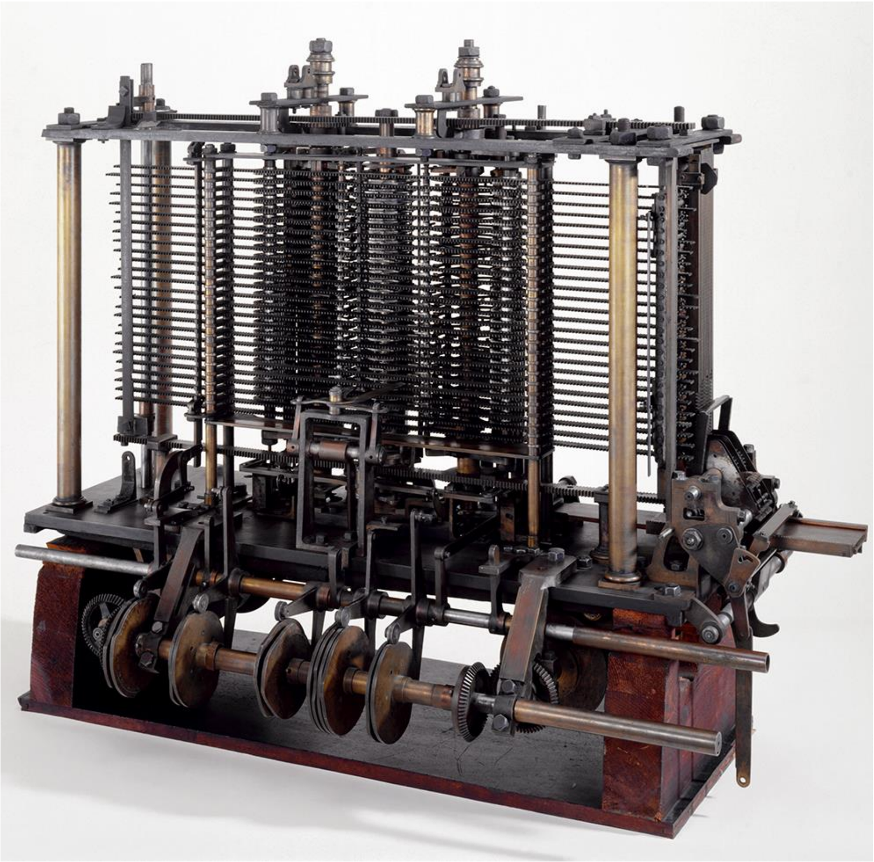
Mathematical Tools

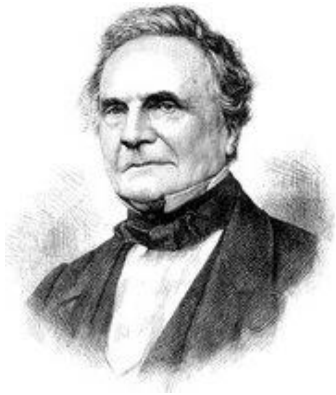
- Throughout the history of calculating we've devised ways to add speed and accuracy while subtracting the drudgery. Many solutions used body parts, notably fingers. A 19th century Chinese technique can count to 10 billion using just two hands!

- Other solutions were mechanical -- both general-purpose tools for everyday calculations and specialized instruments for engineering, navigational, or other scientific and technical problems.



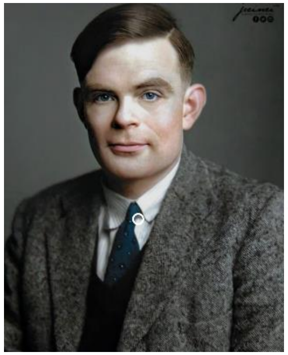
History: Analytical Engine (1883)

