



université
PARIS-SACLAY



ESSEC
BUSINESS SCHOOL

COMPUTER ARCHITECTURE AND SOFTWARE EXECUTION PROCESS

INTRODUCTION TO COMPUTER ARCHITECTURE

🎓 Bachelor in Artificial Intelligence, Data and Management Sciences
🏛️ CentraleSupélec and ESSEC Business School - 2024/2025



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IDIR AIT SADOUNE



- **Associate-Professor** at the Computer Science Department of [CentraleSupélec - Paris-Saclay University](#).
 - ➡ Teacher of Algorithmic and Complexity, Object-Oriented design and programming, Software Engineering, Operating Systems, Modelling and Verification using Formal Methods, etc.
 - ➡ Engineering program, Bachelor program, ...
- **Researcher** at the [Model](#) and [Proof](#) Teams of [LMF - Formal Methods Laboratory](#) of Paris-Saclay.
 - ➡ [PhD thesis in Computer Science](#) graduated from [ENSMA](#) in 2010 about [formal modelling](#) and [verifying](#) Services compositions.
 - ➡ My research activities address the use of [formal methods](#) for modelling and verifying systems using [refinement](#) and [proof-based approaches](#).

OUTLINE

- Description of the course
- Introduction to computer systems
- Representation of data in computer systems
- Machine Language

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LEARNING OUTCOMES AND ASSESSMENT

Main objective → Demystify the computer and its components.

- Analyze the **main components of a computer** and their role.
 - processor, memory, input/output devices, ...
- Describe the **organization** and operation of these entities.
 - how a processor, memory or other components work...
- **Understanding Program Execution.**
 - how does the processor understand and execute a Python program?

SYLLABUS

Chapter	Lecture	TD	Lab
Computer Architecture → Introduction	1h30		
Operating systems	1h30		
Data representation	1h30	1h30	
Internal Architecture of Microprocessors	1h30	1h30	6h00
Memory management	1h30	1h30	

Assessment of learning outcomes

- The practical exam during the Lab sessions (**40%**)
- The final exam (**60%**)

COMMUNICATION ORGANISATION

- Course website → centralesupelec.edunao.com
- You can ask me your questions before, during and after the sessions.
- You can contact me outside of the class hours.
 - ➡ using email → idir.aitsadoune@centralesupelec.fr
 - ➡ remotely by → [MS TEAMS](#)

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COMPUTER SCIENCE

- Computer science is the science of **automatic information processing**.
- Automatic processing of information is done with **programs** executed by **machines**.
 - **programs (software)** describe the process to be executed,
 - **machines (hardware)** run **programs**.



THE CONCEPT OF COMPUTER



The computer is a machine that can be **programmed** to execute a **sequences of operations automatically**.

- ➡ we give him **program** (software)
- ➡ we give him **data** (information)
- ➡ the computer **transforms the data** by using the **program**

THE CONCEPT OF COMPUTER



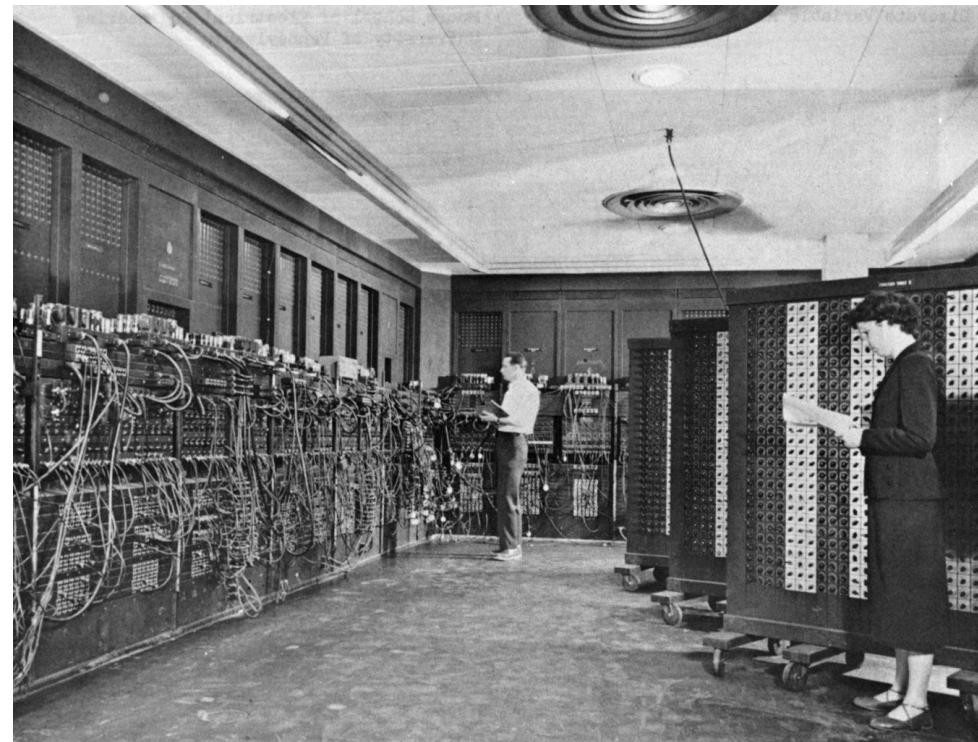
- But today a computer does much more than that ...
- Solve **problems** following a **program**.
 - **Program** → a sequence of instructions describing how the problem is to be solved.
- Two categories of computers
 1. personal computer or **PC**
 2. **embedded system**

