COP 3402 Systems Software

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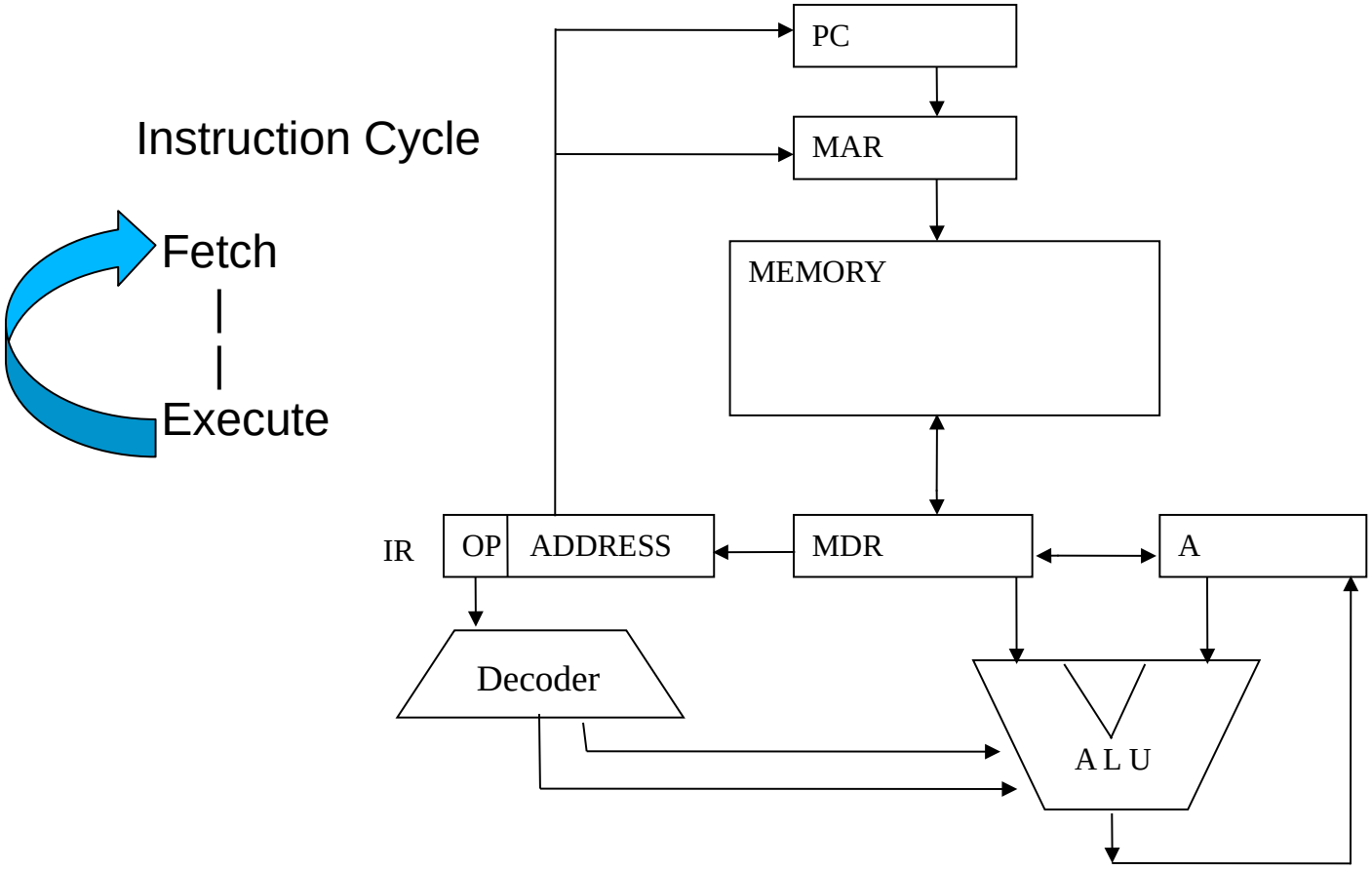
The processor as an instruction interpreter.