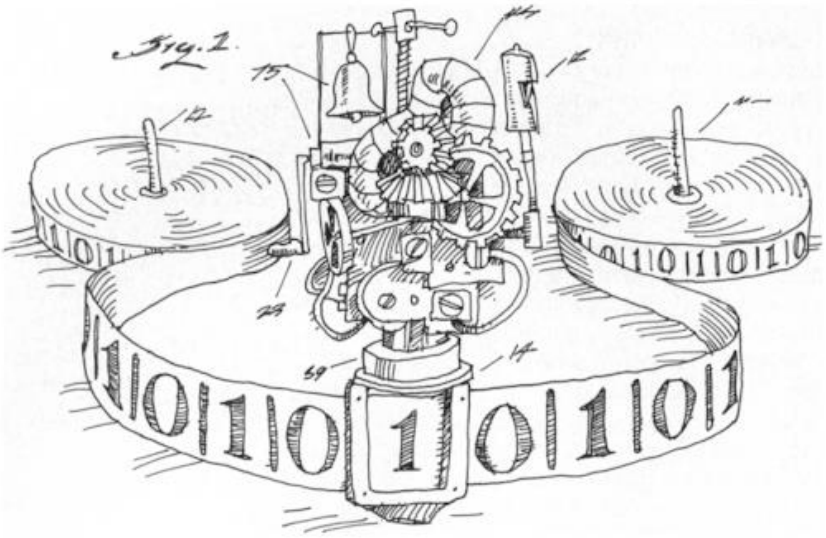


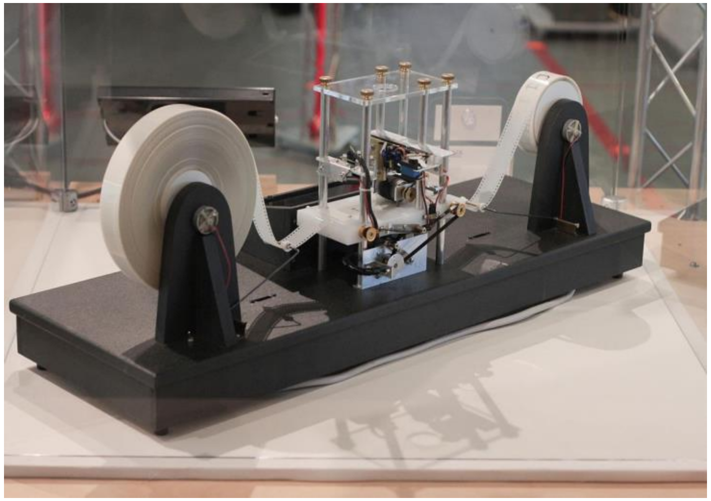


- Charles Babbage (1791-1871, UK)
- Made by mechanical parts.
- Started in 1833; never finished.

Turing Machine (1937)



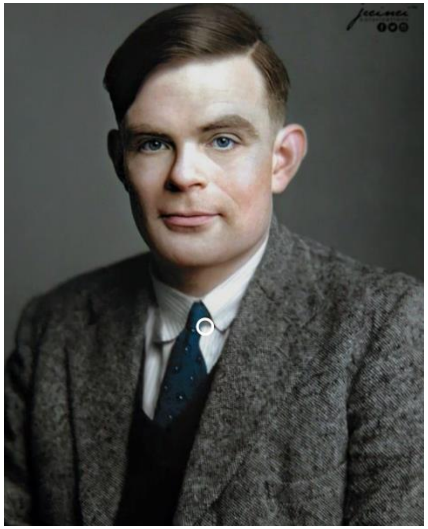




- **A theoretical computing machine, the basis of modern computing.**
  - Theoretically, as powerful as any other computer
  - Conceptually, a finite set of states, a finite alphabet and a finite set of instructions.
  - Physically, it has a head (read, write), and move along an infinitely long tape that is divided into cells storing a letter.