COMPUTER ARCHITECTURE ?

- **Architecture**
 - a general term to **describe** buildings and other **physical structures**
 - the art and **science** of **designing structures**
- **Computer**
 - a machine that can be **programmed** to execute **sequences of operations automatically**.
(personal computer (PC), computer on board an airplane, TV, smartphone, ...)
- **Computer Architecture**
 - a description of the structure of a computer system.

ENIAC - 1945

- was designed in 1945 by John Mauchley and John Eckert at the University of Pennsylvania.
- was the first programmable, electronic, general-purpose digital computer.
- was a large, modular computer with individual panels performing different arithmetic functions.



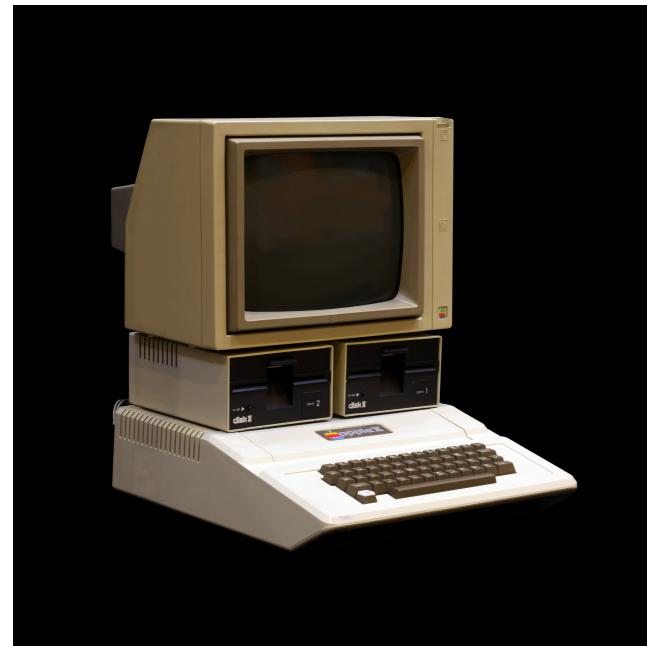
HP 3000 - 1972

- was designed to be the first **minicomputer** with full support for **time-sharing**.
- first implemented with **Transistor-transistor logic**.
- integrating **integrated circuits** on a large scale led to the development of **microprocessors**.