Outline

1. **The structure of a tiny computer.**
2. **A program as an isolated system.**
3. **The instruction format.**
4. **Assembly language.**

Von-Neumann Machine (VN)



Instruction Cycle

- The Instruction Cycle, or Machine Cycle, in the Von-Neumann Machine (VN) is composed of 2 steps:

  Fetch step: Instruction is retrieved from memory and placed in the CPU.

  Execution step: Instruction is executed.

- **A simple Hardware Description Language will be used in order to understand how instructions are executed in VN.**

Definitions

- **Program Counter (PC)** is a register that holds the address of the next instruction to be fetched and executed.

- **Memory Address Register (MAR)** is a register used to select the address of a specific memory location in Main Storage (RAM) so that instructions or data can be written to or read from that location.

- **Main Storage (MEM)** is used to store programs and data. Also known as Random Access Memory (RAM).

Definitions

- **Memory Data Register (MDR)** is a register used to store/load data or instructions from MEM. The contents in the MDR can be either an instruction or simple data such as an integer.

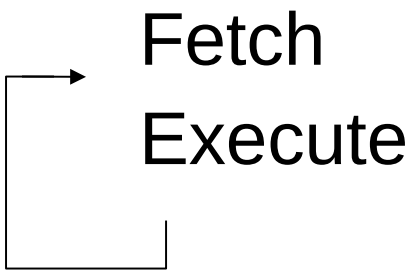
- **Instruction Register (IR)** This register stores the instruction to be executed by the processor.

Definition

- **Arithmetic Logic Unit (ALU)** is used to execute Arithmetic and logic instructions such as ADD or Greater than (>).
- **DECODER** is a circuit that decides which instruction the processor will execute. For example, it takes the instruction op-code from the IR as input and outputs a signal to the Control Unit to carry out the steps to execute an instruction.
- **Accumulator (A)** In this tiny architecture, is the only register that can be used by user programs.

Fetch-Execute Cycle

- In the VN, the Instruction Cycle is defined by the following loop:



- In order to fully explain the Fetch Cycle we need to study the details of the VN data flow.

- The data flow consists of 4 steps.

