



CentraleSupélec

université
PARIS-SACLAY

COMPUTER ARCHITECTURE AND SOFTWARE EXECUTION PROCESS

MICROPROCESSOR ARCHITECTURE

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



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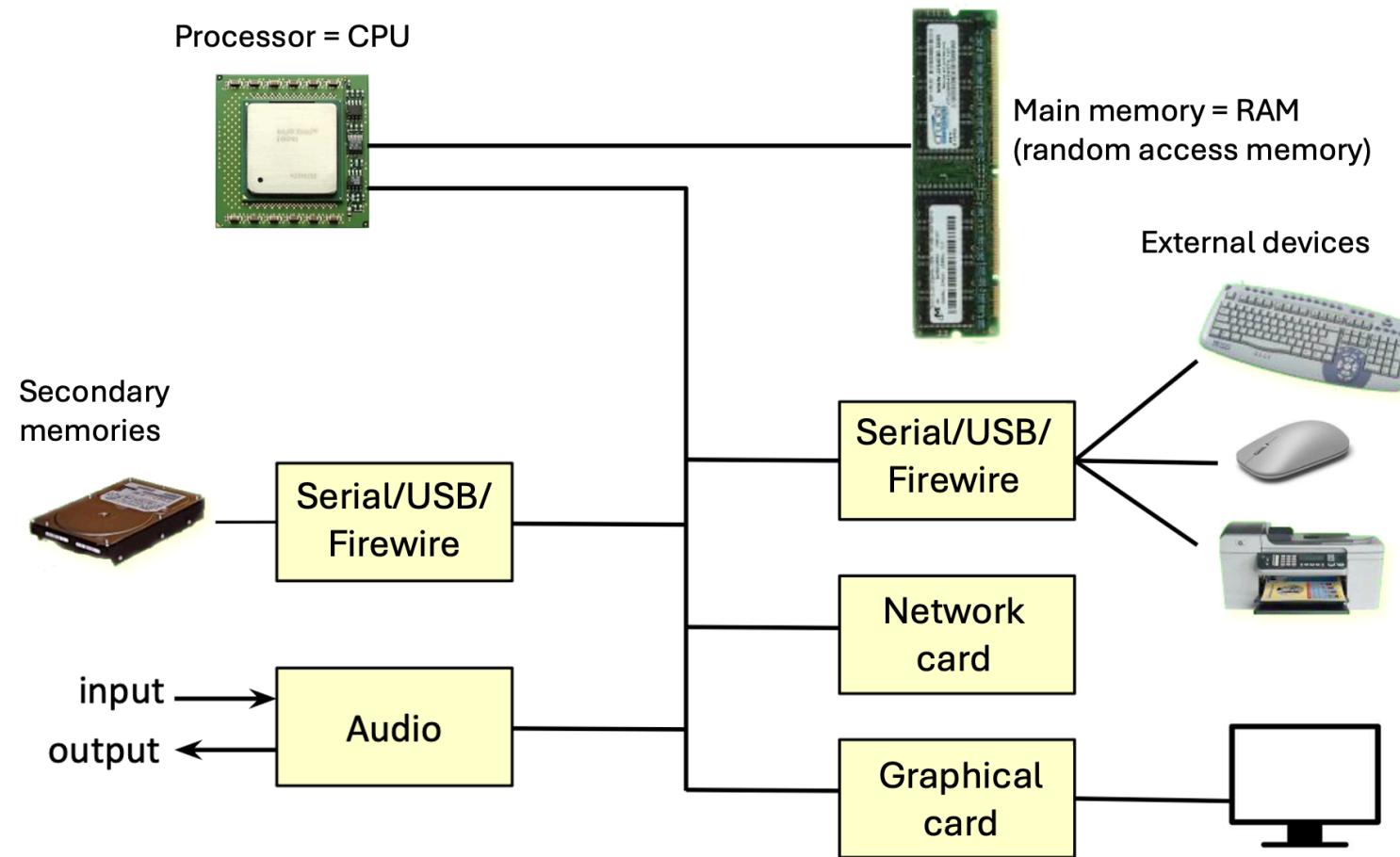
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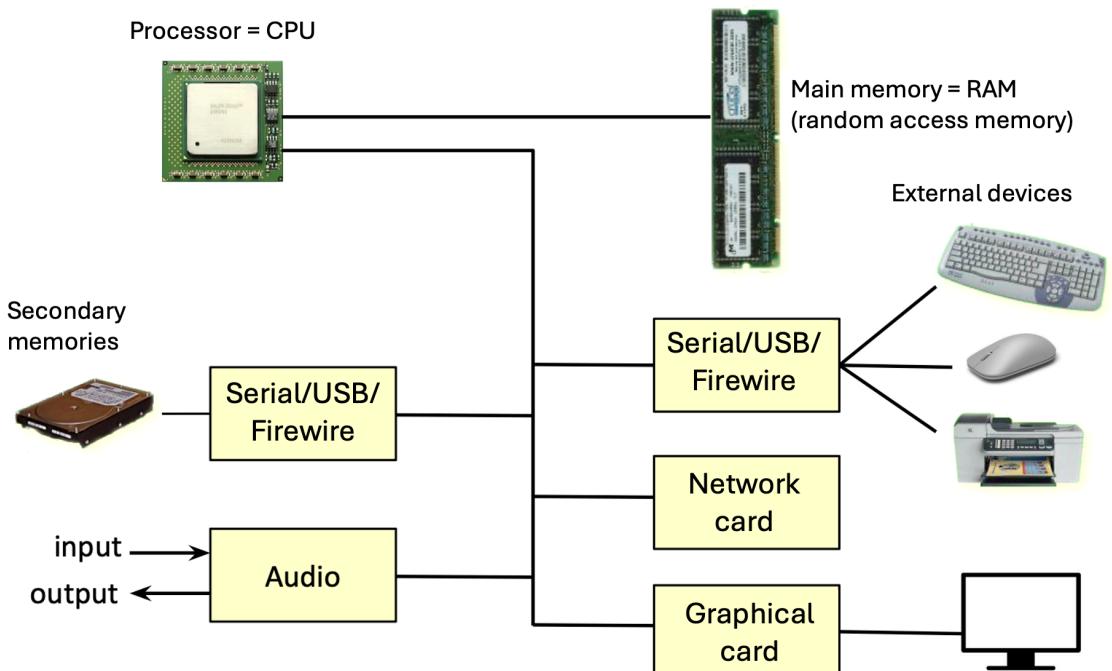
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THE COMPUTER COMPONENTS