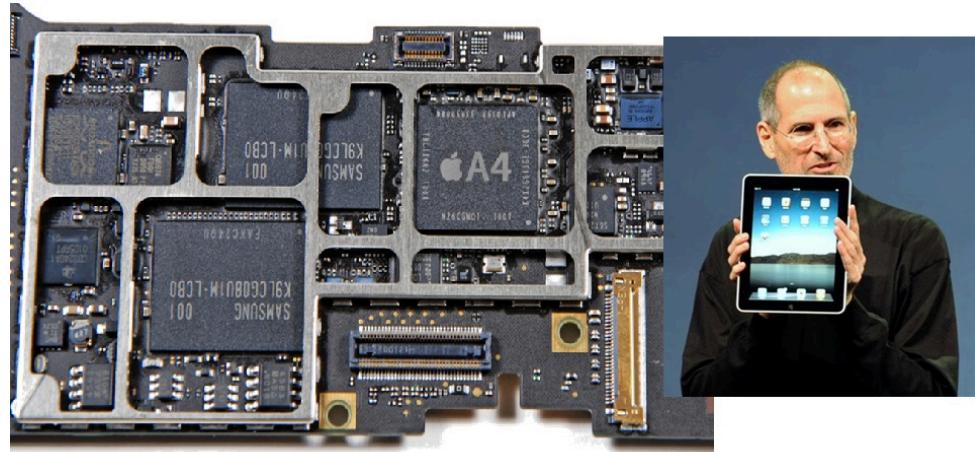
APPLE II - 1977

- one of the first highly successful mass-produced **microcomputer** products.
- designed by **Steve Wozniak**, and launched in **1977** by **Apple**.



TODAY'S COMPUTERS

- System on a Chip (**SOC**) :
a complete system embedded in a chip
(**integrated circuits**).
- An **integrated circuits** can contain:
 - one or more microprocessors,
 - memory,
 - interface devices,
 - or any other component



LAYERED ORGANIZATION



All these systems are built
on a **single model**

- a hardware architecture
- a set of devices
- an operating system
- a set of applications