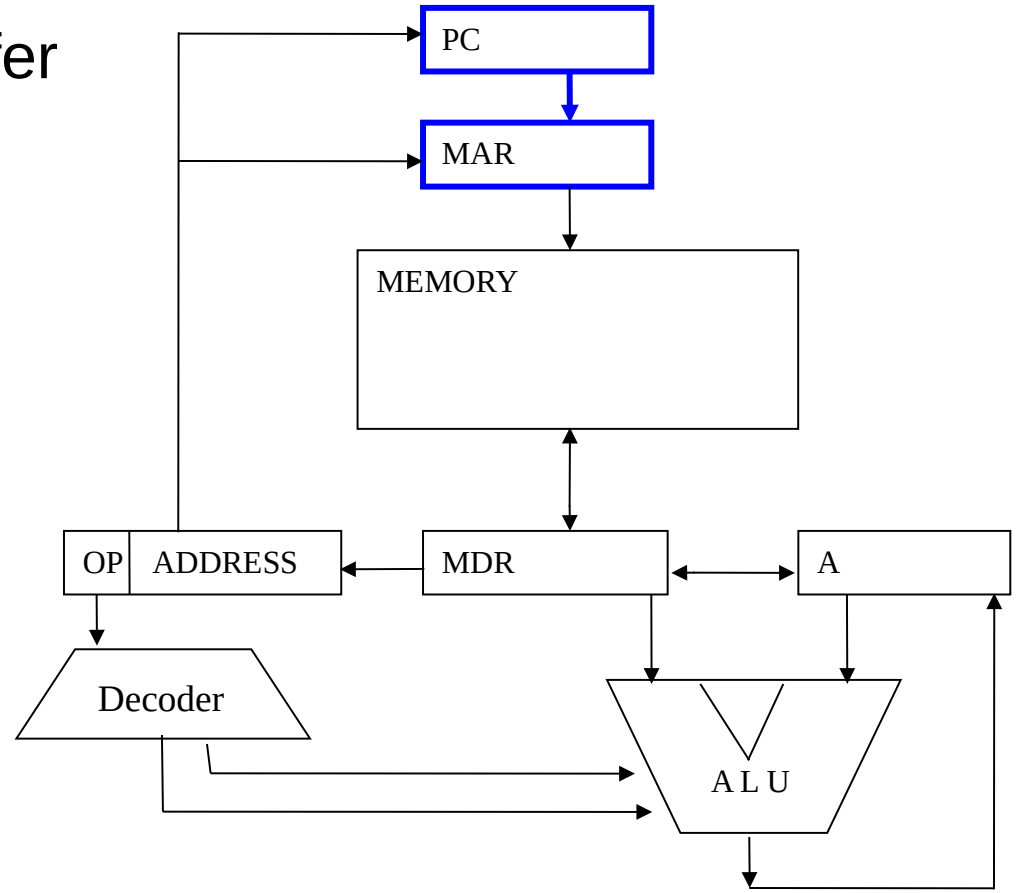
Data Movement 1

- Given registers PC and MAR, the transfer of the contents

  from PC into MAR

  is indicated as:

  MAR□PC

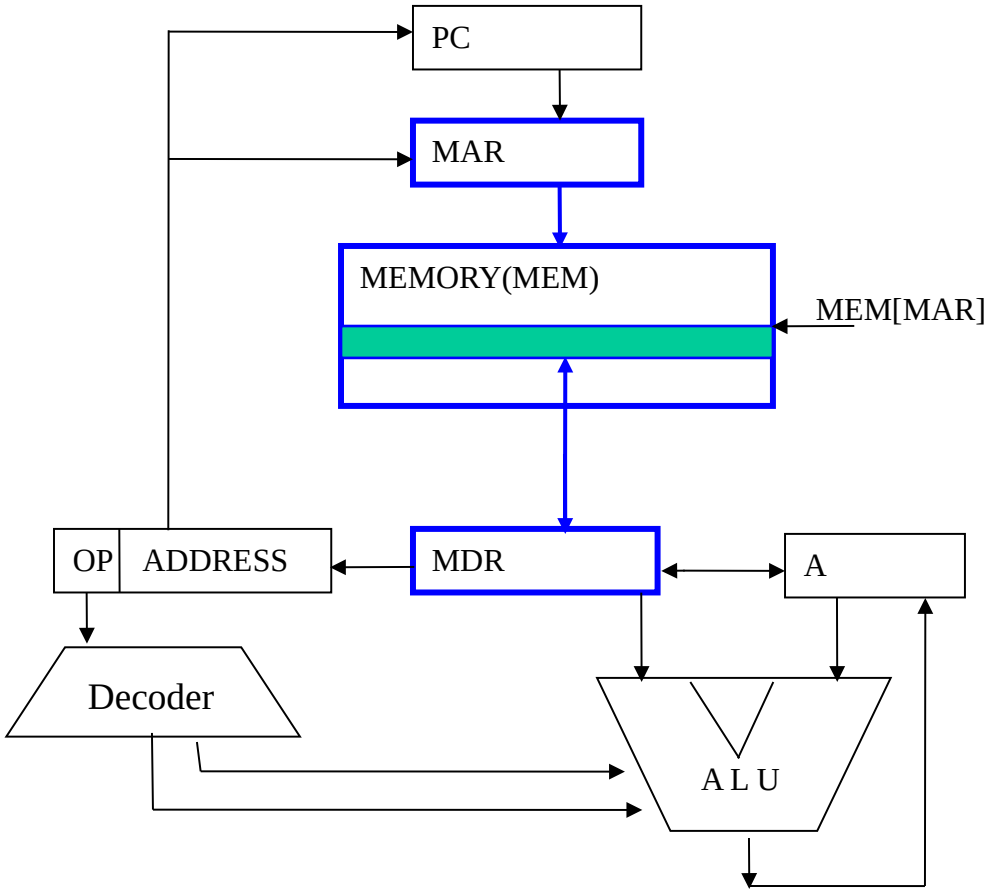


Data Movement 2

- To transfer information from a memory location into the register MDR, we use:

  MDR MEM[MAR]

- The address of the memory location has been stored previously into the MAR register



Data Movement 2 (Cont.)

- To transfer information from the MDR register to a memory location, we use:

  MEM [MAR] MDR

  *see previous slide for diagram

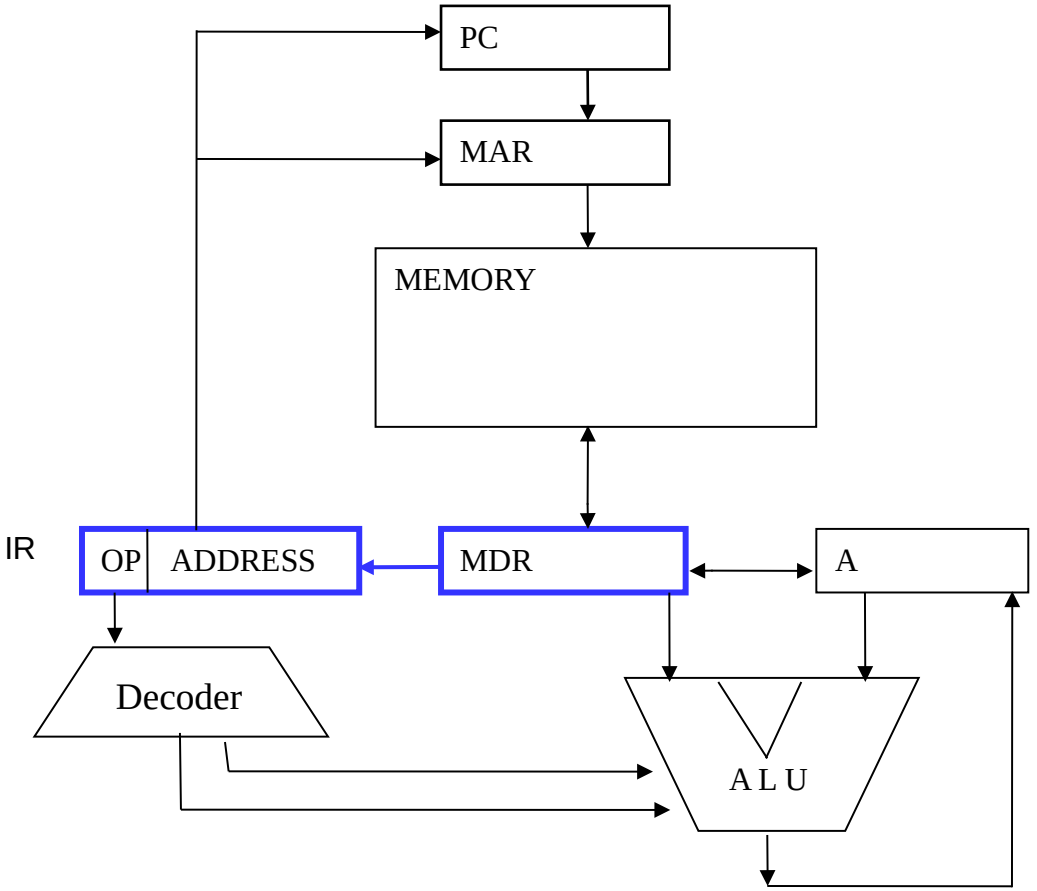
- The address of the memory location has been previously stored into the MAR

Data Movement 3

- Transferring from MDR into IR

  is indicated as:

  IR□MDR



Instruction Register Properties

- The Instruction Register (IR) has two fields:

  Operation (OP) and the ADDRESS.