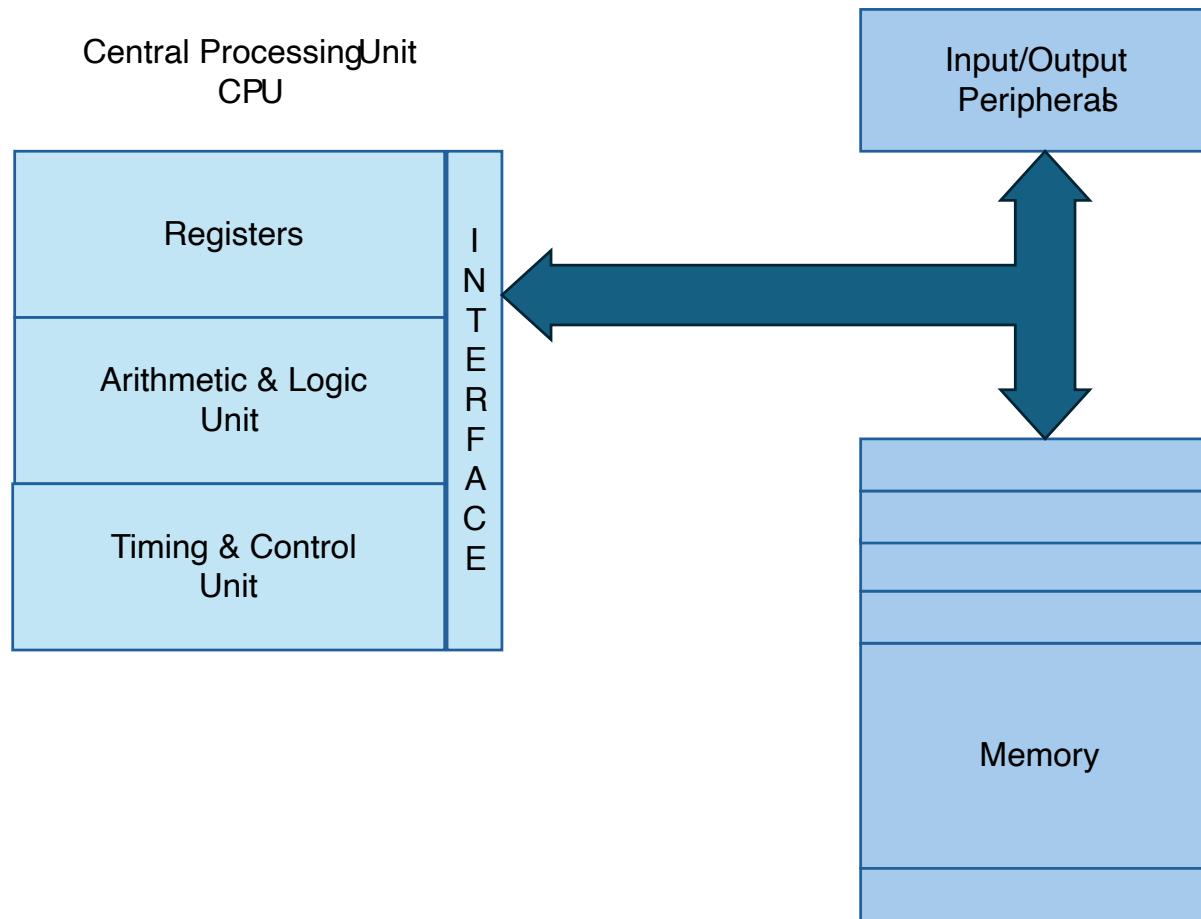


THE COMPUTER COMPONENTS

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



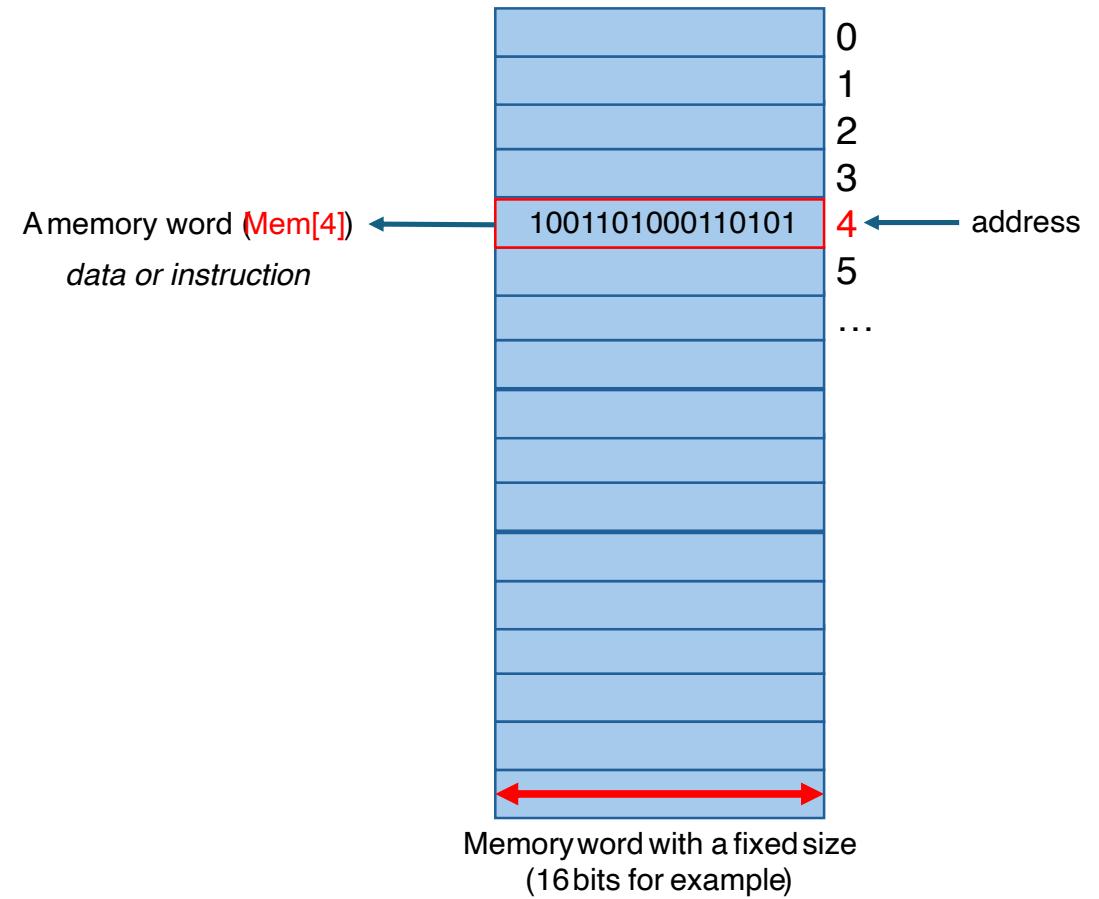
TYPICAL STRUCTURE OF CPU



TYPICAL STRUCTURE OF CPU

MEMORY UNIT

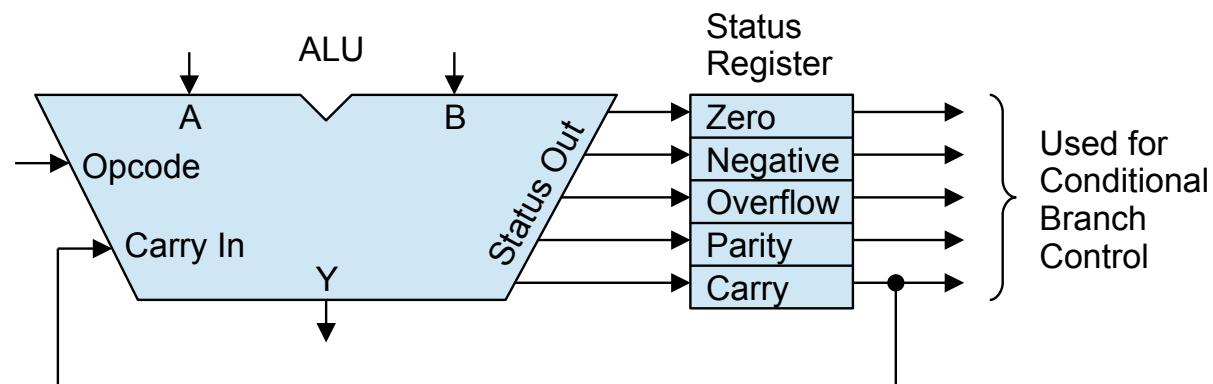
- Computer memory stores information, such as data and programs, for immediate use in the computer.
- The term memory is often synonymous with the terms RAM, main memory, or primary storage.



TYPICAL STRUCTURE OF CPU

ARITHMETIC AND LOGIC UNIT (ALU)

- The **Arithmetic and Logic Unit (ALU)** is a combinational digital circuit that performs **arithmetic and bitwise operations** on integer binary numbers.

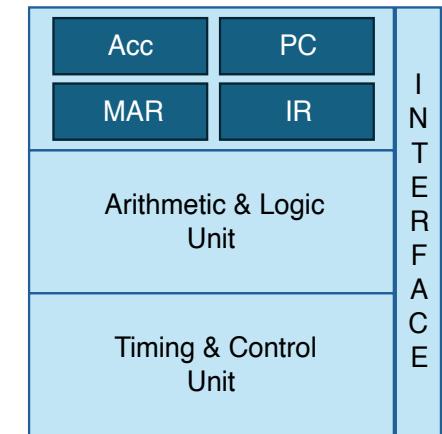


- The **opcode input** conveys to the **ALU** an operation selection code that specifies **the desired arithmetic or logic operation** to be performed by the **ALU**.
 - **add, sub, and, or, ...**
 - generally, an **ALU opcode** is not the same as a **machine language instruction**

TYPICAL STRUCTURE OF CPU

REGISTER SECTION

- A **processor register** is a **quickly accessible memory** available to a computer's processor.
- **Registers** are measured by the **number of bits** they can hold