Layered organization

Applications



Operating system

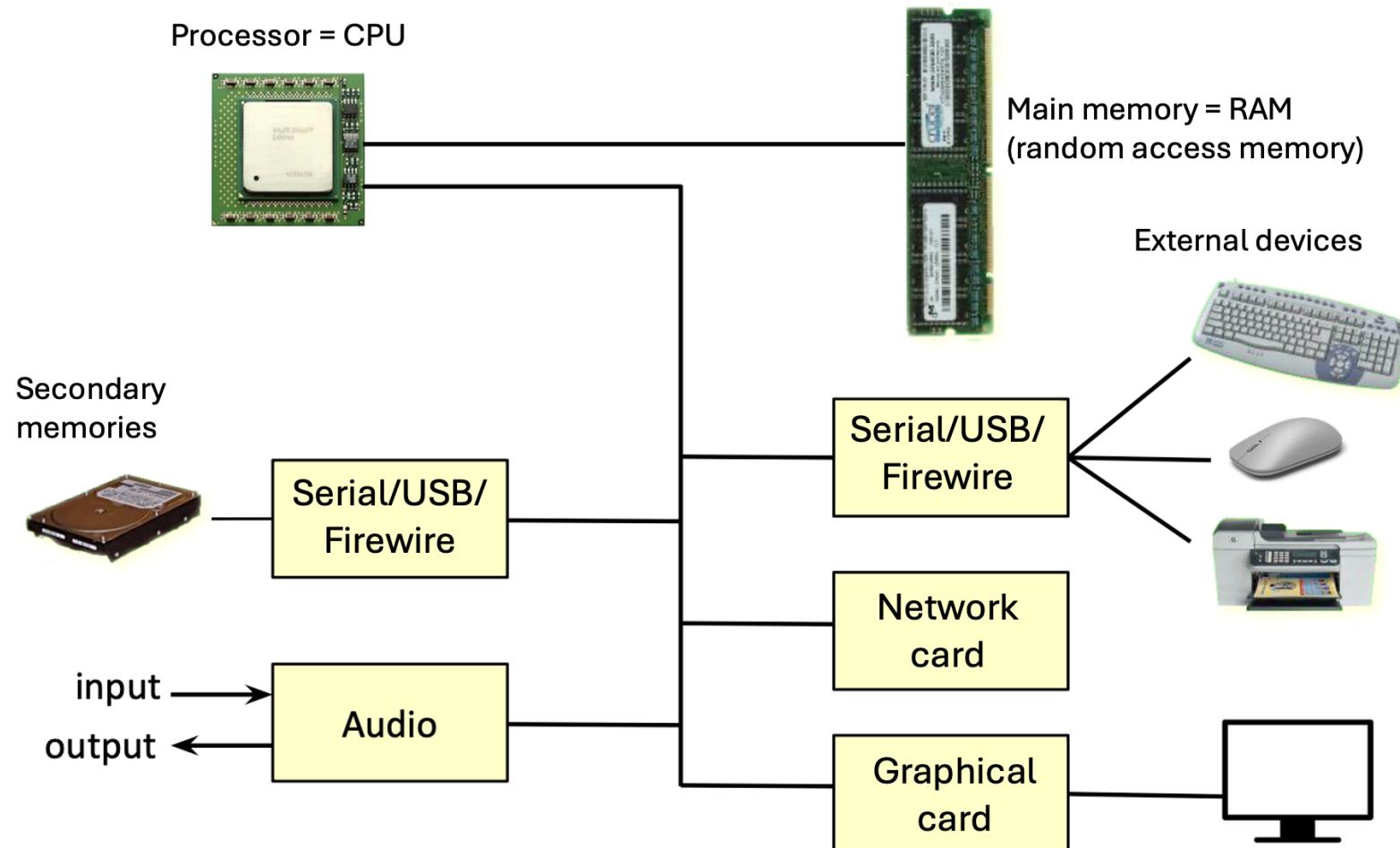


Hardware arch.



A HARDWARE ARCHITECTURE

THE COMPUTER COMPONENTS



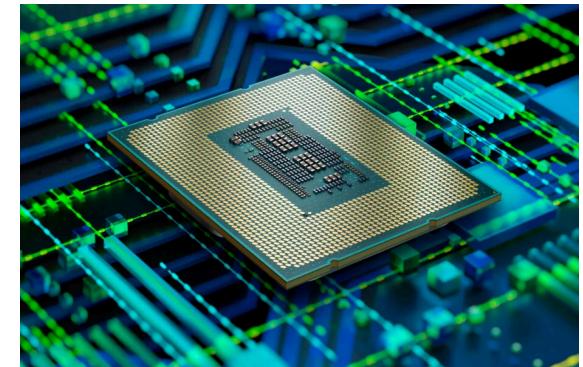
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BINARY SYSTEM

- The processor, memory or any other components are **electronic circuits**.
- The processor contains electronic circuits that calculate one or more **logic functions**.
- A logic circuit uses two logical values (**bits - Binary digITs**).
 - a signal between 0V and 1V → **bit 0**.
 - a signal between 2V and 5V → **bit 1**.
- Electronic/Logic circuits manipulate **sequences of bits** that can correspond to numeric data or more complex objects.



BINARY SYSTEM

Decimal → Binary of 100_{10}

$$100 \div 2 = 50 \rightarrow \text{remainder} = 0$$

$$50 \div 2 = 25 \rightarrow \text{remainder} = 0$$

$$25 \div 2 = 12 \rightarrow \text{remainder} = 1$$

$$12 \div 2 = 6 \rightarrow \text{remainder} = 0$$

$$6 \div 2 = 3 \rightarrow \text{remainder} = 0$$

$$3 \div 2 = 1 \rightarrow \text{remainder} = 1$$

$$1 \div 2 = 0 \rightarrow \text{remainder} = 1$$

$$100_{10} = 1100100_2 = 0b1100100$$

Binary → Decimal of 1100100_2

$$0 \times 2^0 +$$

$$0 \times 2^1 +$$

$$1 \times 2^2 + (= 4)$$

$$0 \times 2^3 +$$

$$0 \times 2^4 +$$

$$1 \times 2^5 + (= 32)$$

$$1 \times 2^6 (= 64)$$

$$1100100_2 = 100_{10}$$

Useful power of 2

- $2^0 = 1$
- $2^3 = 8$
- $2^6 = 64$
- $2^9 = 512$
- $2^1 = 2$
- $2^4 = 16$
- $2^7 = 128$
- $2^{10} = 1024$
- $2^2 = 4$
- $2^5 = 32$
- $2^8 = 256$
- ...

BINARY SYSTEM

EXERCISE

- Convert these decimal numbers to binary:
 - 8, 13, 15, 2025, ...

HEXADECIMAL SYSTEM

BASE 16 or HEX SYSTEM

- In computing systems, the **binary string** equivalents of **large decimal numbers** can become **quite long**.
 - ex. $154863_{10} = 100101110011101111_2$
- The **hexadecimal system** contains 16 sequential numbers as base units.
 - The first nine numbers (**0** to **9**)
 - The next six two-digit numbers (**10** to **15**) are represented by the letters **A, B, C, D, E, F**.
- The format of **hex numbers** is **more compact than binary numbers** because they can represent large binary numbers with fewer digits.
 - **four digits of a binary number** can be represented by **a single hex digit**
 - **binary** \iff **hexadecimal** immediate translation

0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

HEXADECIMAL SYSTEM

BASE 16 or HEX SYSTEM

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0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

- ex. $154863_{10} = 100101110011101111_2 = 10 - 0101 - 1100 - 1110 - 1111_2$

10	0101	1100	1110	1111
2	5	C	E	F

- ex. $154863_{10} = 100101110011101111_2 = 25CEF_{16} = 0x25CEF = \$25CEF$

HEXADECIMAL SYSTEM

BASE 16 or HEX SYSTEM

- Convert these decimal numbers to hexadecimal:
 - 8, 13, 15, 2025, ...