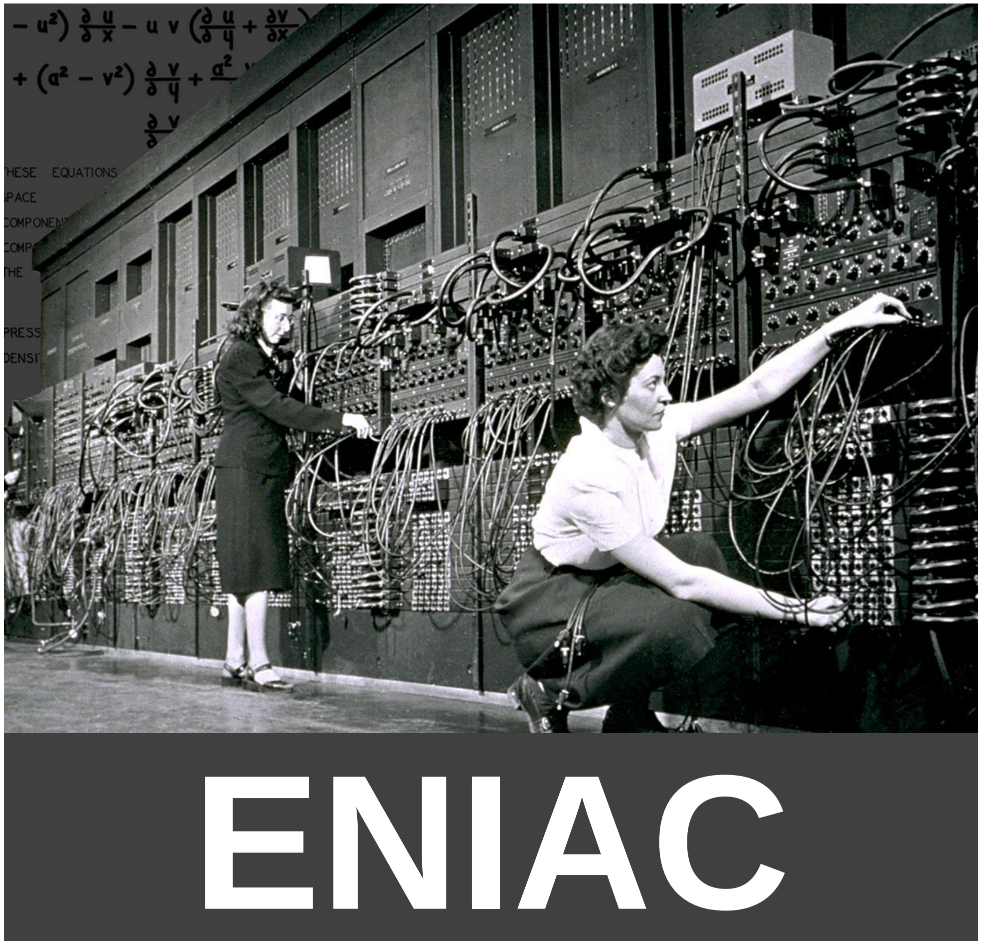
Stored-program Concept (1945)

John von Neumann and Alan Turing, proposed the stored program concept in the 1940s.



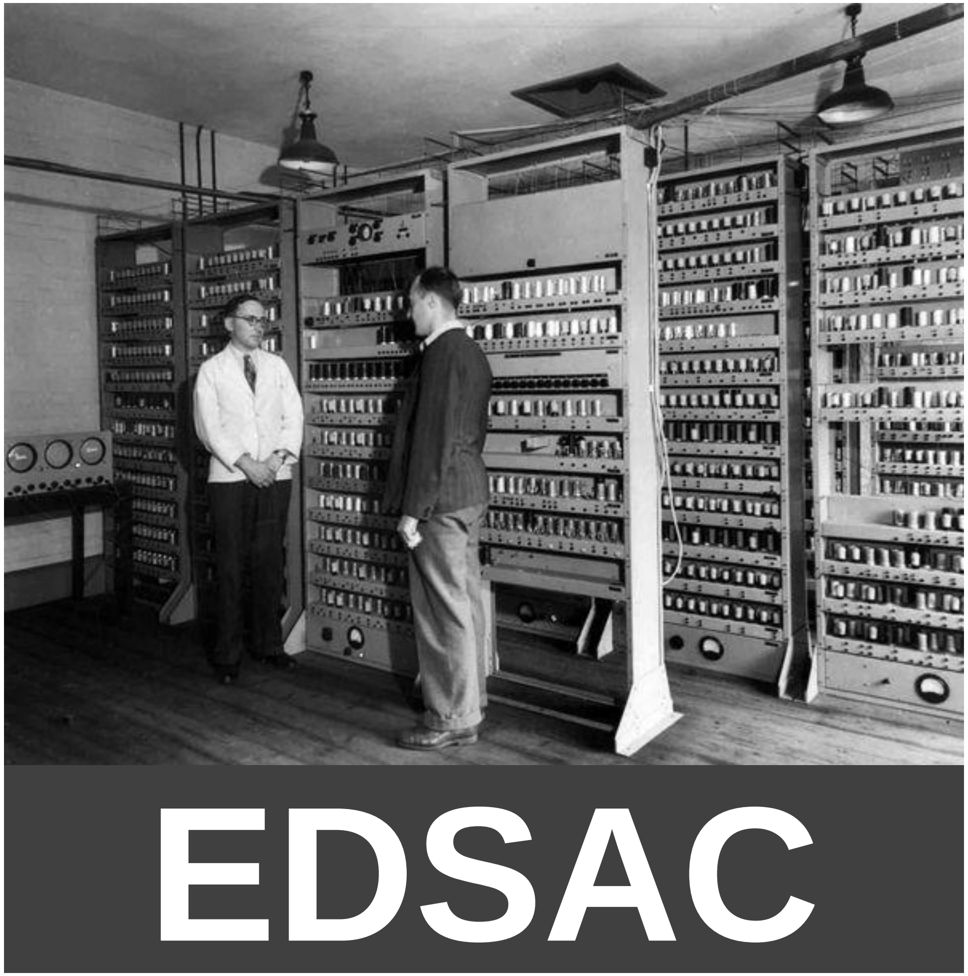
- Store program and data in memory
- A computer can read them from memory.
- Program can be altered.