 - for example, an 8-bit register, 16-bit register, or more.
- A processor often contains several kinds of registers:
 - **Accumulator** → stores **intermediate** arithmetic and logic unit **results**.
 - **Program Counter** → indicates **where** a processor is in its program sequence.
 - **Instruction Register** → holds the **instruction** currently being **executed** or decoded (each instruction to be executed is loaded into the **IR** register)
 - **Memory Address Register** → either stores the **memory address** from which data will be fetched or the **address** to which data will be sent and stored.

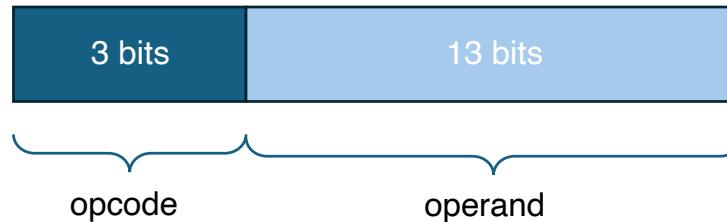


MACHINE LANGUAGE (INSTRUCTIONS)

- Machine language is built up from instructions.
- Instruction → an elementary operation that a processor can perform.
- A given instruction may specify:
 - opcode → the instruction to be performed
 - any explicit operands → registers, constant values, addressing modes used to access memory
- Example:
 - LOAD *addr* → Acc := Mem[*addr*]
 - LOAD *val* → Acc := *val*
 - STORE *addr* → Mem[*addr*] := Acc
 - ADD *addr* → Acc := Acc + Mem[*addr*]
 - ADD *val* → Acc := Acc + *val*
 - SUB *addr* → Acc := Acc - Mem[*addr*]
 - SUB *val* → Acc := Acc - *val*



