COMPUTER ARCHITECTURE
AND SOFTWARE EXECUTION PROCESS

INTRODUCTION TO COMPUTER ARCHITECTURE

Bachelor in Artificial Intelligence, Data and Management Sciences
CentraleSupelec and ESSEC Business School - 2025/2026

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- **Associate-Professor** at the **Computer Science Department** of CentraleSupelec - Paris-Saclay University.
  - ➠ Teaching in **Engineering** and **Bachelor** programs
  - ➠ Algorithmic and Complexity, Object-Oriented design and programming, Software Engineering, Operating Systems, Modelling and Verification using Formal Methods, etc.
- **Researcher** at the **Model** and **Proof** Teams of Formal Methods Laboratory - LMF of Paris-Saclay.
  - ➠ **Formal methods** for system modelling and verification.
  - ➠ **Refinement** and **proof-based** methods

DISCUSSION ABOUT STUDENTS' EXPECTATIONS

1. go to wooclap.com
2. enter the **XNNZZB** code in the top banner to join a Wooclap event

OUTLINE

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LEARNING OUTCOMES AND ASSESSMENT

Main objective $\longrightarrow$ Demystify the computer and its internal components.

- Identify and analyze the main components of a computer system
  - processor, memory, input/output devices, etc.
- Explain the organization and operation of these components
  - how the processor, memory, and peripherals work
- Understand program execution.
  - how a processor interprets and executes a software (**ex.** Python program)

SYLLABUS

Chapter	Lecture	Tutorial	Lab session
Computer Architecture $\rightarrow$ Introduction	1h30		
Operating systems	1h30		
Data representation	1h30	1h30	
Internal Architecture of Microprocessors	1h30	1h30	$2 \times$ 3h00
Memory management	1h30	1h30	

Assessment of learning outcomes

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

COMMUNICATION & ORGANIZATION

- **Course website**
  - ➠ centralesupelec.edunao.com

- **Questions & discussions**
  - ➠ before, during, and after sessions
  - ➠ outside class hours if needed

- **Contact**
  - ➠ email $\longrightarrow$ idir.aitsadoune@centralesupelec.fr
  - ➠ remote meetings $\longrightarrow$ **MS TEAMS**

OUTLINE

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COMPUTER SCIENCE

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

THE CONCEPT OF COMPUTER

A computer is a machine that can be programmed to automatically execute a sequence of operations (**program**).

- We provide the computer with:
  - ➠ **program** (software)
  - ➠ **data** (information)

- The computer **processes the data** by executing the program

THE CONCEPT OF COMPUTER

- But today a computer does much more than that ...

- Solving **complex problems**
  - achieved by following **a program**
  - a **sequence of instructions** describing how a problem is solved

- **Two main categories of computers**
  1. **personal computer**
     → (PCs)
  2. **on-board (embedded) computers**
     → (train control systems, medical devices, smart TV, smartphone, ...)

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 automatically execute a sequence of operations (**program**)
- **Computer Architecture**
  - explaining how a **computer** is designed and how programs run on it

OUTLINE

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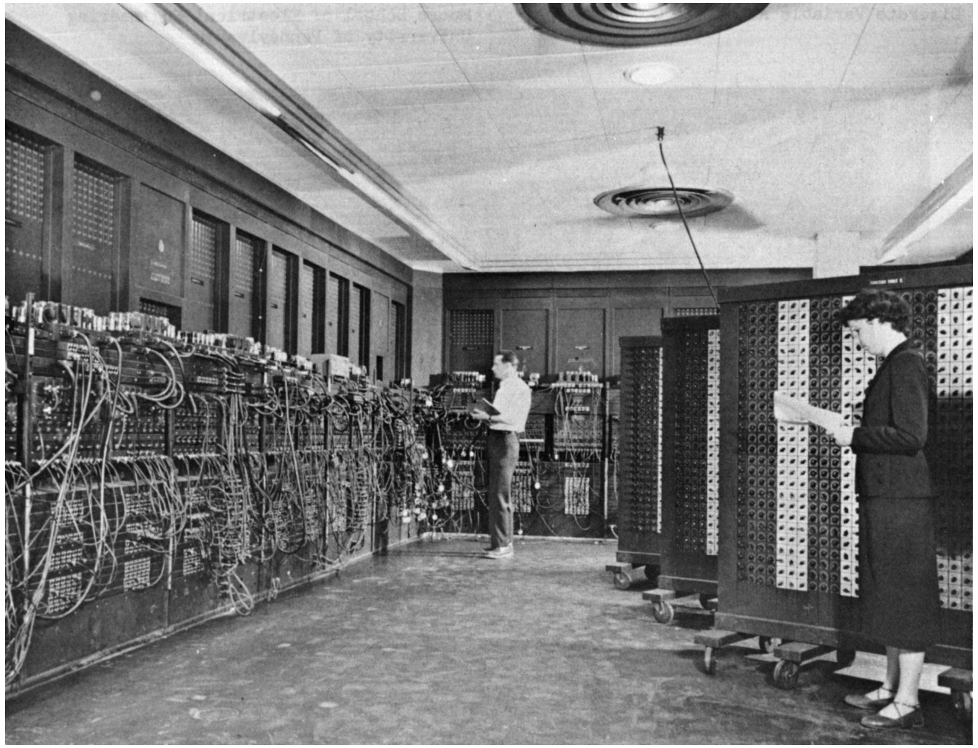
ENIAC - 1945