[link to a converter](#)

DATA MEASUREMENT UNIT

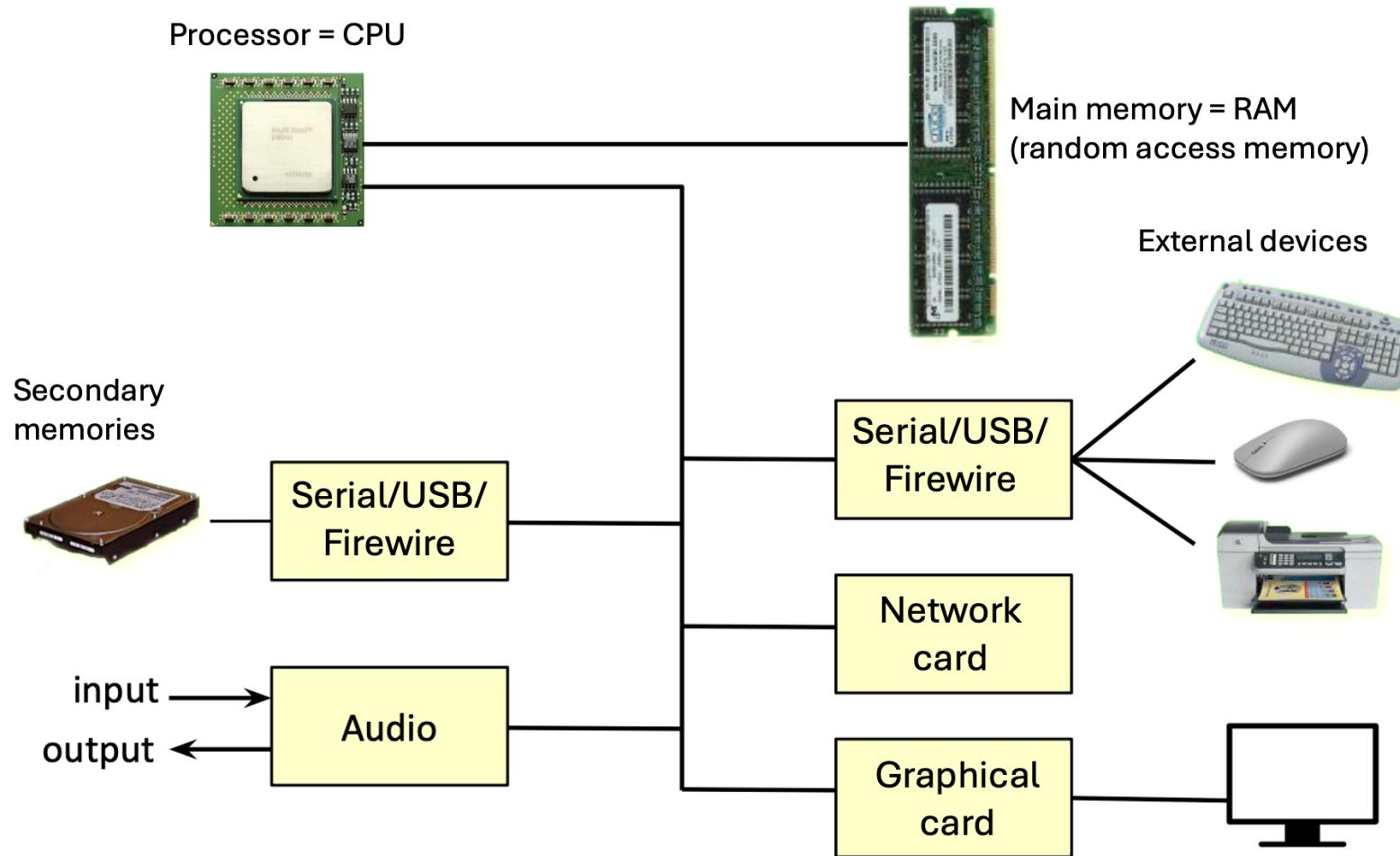
- In computer systems, a **unit of information** is used to describe the **capacity** of a digital data storage device.
- A **byte** is a unit that computers use **to represent** a character such as a letter, number, or a typographic symbol (**for example**, “h”, “7”, or “\$”)
 - ➡ will be discussed later in the **3rd chapter**.
- The **byte** is a **unit of digital information** that most commonly consists of **8 bits**.
 - 1 byte = 8 bits (binary digits)
- **Multiples of byte**
 - 1 **Kilobyte** (KB) = 2^{10} bytes = 1 024 bytes $\approx 10^3$ bytes
 - 1 **Megabyte** (MB) = 2^{20} bytes = 1 024 KB = 1 048 576 bytes $\approx 10^6$ bytes
 - 1 **Gigabyte** (GB) = 2^{30} bytes = 1 024 MB = 1 073 741 824 bytes $\approx 10^9$ bytes
 - 1 **Terabyte** (TB) = 2^{40} bytes = 1 024 GB = 1 099 511 627 776 bytes $\approx 10^{12}$ bytes