1st Electronic Computer (1946)



- J. Eckert and J. Mauchly at Univ. of Pennsylvania
- 18,000 vacuum tubes
- 80 feet long; 8.5 feet high and several feel wide.
- 1,900 additions/sec

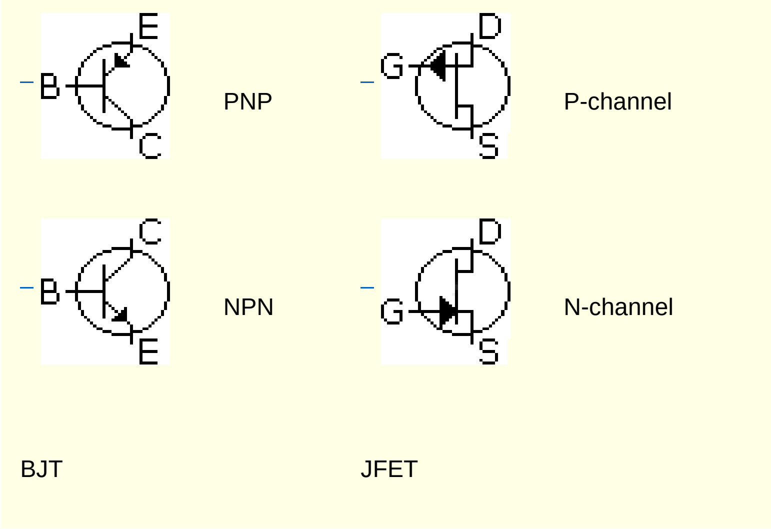
1st Full-Scale Stored-program Machine (1949)



- Maurice Wiles at Cambridge University
- 1st stored-program machine.
- 600 instructions/sec
- Occupied a room 5m by 4m

Transistor (1947)

- Solid State device made from Silicon (Sand)
- Act as a variable valve: based on its input current (BJT) or input voltage (FET), *allows* a precise amount of current to flow through it from the circuit's voltage supply.
- Invented by John Bardeen, Walter H. Brattain, and William B. Shockley, awarded the Nobel Prize in physics in 1956.
- Smaller and cheaper with less heat dissipation



IBM 7094 (1962)

- Made by transistors (invented at Bell Lab in 1947).
- Manufacture components separately and then wire together onto circuit board.
- 10,000 transistors
- Clock Cycle = 2 us (500 KHz)
- 32 K Memory
- Price: $3M.