- 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

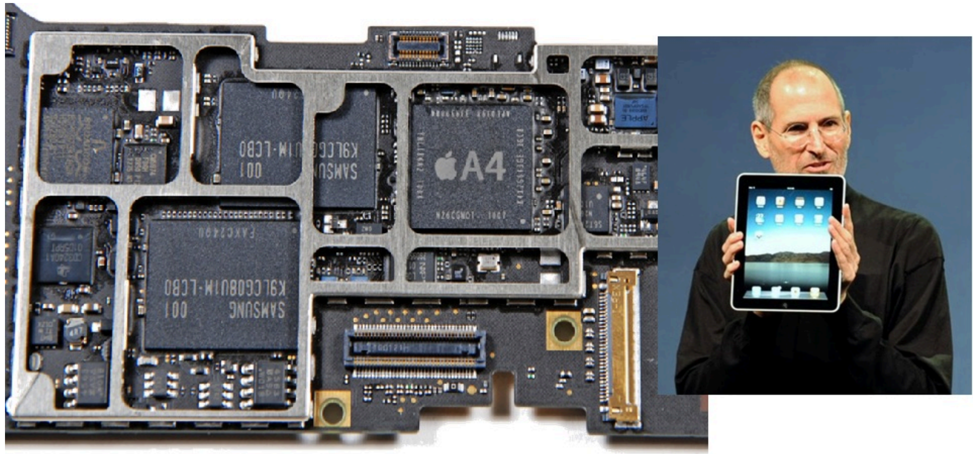
- was designed to be the first **minicomputer** with full support for time-sharing.
- first implemented with Transistor-transistor logic.
- integrating integrated circuits on a large scale led to the development of **microprocessors**.