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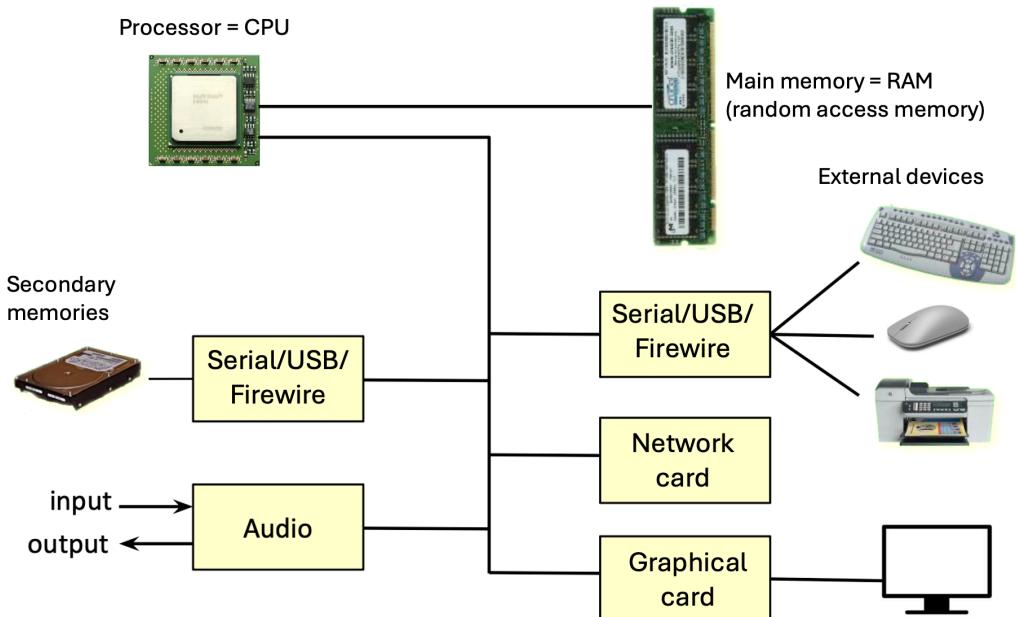
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THE COMPUTER COMPONENTS