1st Electronic Computer (1946)

Assemble discrete components mode from separate pieces of silicon into a circuit board

Easy Extension

Fabricate an entire circuit in a piece of silicon

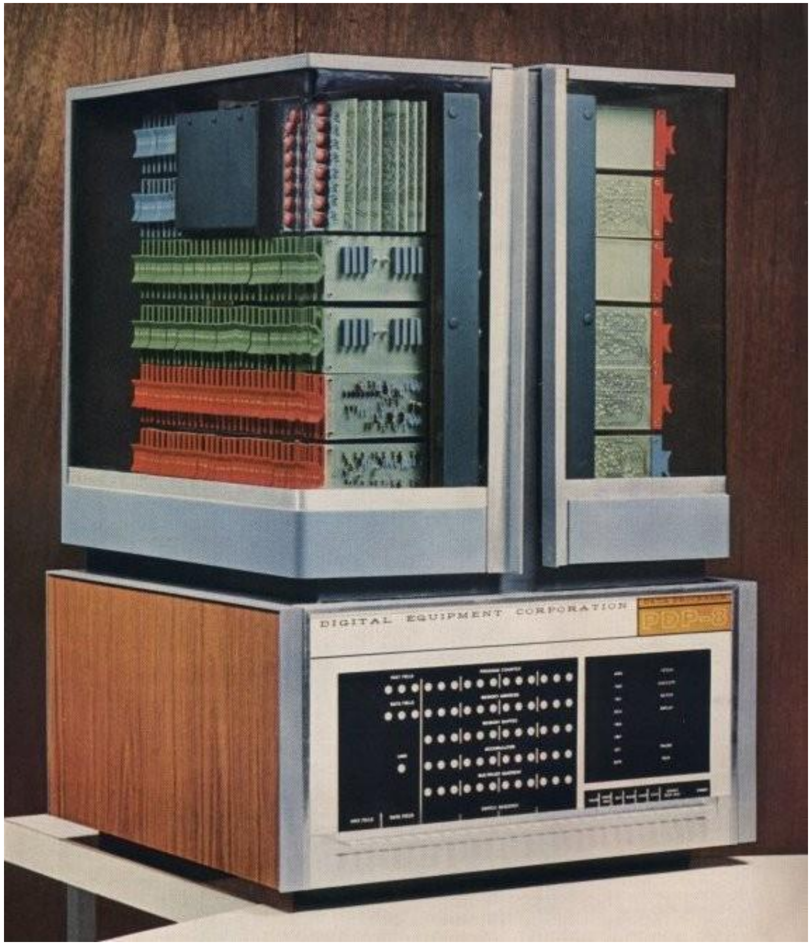
- The cost of a chip virtually unchanged with the growth in density.
- Components are placed closer, the electrical path is shorten so the speed and capacity are increased.
- Computers become smaller
- Reduction in power and cooling requirement
- The interconnection is much more reliable than solder connections.

IBM System/360 (1964)

- A line of computers: the first planned family of computers (mainframe).
- Made by Integrated Circuits.
- Four models varied in cost and performance.

Model No.	Clock Rate	Memory Size	Price
40	1.6 MHz	32-256KB	$225,000
50	2.0 MHz	128-256KB	$550,000
65	5.0 MHz	256KB-1MB	$1,200,000
75	5.1 MHz	256KB-1MB	$1,900,000

PDP-8 (1965): The 1st Minicomputer



- Made by Integrated Circuits.
- Price: $16,000, cheap enough for each lab technician to have one.
- 500K Instruction/s (0.5 MIPS)
- 8 Cubic Feet

1993年的海报，现在上面所有设备都被一部手机代替。

Moore's Law (1965)

- **In 1965, Moore predicted that the number of transistors that could be put on a single chip will be doubling every year.**

- **The pace slowed to a doubling every 18 months in 70s.**

- **Moore's Law turns 40. What is its future?**
  - From a theoretical point of view, silicon transistors could continue to be shrunk until about the 4-nanometer manufacturing generation, which could appear about 2023.
  - At that point, the source and the drain, which are separated by the transistor gate and gate oxide, will be so close that electrons will drift over on their own.

Moore's Law (1965)

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip

By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor division of Fairchild Camera and Instrument Corp.