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

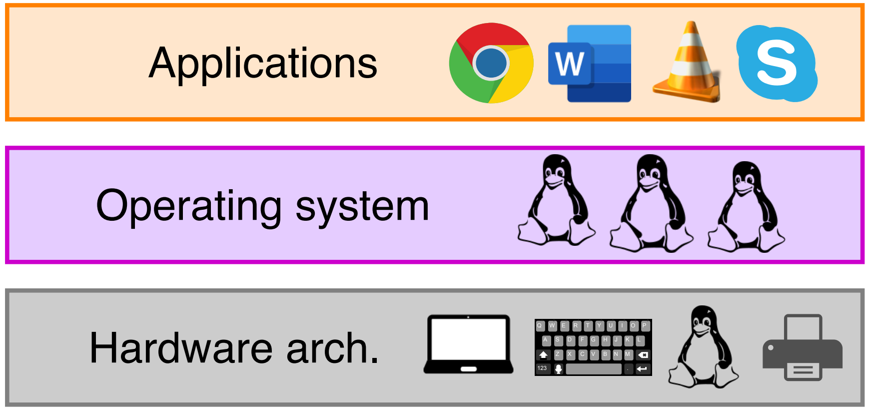



LAYERED ORGANIZATION

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

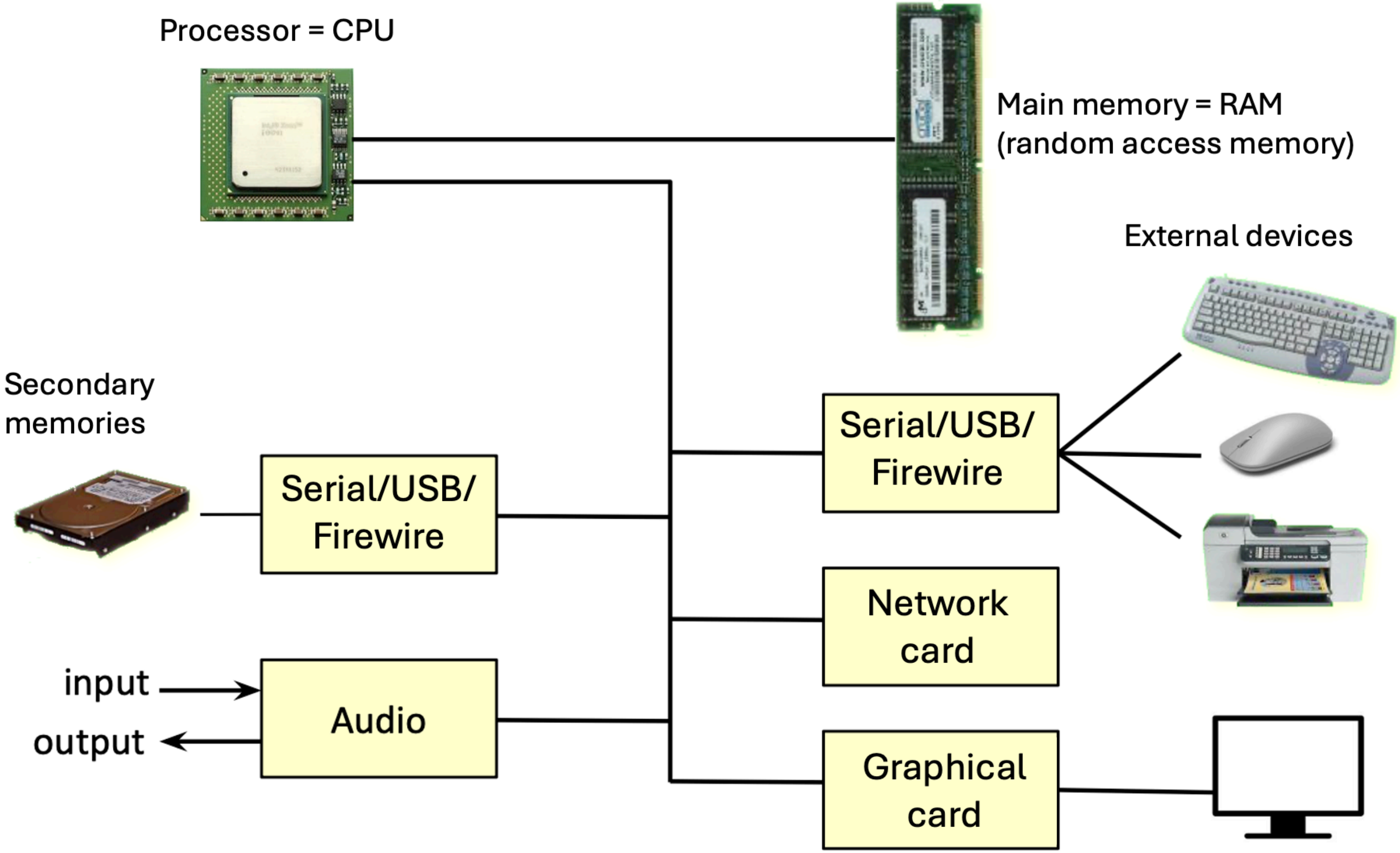
- a hardware architecture
- a set of devices
- an operating system
- a set of applications