EXAMPLES



- **OPCODE OPERAND**

$xxx\ xxxxxxxxx$

- **LOAD 25** \rightarrow Acc := Mem[25]

$000\ 000000011001 = (0019)_{16}$

- **LOAD 12** \rightarrow Acc := 12

$100\ 000000001100 = (800C)_{16}$

- **STORE 54** \rightarrow Mem[54] := Acc

$001\ 000000110110 = (2036)_{16}$

- **ADD 41** \rightarrow Acc := Acc + Mem[41]

$010\ 0000000101001 = (4029)_{16}$

- **ADD 10** \rightarrow Acc := Acc + 10

$110\ 000000001010 = (C00A)_{16}$

- **SUB 14** \rightarrow Acc := Acc - Mem[14]

$011\ 000000001110 = (600E)_{16}$

- **SUB 112** \rightarrow Acc := Acc - 112

$111\ 000001110000 = (E070)_{16}$

EXAMPLES

```
1 int a = 3;  
2 int b = 0;  
3  
4 b = a + 10;
```

```
1 LOAD a  
2 ADD 10  
3 STORE b  
4 ...  
5 @a: memval 3  
6 ...  
7 @b: memval 0
```

```
1 0000: 0019  
2 0001: C00A  
3 0002: 2036  
4 ...  
5 0019: 0003  
6 ...  
7 0036: 0000
```

PROGRAM EXECUTION

- A program's instructions are stored at **contiguous addresses**
- The processor reads the program instructions **from memory one by one.**
- The address of the **next instruction** to be read is stored in the **Program Counter (PC)** register.

0100000000101001	0
1100000000101001	1
0110000000101001	2
0100000000101001	3
1110000000101001	4
0000000000101001	5
	...

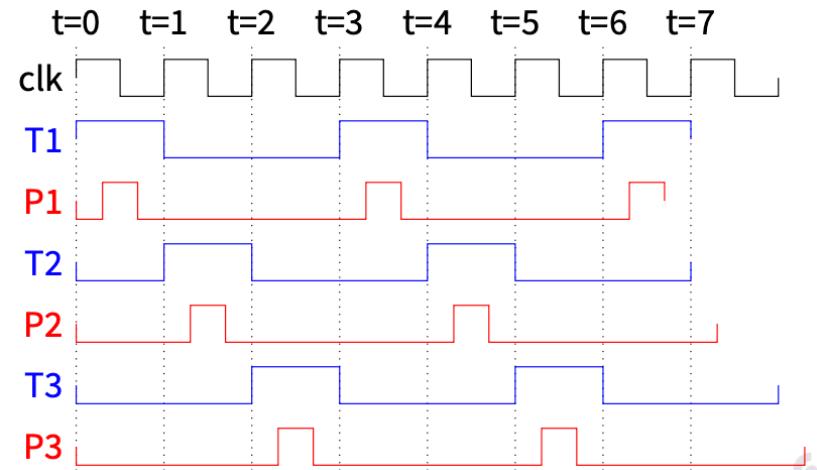
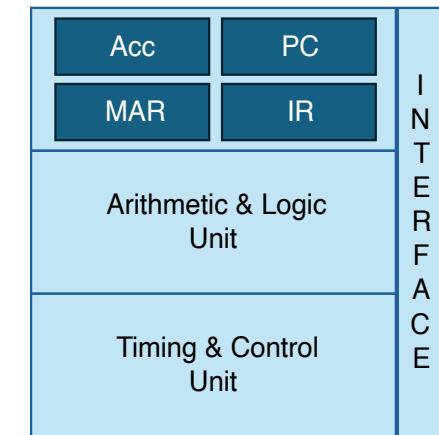
PROGRAM EXECUTION

1. **Fetch** → the instruction contained at the address indicated by the **PC** register is copied into the **Instruction Register (IR)**
 - The value contained in the **PC** register is incremented.
2. **Decode** → the processor "understands" the instruction to be executed.
3. **Execute** → The instruction is **executed** by the processor.

0100000000101001	0
1100000000101001	1
0110000000101001	2
0100000000101001	3
1110000000101001	4
0000000000101001	5
	...