- These fields can be accessed using the selector operator “**.**”

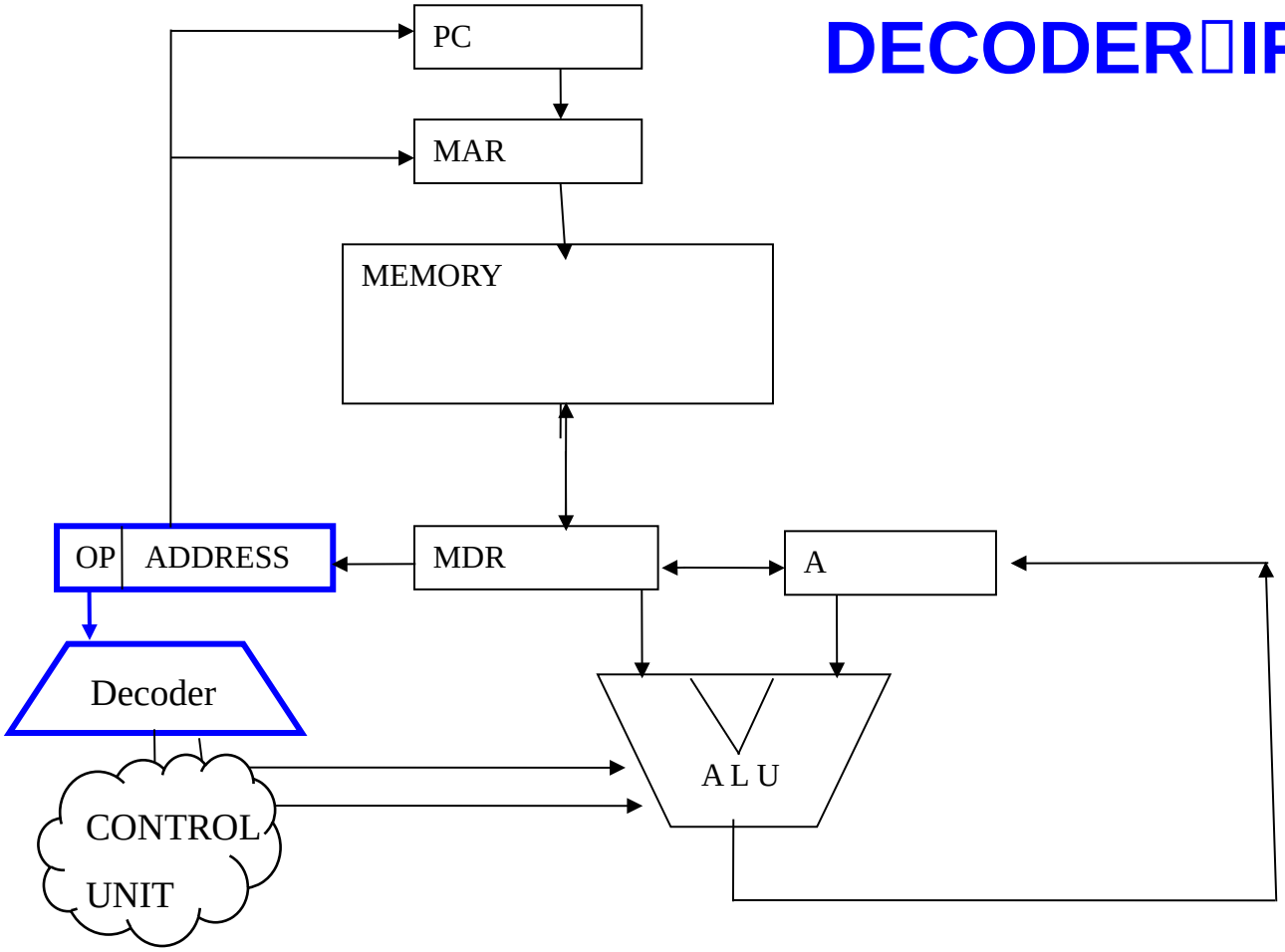
Data Movement 4

- The Operation portion of the field is accessed as IR.OP
- The operation field of the IR register is sent out to the Control Unit through a DECODER using:

Control Unit DECODER IR.OP

- DECODER: If the value of IR.OP==00, then the decoder is set to execute the fetch cycle again.

Data Movement 4 Cont.



DECODER□IR.OP

Instruction Cycle

- The Instruction Cycle has 2 components.
- Fetch Cycle which retrieves the instruction from memory.
- Execution Cycle which carries out the execution of the instruction retrieved.

00 Fetch Cycle

1.MAR ←PC

2.PC ←PC+1

3.MDR ←MEM[MAR]

4.IR ←MDR

1. Copy contents of PC into MAR
2. Increment PC Register
3. Load content of memory location into MDR
4. Copy value stored in MDR to IR

CU ← DECODER ← IR.OP. ←

Once Instruction is in IR, Opcode is sent through DECODER to Control Unit for execution.

00 Fetch Cycle

1. MAR ← PC
2. PC ← PC+1 || MDR ← MEM[MAR]
3. IR ← MDR

Steps 2 and 3 in the former slide, can be executed in parallel

(Symbol "||" means in parallel with)

Execution: 01 LOAD

1. MAR ← IR.ADDR
2. MDR ← MEM[MAR]
3. A ← MDR
4. DECODER ← 00

1. Copy the IR address value field into MAR
2. Load the content of a memory location into MDR
3. Copy content of MDR into A register
4. Set Decoder to execute Fetch Cycle

Execution: 02 ADD

1. MAR ← IR.ADDR
2. MDR ← MEM[MAR]
3. A ← A + MDR
4. DECODER ← 00

1. Copy the IR address value field into MAR
2. Load content of memory location to MDR
3. Add contents of MDR and A register and store result back into A
4. Set Decoder to execute Fetch cycle

Execution: 03 STORE

1. MAR ← IR.ADDR
2. MDR ← A
3. MEM[MAR] ← MDR
4. DECODER ← 00

1. Copy the IR address value field into MAR
2. Copy A register contents into MDR
3. Copy content of MDR into a memory location
4. Set Decoder to execute fetch cycle

Execution: 07 HALT

1. STOP

1. Program ends normally

Instruction Set Architecture (ISA)

00 Fetch (hidden instruction)

- **MAR ← PC**
- **MDR ← MEM[MAR]**
- **IR ← MDR**
- **PC ← PC+1**
- **DECODER ← IR.OP**

02 Add

- **MAR ← IR.Address**
- **MDR ← MEM[MAR]**
- **A ← A + MDR**
- **DECODER ← 00**

01 Load

- **MAR ← IR.Address**
- **MDR ← MEM[MAR]**
- **A ← MDR**
- **DECODER ← 00**

03 Store

- **MAR ← IR.Address**
- **MDR ← A**
- **MEM[MAR] ← MDR**
- **DECODER ← 00**

07 Halt

One Address Architecture (instruction format)

- The instruction format of this one-address architecture is:

OP	ADDRESS
LOAD	0110 0110 0110

Instruction Set Architecture

- **01 - LOAD <X> = LOAD A, <X>**

  Loads the contents of memory location “X” into A (A stands for Accumulator register).

- **02 – ADD <X>**

  The data value stored at address “X” is added to A and the result is stored back in the A. **A A + MEM[X])**

- **03 – STORE <X>**

  Store the contents of A into memory location “X”.