Layered organization



A HARDWARE ARCHITECTURE

THE COMPUTER COMPONENTS



CPU = central processing unit

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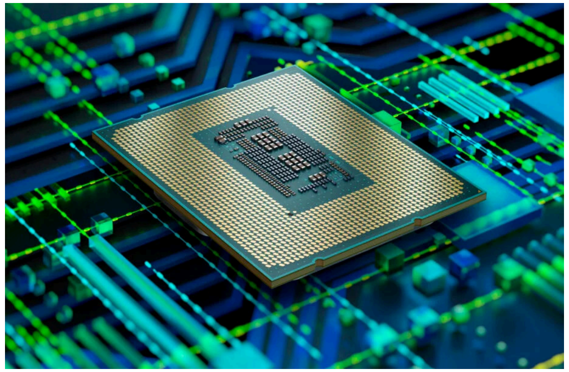
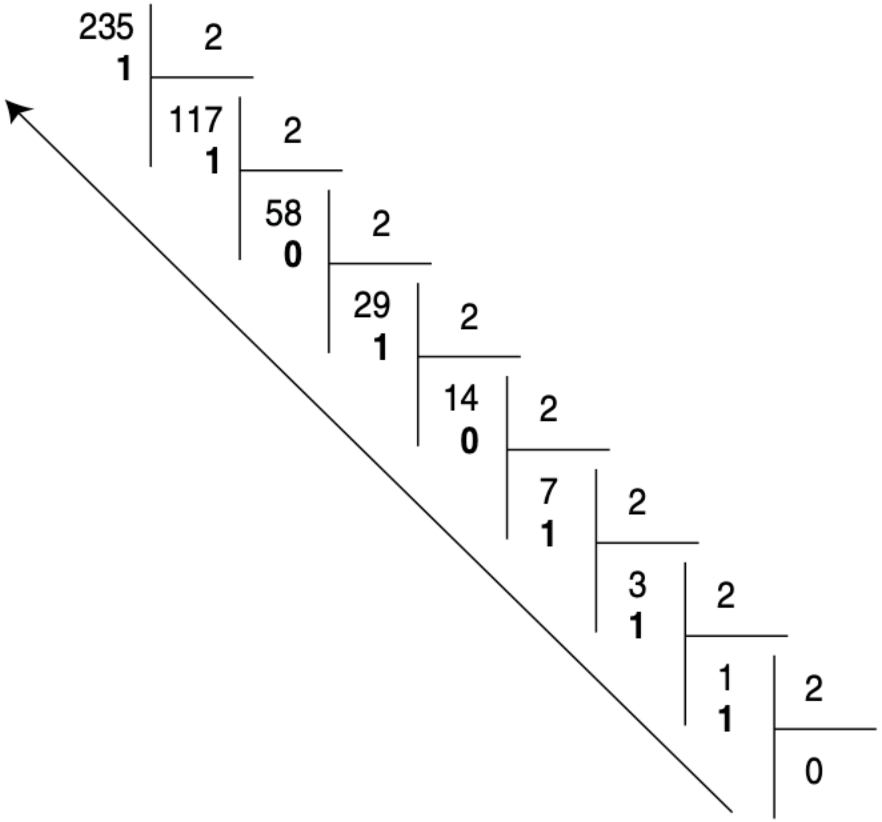
BINARY SYSTEM



- All computer components are **electronic devices** that process and store information.
- **electronic devices** $\rightarrow$ circuits that perform logic & arithmetic operations.
- **electronic devices** $\rightarrow$ manipulate two states or values (**Binary digITs** - **bits**).
  - a weak electrical signal (between 0V and 1V) $\rightarrow$ value 0 or bit 0.
  - a high electrical signal (between 2V and 5V) $\rightarrow$ value 1 or bit 1.
- **electronic devices** $\rightarrow$ manipulate a sequence of bits representing **numbers** or **complex data**.

BINARY SYSTEM

DECIMAL $\longrightarrow$ BINARY OF 235_{10}



$$235 \div 2 = 117 \rightarrow \text{remainder} = 1$$
$$117 \div 2 = 58 \rightarrow \text{remainder} = 1$$
$$58 \div 2 = 29 \rightarrow \text{remainder} = 0$$
$$29 \div 2 = 14 \rightarrow \text{remainder} = 1$$
$$14 \div 2 = 7 \rightarrow \text{remainder} = 0$$
$$7 \div 2 = 3 \rightarrow \text{remainder} = 1$$
$$3 \div 2 = 1 \rightarrow \text{remainder} = 1$$
$$1 \div 2 = 0 \rightarrow \text{remainder} = 1$$

$$235_{10} = 11101011_2 = \texttt{0b}11101011$$

BINARY SYSTEM

BINARY $\longrightarrow$ DECIMAL OF 1100100_2

$$(0 \times 2^0) + (0 \times 2^1) + (1 \times 2^2) + (0 \times 2^3) + (0 \times 2^4) + (1 \times 2^5) + (1 \times 2^6)$$