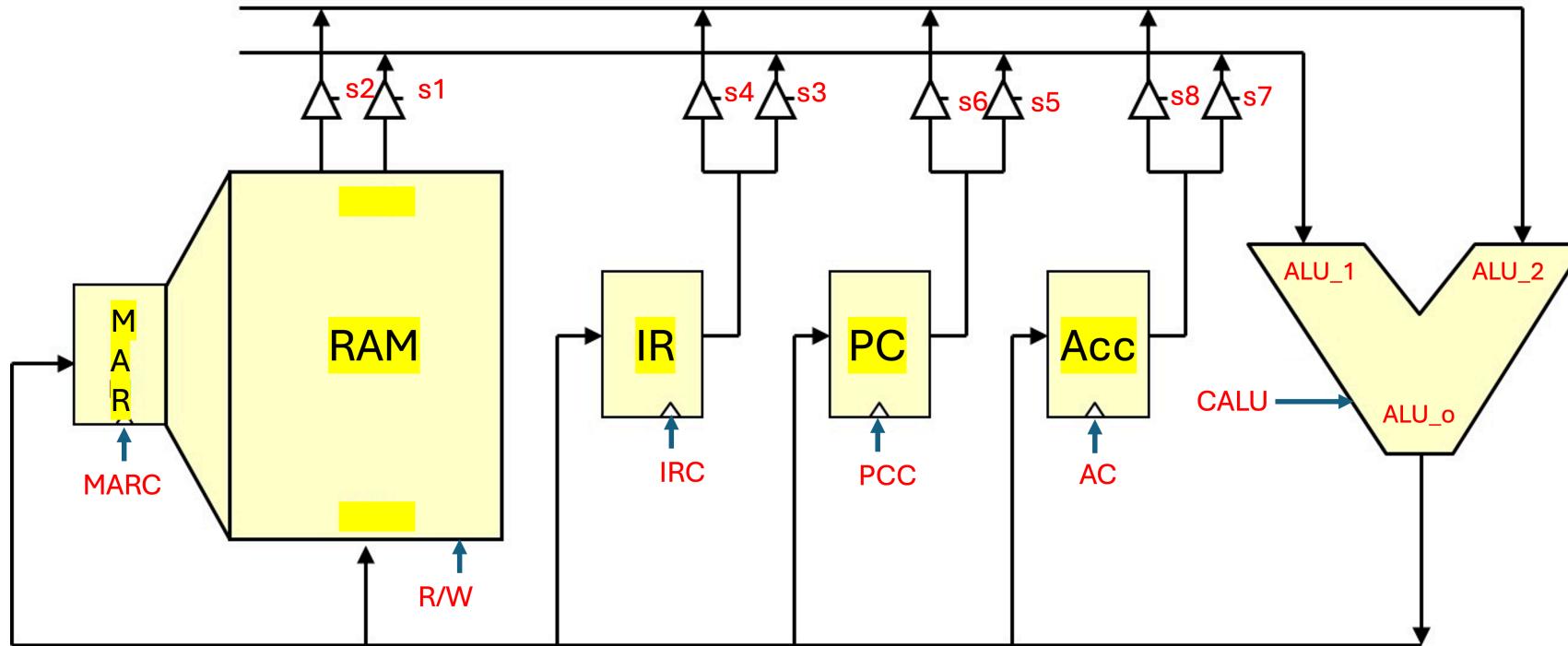
IMPLEMENTING THE CONTROL UNIT

- Creating a Time Table
 - One line for each instruction
 - One column for each clock time
 - For each time, the data path signals to be activated
- Derivation of a set of logical equations
 - An equation for each signal in the data path
 - An equation indicates when a signal should be activated
 - An equation depends on the control unit inputs and the **T, P signals**



- $T_i \rightarrow$ setup time
- $P_i \rightarrow$ memorization time

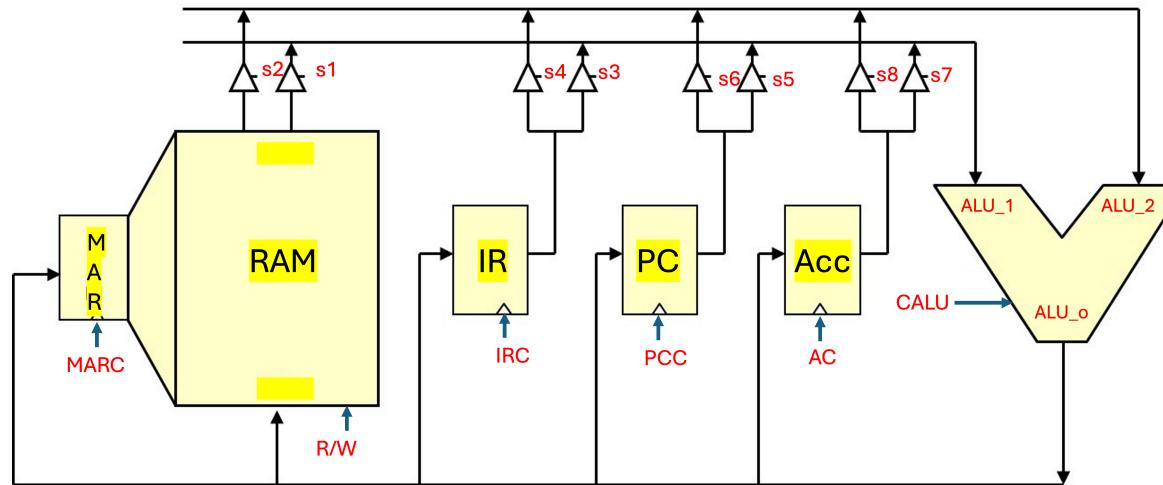
DATA PATH



CALU= 00 ($ALU_o = ALU_1$), 01 ($ALU_o = ALU_1 + ALU_2$), 10 ($ALU_o = ALU_1 + 1$), 11 ($ALU_o = ALU_1 - ALU_2$)

R/W= 0 (READ), 1 (WRITE)

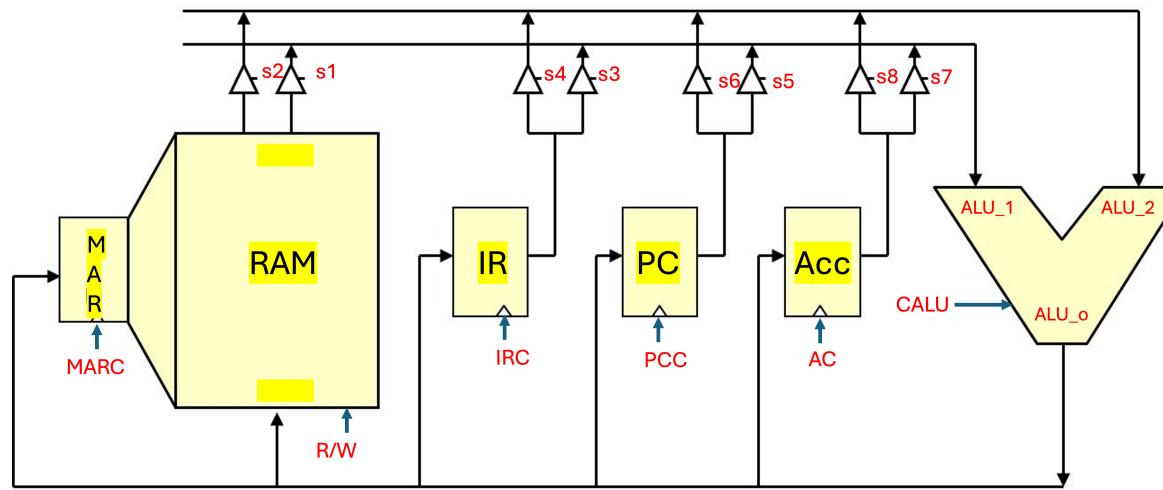
TIME TABLE - FETCH



xxx	time 1 (PC → RAM)	time 2 (RAM → IR)	time 3 (PC+1 → PC)
	PC → ALU ₁ , ALU _O → MAR s ₅ =1, CALU=00 (T_1) MARC=1 (P_1)	RAM → ALU ₁ , ALU _O → IR s ₁ =1, CALU=00 (T_2) IRC=1 (P_2)	PC → ALU ₁ , ALU _O → PC s ₅ =1, CALU=10 (T_3) PCC=1 (P_3)