- **04 - SUB <X> (A A – MEM[X])**

  Subtracts the value located at address “X” from A and stored the result back in the A.

Instruction Set Architecture

- **05 - IN <Device #>**

  A value from the input device is transferred into the AC.

- **06 - OUT <Device #>**

  Print out the contents of the AC in the output device.

Device #	Device
3	Keyboard
7	Printer
9	Screen

  For instance you can write: **IN <3> “23”** where “23” is the value you are typing in.

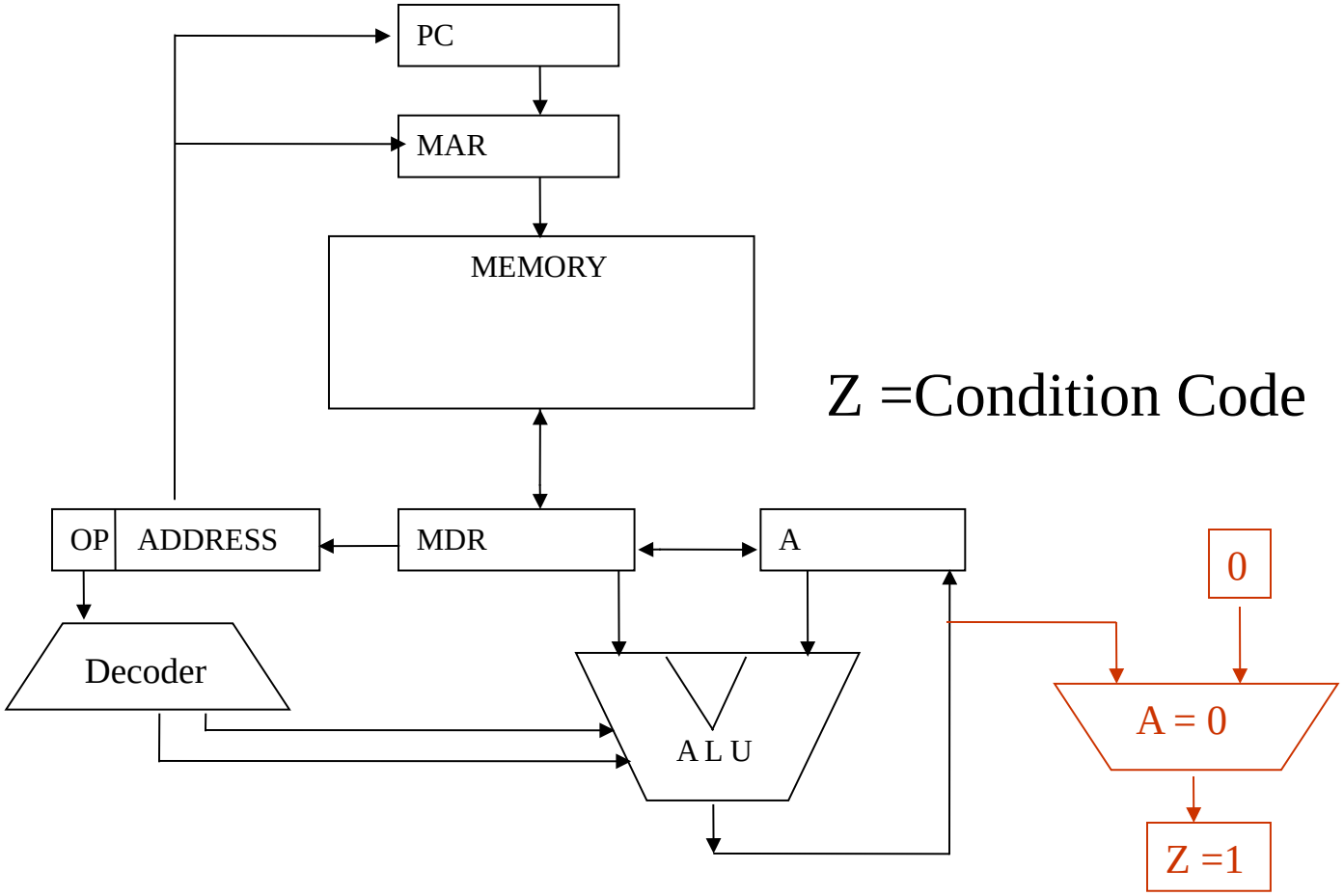
Instruction Set Architecture

- **07 - Halt**
  The machine stops execution of the program.
  (Return to the O.S)