Useful power of 2

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

$$1100100_2 = (2^2 + 2^5 + 2^6) = (4 + 32 + 64) = 100_{10}$$

BINARY SYSTEM

EXERCISE

Useful power of 2

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

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

BASE 16 or HEXADECIMAL SYSTEM

- The **hexadecimal system** uses 16 symbols.
  - digits $\rightarrow$ **0** to **9**
  - letters $\rightarrow$ **A**, **B**, **C**, **D**, **E**, **F**

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

- The **hexadecimal number** format is more compact than the binary one
  - four binary digits are represented by one hexadecimal digit
  - **an easier way for humans to read and write binary data**

- A **binary representation** of a **big decimal number** can be **pretty long**.
  - **ex.** $154863_{10} = 100101110011101111_2 = 10/0101/1100/1110/1111_2$

0010	0101	1100	1110	1111
2	5	C	E	F

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

BASE 16 or HEXADECIMAL SYSTEM

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

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

link to a converter

DATA MEASUREMENT UNIT - BYTE

- The **byte** is a unit of digital information that most commonly consists of **8 bits**.
  - 1 byte = 8 bits (binary digits)
- A **byte** measures the capacity of digital storage devices.
  - how many **bytes** is it possible to store in a memory?
- **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
- A **byte** can correspond to a **binary code** (a squence of 8 bits) representing a displayed character of a letter, a number, or a symbol (**ex.**, “h”, “7”, or “$”)

  ➠ will be discussed later in the chapter 3.