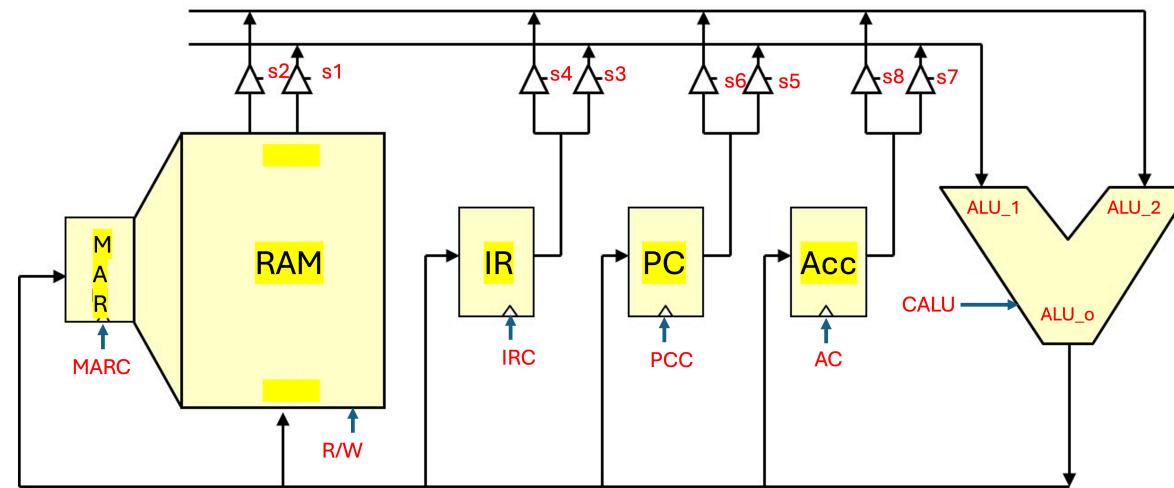
The fetch steps are the same for all instructions.

TIME TABLE - LOAD addr/value



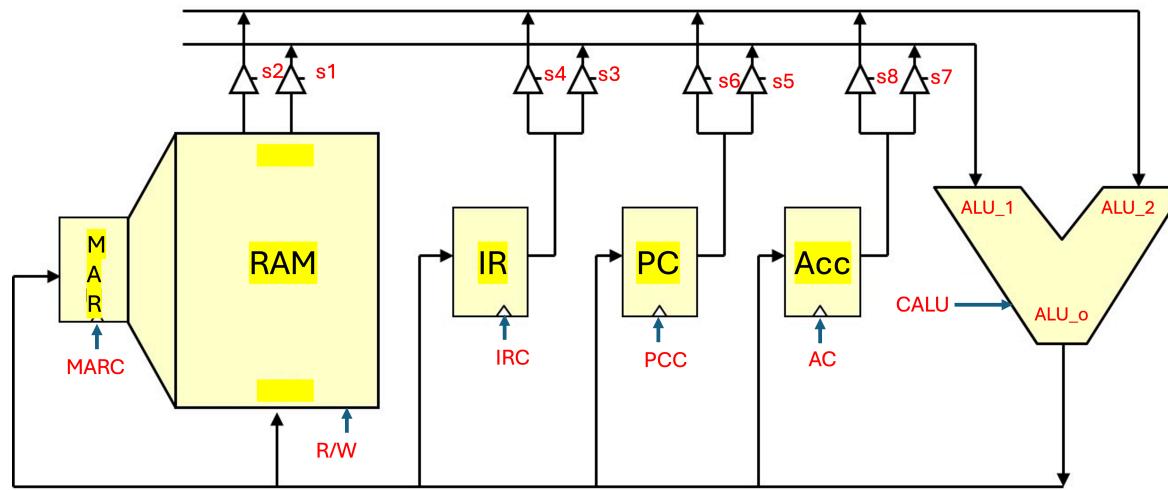
LOAD₁ addr	time 4 (IR → RAM)	time 5 (RAM → ACC)
	IR → ALU ₁ , ALU _O → MAR s3=1, CALU=00 (T_4) MARC=1 (P_4)	RAM → ALU ₁ , ALU _O → ACC s1=1, CALU=00 (T_5) AC=1 (P_5)
LOAD₂ value	time 4 (IR → ACC)	
	IR → ALU ₁ , ALU _O → ACC s3=1, CALU=00 (T_4) AC=1 (P_4)	

TIME TABLE - STORE addr



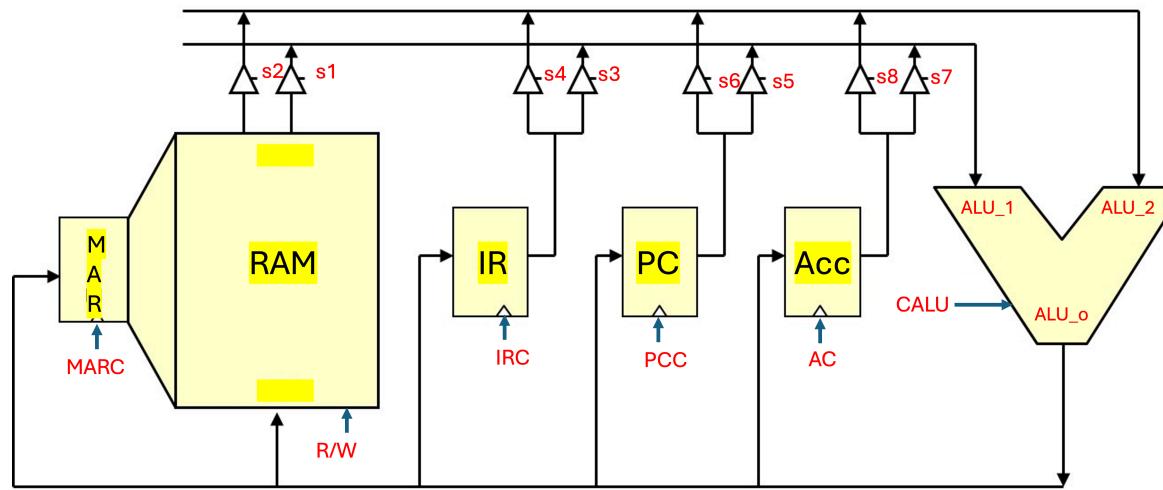
STORE addr	time 4 (IR → RAM)	time 5 (ACC → RAM)
	$IR \rightarrow ALU_1, ALU_O \rightarrow MAR$ $s3=1, CALU=00 (T_4)$ $MARC=1 (P_4)$	$ACC \rightarrow ALU_1, ALU_O \rightarrow RAM$ $s7=1, CALU=00 (T_5)$ $R/W=1 (P_5)$