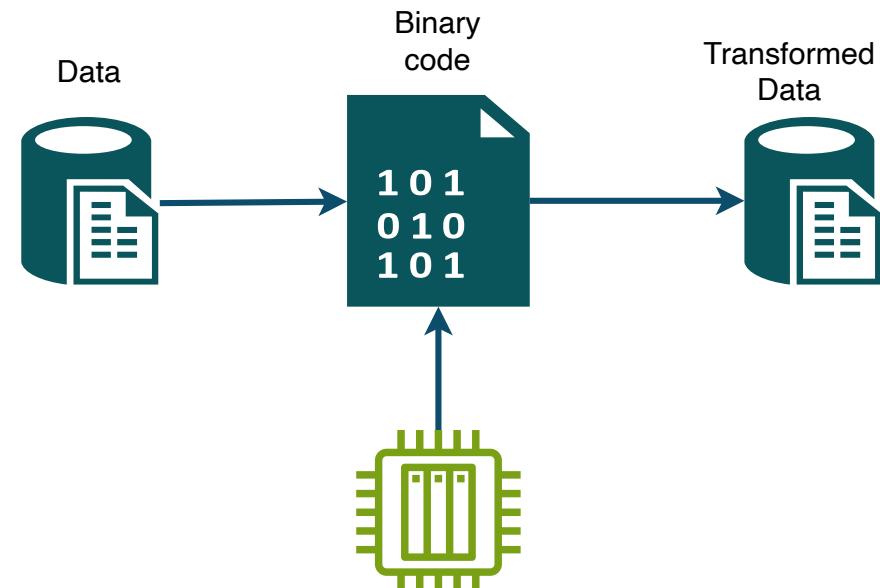
THE COMPUTER COMPONENTS

- What can a computer (processor) do?
 - ➡ **copy values** between storage units
 - ➡ **perform logical/arithmetic operations** between stored values
 - ➡ **move within the program**, possibly conditionally



MACHINE LANGUAGE

- A **processor** executes a **very low level language (Machine Language)**
 - ➡ the instructions of this kind of language execute **elementary operations**.
 - ➡ machine instructions **control electronic/logic circuits**.
- **Machine language** coding must be simple to decode and optimized
 - ➡ each instruction is a **sequence of binary numbers (bits)**.
 - ➡ this coding is **not textual** → it is done at **bit level (binary code)**
 - ➡ in practice, we represent these codes in **hexadecimal form**



```
1 2B50: 12AE 2B1E
2 2B52: 12AF #0002
3 2B54: 13BE
4 2B55: 12BD 2B1E
5 ...
6 2B1E: 0003
```

ASSEMBLY LANGUAGE

- **Unreasonable** to want to write/read binary machine language **directly**.
- Definition of an equivalent **symbolic representation (Assembly language)**
 - **textual mnemonics** for operations/functions
 - **textual writing** of the entire program

```
1    mov eax, a
2    mov ebx, 2
3    add ecx, eax, ebx
4    mov a, ecx
5    ...
6 @a: memval 3
```

```
1 2B50: 12AE 2B1E
2 2B52: 12AF #0002
3 2B54: 13BE
4 2B55: 12BD 2B1E
5 ...
6 2B1E: 0003
```

- **Assembly language**
 - very close to the **machine**, **very low level**
 - you need to be well-known in the **technical details of the processor**.
 - **Assembler** → translator from **assembly language** to **machine language**.

HIGH LEVEL PROGRAMMING LANGUAGE

- Most software is written in a **high-level programming language**.
 - example → Python, Java, C, C++, ...
- **High-level language** → expressing instructions using **words** and **mathematical symbols**.
 - Easy to learn.
 - does not require knowledge of the machine's processor.
- High-level programming languages provide **abstract concepts** that are not present in machine language.
 - **data types** → integers, reals, strings ...
 - **control structures** → **if...then...else**, **while**, **for**, functions.