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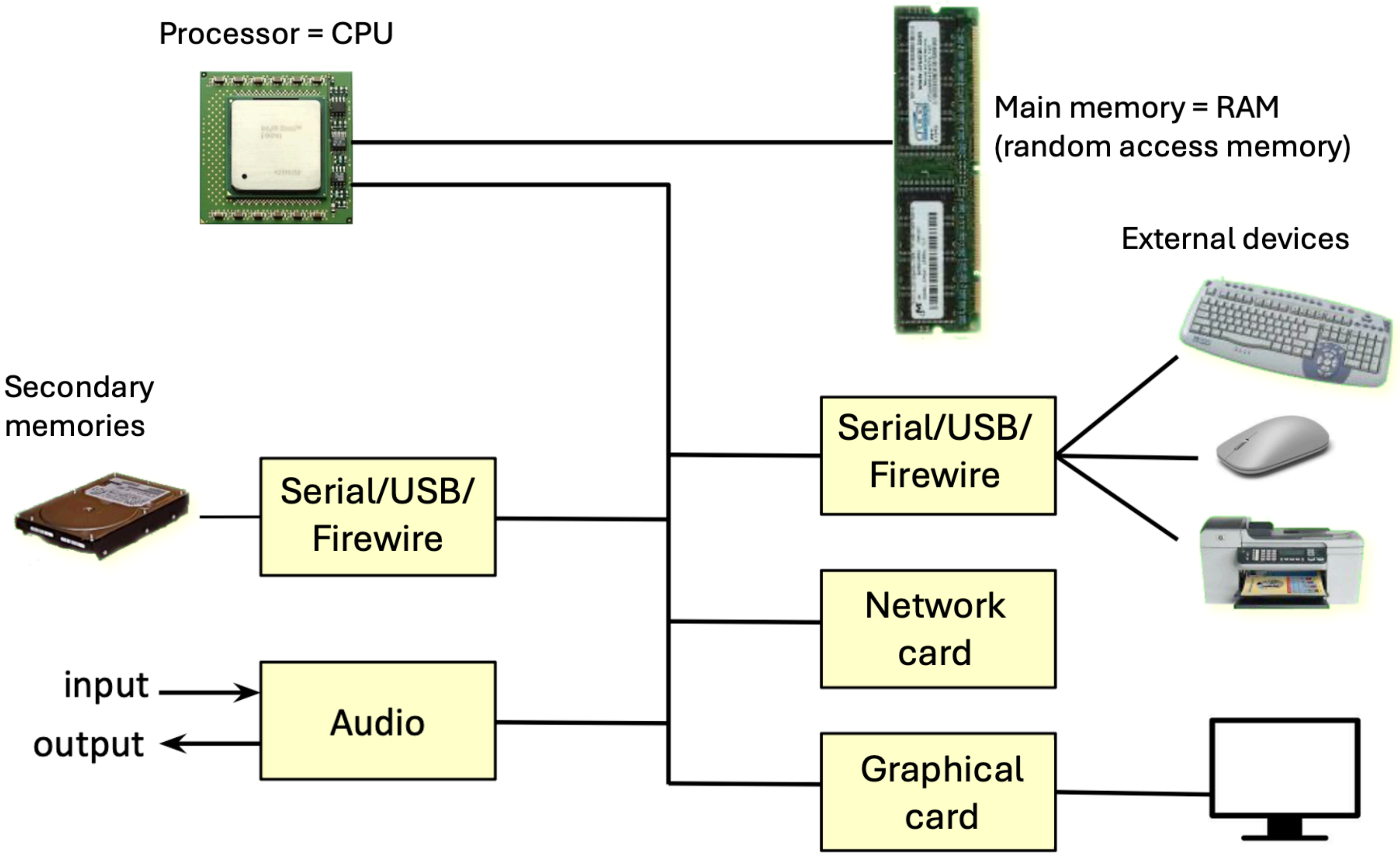
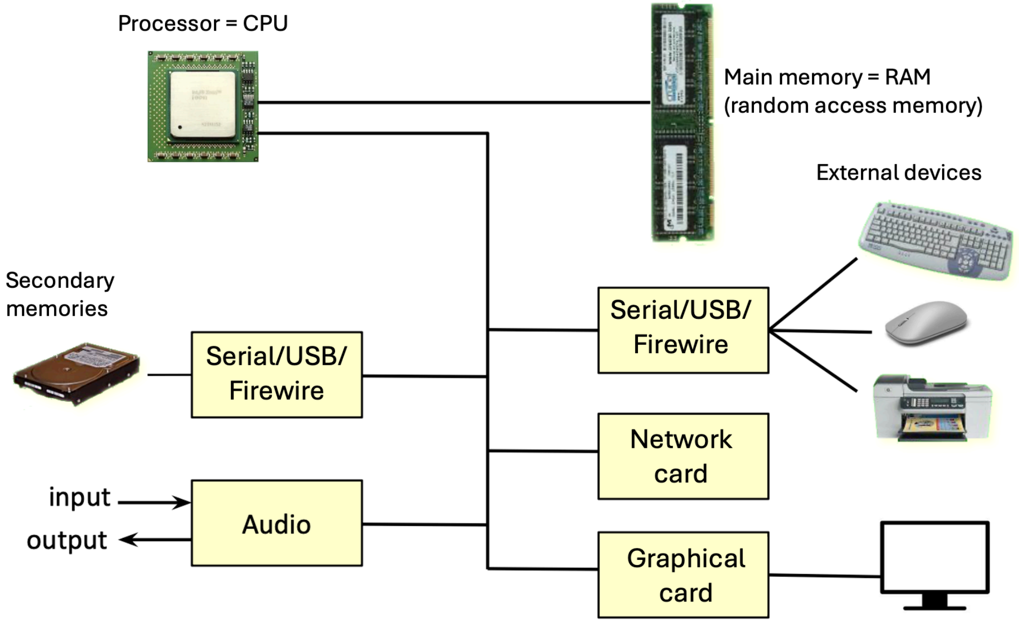
THE COMPUTER COMPONENTS