TIME TABLE - ADD *addr/value*



ADD₁ addr	time 4 (IR → RAM)	time 5 (ACC + RAM → ACC)
	$IR \rightarrow ALU_1, ALU_O \rightarrow MAR$ $s3=1, CALU=00 (T_4)$ $MARC=1 (P_4)$	$ACC \rightarrow ALU_1, RAM \rightarrow ALU_2, ALU_O \rightarrow ACC$ $s2=1, s7=1, CALU=10 (T_5)$ $AC=1 (P_5)$
ADD₂ value	time 4 (ACC + IR → ACC)	
	$ACC \rightarrow ALU_1, IR \rightarrow ALU_2, ALU_O \rightarrow ACC$ $s3=1, s7=1, CALU=10 (T_4)$ $AC=1 (P_4)$	

TIME TABLE - SUB addr/value



SUB ₁ addr	time 4 (IR → RAM)	time 5 (ACC - RAM → ACC)
	$IR \rightarrow ALU_1, ALU_O \rightarrow MAR$ $s3=1, CALU=00 (T_4)$ $MARC=1 (P_4)$	$ACC \rightarrow ALU_1, RAM \rightarrow ALU_2, ALU_O \rightarrow ACC$ $s2=1, s7=1, CALU=11 (T_5)$ $AC=1 (P_5)$
SUB ₂ value	time 4 (ACC - IR → ACC)	
	$ACC \rightarrow ALU_1, IR \rightarrow ALU_2, ALU_O \rightarrow ACC$ $s3=1, s7=1, CALU=11 (T_4)$ $AC=1 (P_4)$	

TIME TABLE

fetch	s5=1, CALU=00 (T_1) MARC=1 (P_1)	s1=1, CALU=00 (T_2) IRC=1 (P_2)	s5=1, CALU=10 (T_3) PCC=1 (P_3)
--------------	---	--	--

LOAD₁ addr	s3=1, CALU=00 (T_4) MARC=1 (P_4)	s1=1, CALU=00 (T_5) AC=1 (P_5)
------------------------------	---	---

LOAD₂ value	s3=1, CALU=00 (T_4) AC=1 (P_4)
-------------------------------	---

STORE addr	s3=1, CALU=00 (T_4) MARC=1 (P_4)	s7=1, CALU=00 (T_5) R/W=1 (P_5)
-------------------	---	--

ADD₁ addr	s3=1, CALU=00 (T_4) MARC=1 (P_4)	s2=1, s7=1, CALU=10 (T_5) AC=1 (P_5)
-----------------------------	---	---

ADD₂ value	s3=1, s7=1, CALU=10 (T_4) AC=1 (P_4)
------------------------------	---

SUB₁ addr	s3=1, CALU=00 (T_4) MARC=1 (P_4)	s2=1, s7=1, CALU=11 (T_5) AC=1 (P_5)
-----------------------------	---	---

SUB₂ value	s3=1, s7=1, CALU=11 (T_4) AC=1 (P_4)
------------------------------	---

EXAMPLE OF LOGICAL EQUATION

fetch s5=1, CALU=00 (T_1) s1=1, CALU=00 (T_2) s5=1, CALU=10 (T_3)
MARC=1 (P_1) IRC=1 (P_2) PCC=1 (P_3)

LOAD₁ addr s3=1, CALU=00 (T_4) s1=1, CALU=00 (T_5)
 MARC=1 (P_4) AC=1 (P_5)

LOAD₂ value s3=1, CALU=00 (T_4)
 AC=1 (P_4)

STORE addr s3=1, CALU=00 (T_4) s7=1, CALU=00 (T_5)
 MARC=1 (P_4) R/W=1 (P_5)

ADD₁ addr s3=1, CALU=00 (T_4) s2=1, s7=1, CALU=10 (T_5)
 MARC=1 (P_4) AC=1 (P_5)

ADD₂ value s3=1, s7=1, CALU=10 (T_4)
 AC=1 (P_4)

SUB₁ addr s3=1, CALU=00 (T_4) s2=1, s7=1, CALU=11 (T_5)
 MARC=1 (P_4) AC=1 (P_5)

SUB₂ value s3=1, s7=1, CALU=11 (T_4)
 AC=1 (P_4)

EXAMPLE OF LOGICAL EQUATION

$$\text{MARC} = P_1 + (\text{LOAD}_1 \cdot P_4) + (\text{STORE} \cdot P_4) + (\text{ADD}_1 \cdot P_4) + (\text{SUB}_1 \cdot P_4)$$

EXAMPLE OF LOGICAL EQUATION

fetch $s_5=1, \text{CALU}=00 (T_1)$ $s_1=1, \text{CALU}=00 (T_2)$ $s_5=1, \text{CALU}=10 (T_3)$
 MARC=1 (P_1) IRC=1 (P_2) PCC=1 (P_3)

LOAD₁ addr $s_3=1, \text{CALU}=00 (T_4)$ $s_1=1, \text{CALU}=00 (T_5)$
 MARC=1 (P_4) AC=1 (P_5)

LOAD₂ value $s_3=1, \text{CALU}=00 (T_4)$
 AC=1 (P_4)