- Number of transistors per chip is $1.59^{year-1959}$ (originally $2^{year-1959}$)
- Classical scaling theory (Denard, 1974)
  - With every feature size scaling of n
    - You get $O(n^2)$ transistors
    - They run $O(n)$ times faster
- Subsequently proposed:
  - "Moore's Design Law" (Law #2)
  - "Moore's Fab Law" (Law #3)

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

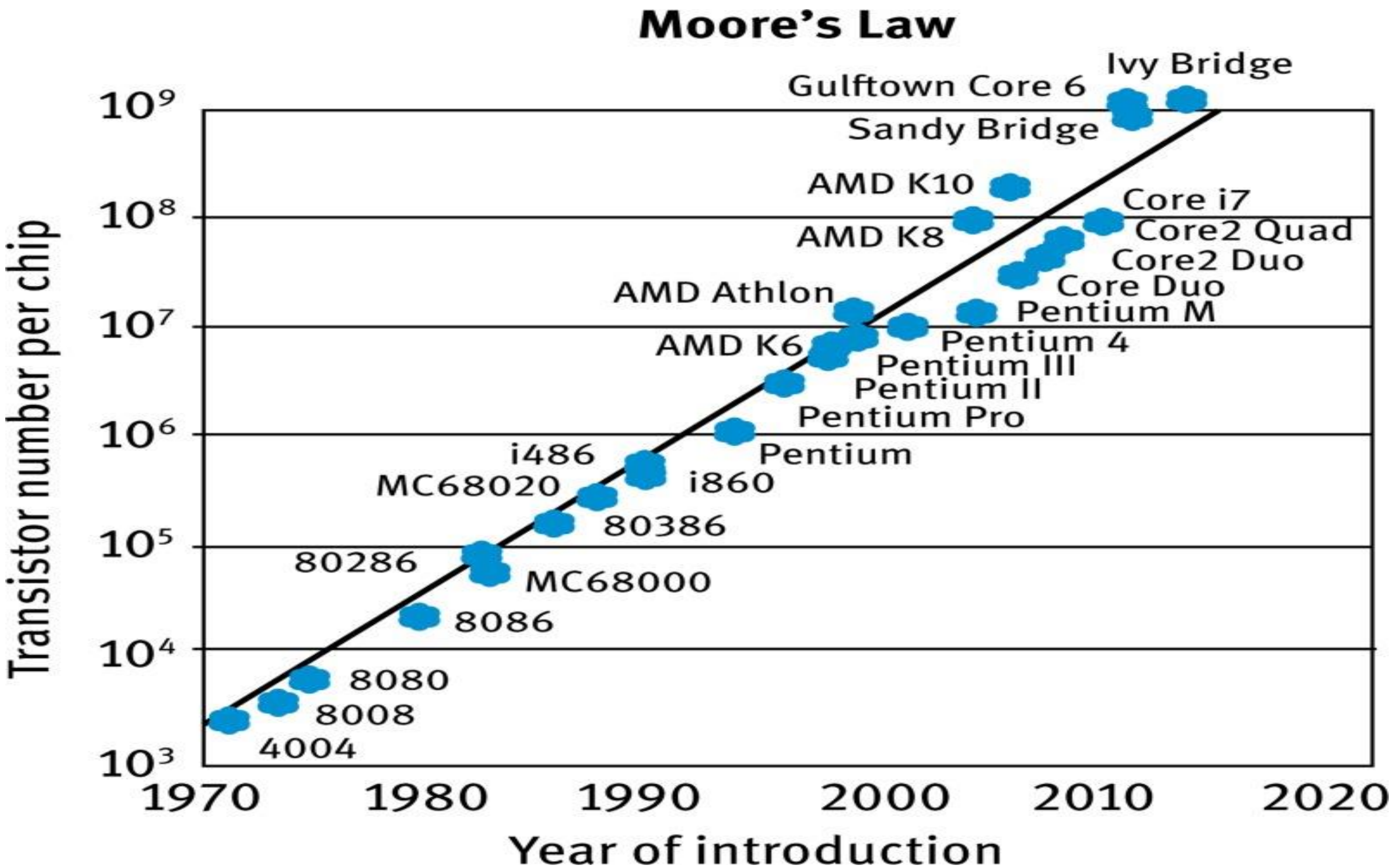
Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wrist-

machine instead of being concentrated in a central unit. In addition, the improved reliability made possible by integrated circuits will allow the construction of larger processing units. Machines similar to those in existence today will be built at lower costs and with faster turn-around.

Present and future

By integrated electronics, I mean all the various technologies which are referred to as microelectronics today as

Moore’s Law » [Intel Microprocessors]



https://www.ncbi.nlm.nih.gov/books/NBK321721/figure/oin_tutorial.F3/

The Chip Manufacturing Process