THE COMPUTER COMPONENTS

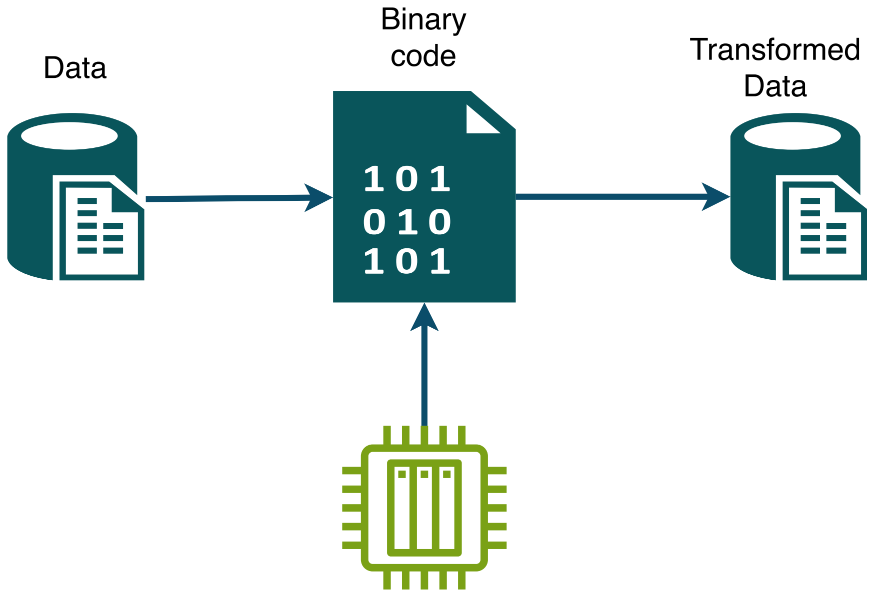
- What can a computer (processor) do?
  - **copy values** between storage units
  - **perform logical/arithmetic operations** between stored values
  - **move within the program**, possibly conditionally



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** programming must be optimized and simple to decode
  - ➠ each instruction represented by a sequence of binary digits (bits).
  - ➠ we represent these codes in **hexadecimal form**




```
2B50: 12AE 2B1E
2B52: 12AF #0002
2B54: 13BE
2B55: 12BD 2B1E
        ...
2B1E: 0003
```

ASSEMBLY LANGUAGE

- **Programming directly in binary is impractical.**
- An equivalent **symbolic representation** (**Assembly language**) exists
  - **textual mnemonics** for operations/functions
  - **textual writing** of the entire program

```
    mov eax, a
    mov ebx, 2
    add ecx, eax, ebx
    mov a, ecx
    ...
@a: memval 3
```

```
2B50: 12AE 2B1E
2B52: 12AF #0002
2B54: 13BE
2B55: 12BD 2B1E
      ...
2B1E: 0003
```

- **Assembly language**
  - very close to the machine - considered a low-level language
  - requires detailed knowledge of the processor's architecture
  - each instruction corresponds almost directly to a machine code operation
  - **Assembler** $\longrightarrow$ 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.
- Provide **abstract concepts** that are not present in machine language.
  - **data types** → integers, reals, strings, array, ...
  - **control structures** → `if`...`then`...`else`, `while`, `for`, functions.

```
num1 = 1.5
num2 = 6.3

if num1 > num2 :
  res = num1 - num2
else :
  res = num2 - num1
```

HIGH-LEVEL LANGUAGE vs LOW-LEVEL LANGUAGE

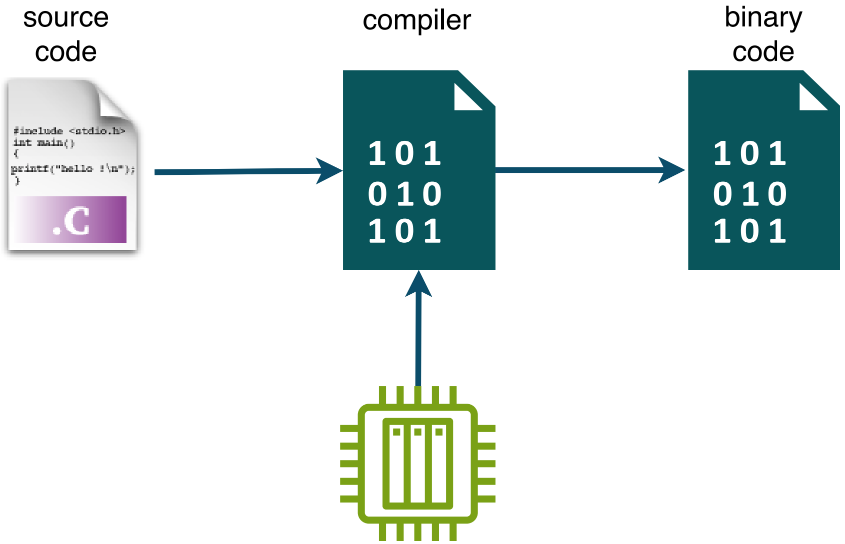
- **From High-Level Code to Execution**
  - Programmer writes $\longrightarrow$ High-level language
  - Processor executes $\longrightarrow$ Low-level code (binary)