STORE addr $s_3=1, \text{CALU}=00 (T_4)$ $s_7=1, \text{CALU}=00 (T_5)$
 MARC=1 (P_4) R/W=1 (P_5)

ADD₁ addr $s_3=1, \text{CALU}=00 (T_4)$ $s_2=1, s_7=1, \text{CALU}=10 (T_5)$
 MARC=1 (P_4) AC=1 (P_5)

ADD₂ value $s_3=1, s_7=1, \text{CALU}=10 (T_4)$
 AC=1 (P_4)

SUB₁ addr $s_3=1, \text{CALU}=00 (T_4)$ $s_2=1, s_7=1, \text{CALU}=11 (T_5)$
 MARC=1 (P_4) AC=1 (P_5)

SUB₂ value $s_3=1, s_7=1, \text{CALU}=11 (T_4)$
 AC=1 (P_4)

EXAMPLE OF LOGICAL EQUATION

$$s_2 = (\text{ADD}_1 \cdot T_5) + (\text{SUB}_1 \cdot T_5)$$

EXAMPLE OF LOGICAL EQUATION

fetch $s_5=1$, CALU=00 (T_1) $s_1=1$, CALU=00 (T_2) $s_5=1$, CALU=10 (T_3)
 MARC=1 (P_1) IRC=1 (P_2) PCC=1 (P_3)

LOAD₁ addr $s_3=1$, CALU=00 (T_4) $s_1=1$, CALU=00 (T_5)
 MARC=1 (P_4) AC=1 (P_5)

LOAD₂ value $s_3=1$, CALU=00 (T_4)
 AC=1 (P_4)

STORE addr $s_3=1$, CALU=00 (T_4) $s_7=1$, CALU=00 (T_5)
 MARC=1 (P_4) R/W=1 (P_5)

ADD₁ addr $s_3=1$, CALU=00 (T_4) $s_2=1, s_7=1$, CALU=10 (T_5)
 MARC=1 (P_4) AC=1 (P_5)

ADD₂ value $s_3=1, s_7=1$, CALU=10 (T_4)
 AC=1 (P_4)

SUB₁ addr $s_3=1$, CALU=00 (T_4) $s_2=1, s_7=1$, CALU=11 (T_5)
 MARC=1 (P_4) AC=1 (P_5)

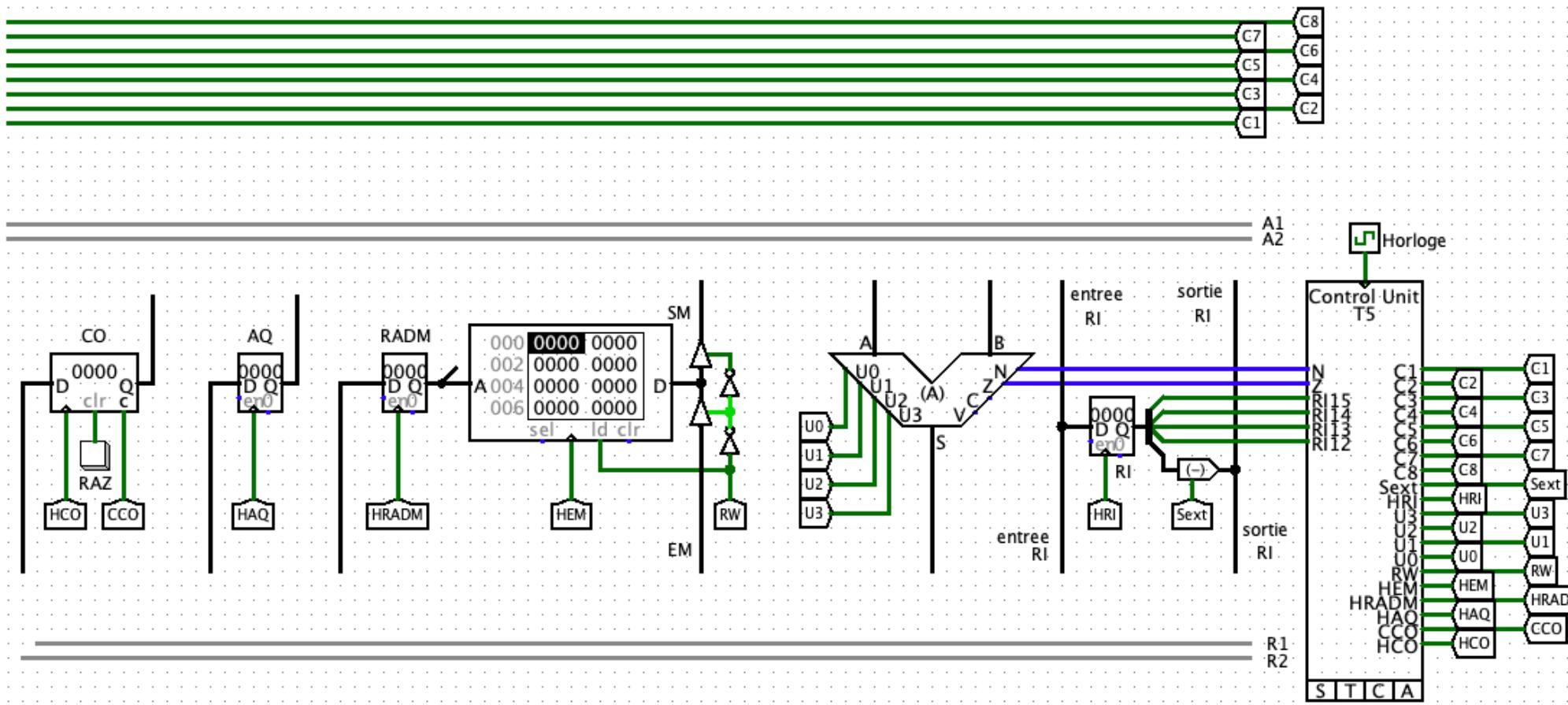
SUB₂ value $s_3=1, s_7=1$, CALU=11 (T_4)
 AC=1 (P_4)

EXAMPLE OF LOGICAL EQUATION

$$s3 = T_4$$

LAB SESSION

LOGISIM SIMULATOR



THANK YOU

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