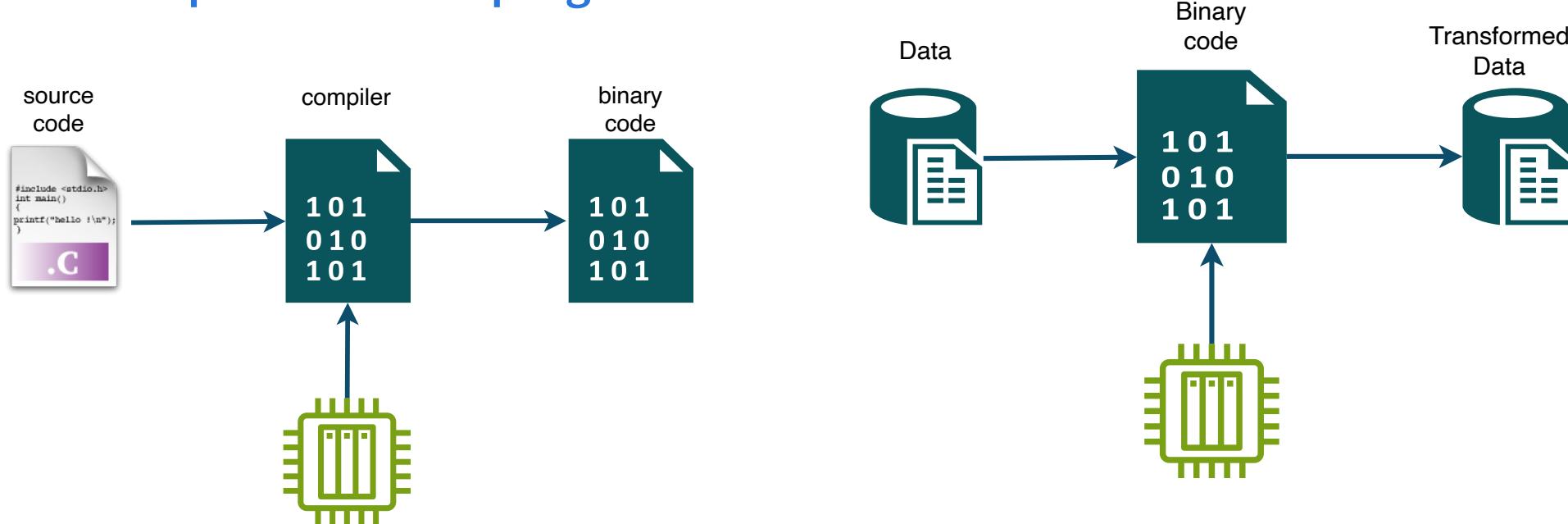
```
1 # This program adds two numbers
2 num1 = 1.5
3 num2 = 6.3
4
5 # Add two numbers
6 sum = num1 + num2
```

HIGH-LEVEL LANGUAGE vs LOW-LEVEL LANGUAGE

- The programmer writes a program with **high-level language**, and the processor executes a **low-level code (binary code)**.
- How is a program written in a high-level programming language **executed**?
 1. a **compilation** process
 2. an **interpretation** process

THE COMPILED PROCESS

The compiler is itself a program



Compilation is performed only once

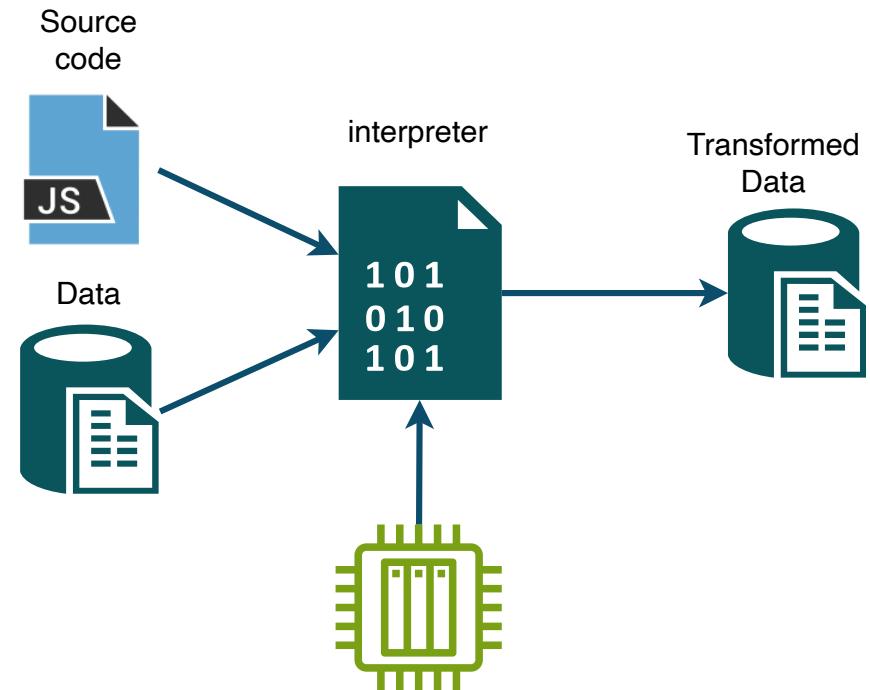
- No more need for source code
- No more need for compiler

- The two most popular compiled languages are **C** and **C++**.
 - used in creating games, software, artificial intelligence, operating systems, and more.

THE INTERPRETATION PROCESS

- Still need the source code
- Still need the interpreter
- **No binary code created**

The interpreter is itself a program



- The two most popular compiled languages are **Python** and **Javascript**.
 - used in web development, data science, machine learning, and more.

THANK YOU

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