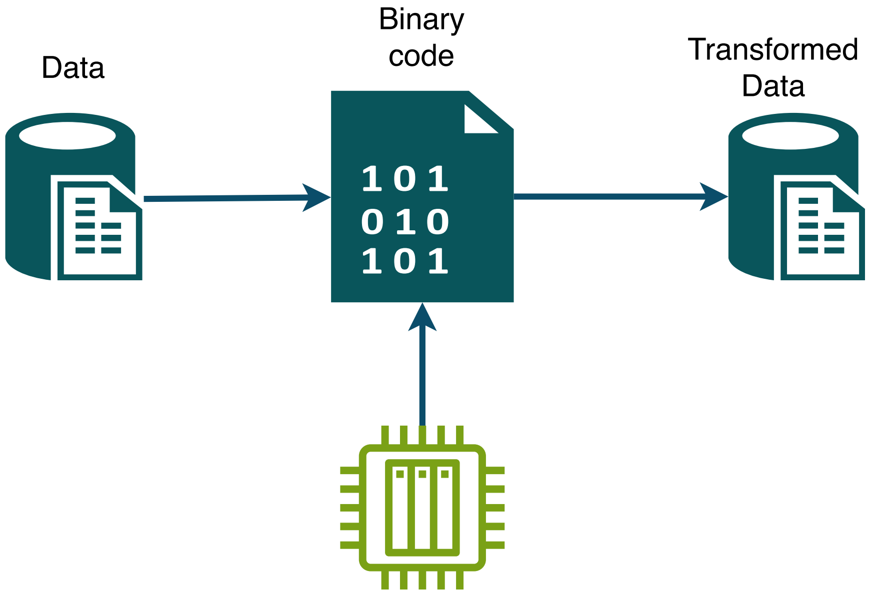
- How is a high-level program executed?
  1. **Compilation** process
  2. **Interpretation** process

THE COMPILATION PROCESS

converting the entire program into binary code before execution

The compiler is itself **a program**





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

Compilation is performed only once

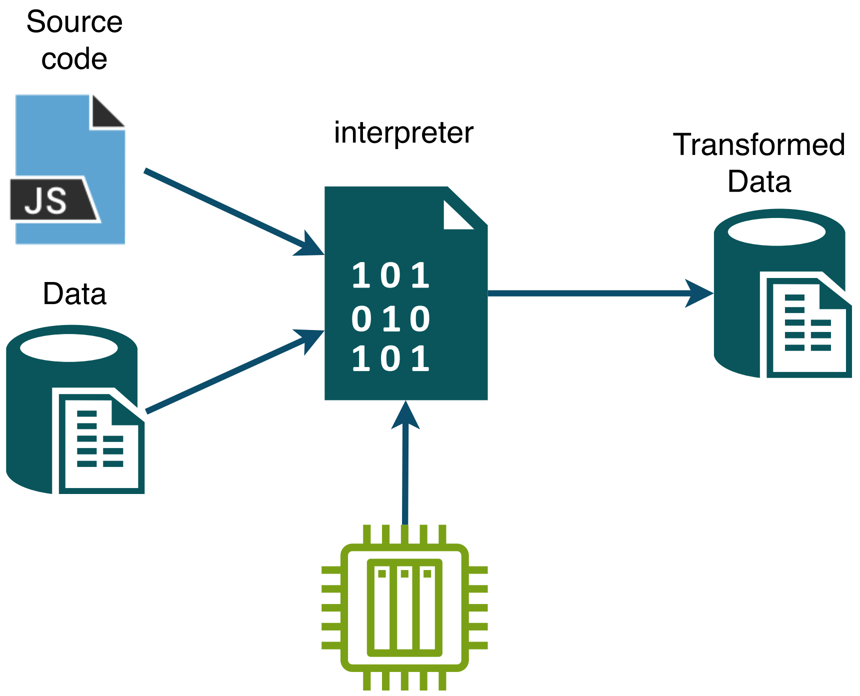
- The two most popular compiled languages are **C** and **C++**.
  - used in games, software, artificial intelligence, operating systems, and more.

THE INTERPRETATION PROCESS

translating and executing the program line by line

The interpreter is itself **a program**

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



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

THANK YOU

PDF version of the slides

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