- **08 - JMP <X>**
  Causes an unconditional branch to address “X”.
  PC X

- **09 - SKIPZ**
  If the contents of Accumulator = 0 then PC=PC+1 (the next instruction is skipped).
  (If the output of the ALU equals zero, the Z flag is set to 1. In this machine we test the flag and if Z = 1 the next instruction is skipped (pc= pc + 1)

If the output of the ALU equals zero, the Z flag is set to 1



Instruction Set Architecture

- For this tiny assembly language, we are using only one condition code (CC) Z = 0 .
- Condition codes indicate the result of the most recent arithmetic operation
- Two more flags (CC) can be incorporated to test negative and positives values:

  G = 1 Positive value

  Z = 1 Zero

  L = 1 Negative value

Program State Word (condition codes - CC)

The PSW is a register in the CPU that provides the OS with information on the status of the running program

PC	Interrupt Flags						MASK	CC			Mode
	OV	MP	PI	TI	I/O	SVC	To be defined later	G	Z	L	

In addition to the Z flag, we can incorporate two more flags:

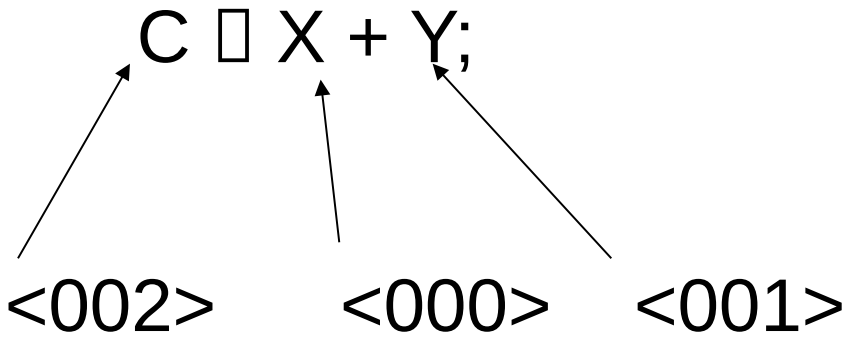
1) G meaning “greater than zero”
2) L meaning “less than zero”

ISA
Instruction descriptions

opcode	mnemonic	meaning
0001	LOAD <x>	A ← Mem[x]
0010	ADD <x>	A ← A + Mem[x]
0011	STORE <x>	Mem[x] ← A
0100	SUB <x>	A ← A – Mem[x]
0101	IN <Device_#>	A ← read from Device
0110	OUT <Device_#>	A → output to Device
0111	HALT	Stop
1000	JMP <x>	PC ← x
1001	SKIPZ	If Z = 1 Skip next instruction
1010	SKIPG	If G = 1 Skip next instruction
1011	SKIPL	If L = 1 Skip next instruction

Assembly language Programming examples

Assign a memory location to each variable:



If it is necessary to use temporary memory locations, assign labels (names) to them.

Assembly language Programming examples

Memory

000	1245
001	1755
002	0000
003	Load <000>
004	Add <001>
005	Store <002>
006	Halt

After execution →

Memory

000	1245
001	1755
002	3000
003	Load <000>
004	Add <001>
005	Store <002>
006	Halt

One Address Architecture

- The instruction format of this one-address architecture consists of 16 bits: 4 bits to represent instructions and 12 bits for addresses :

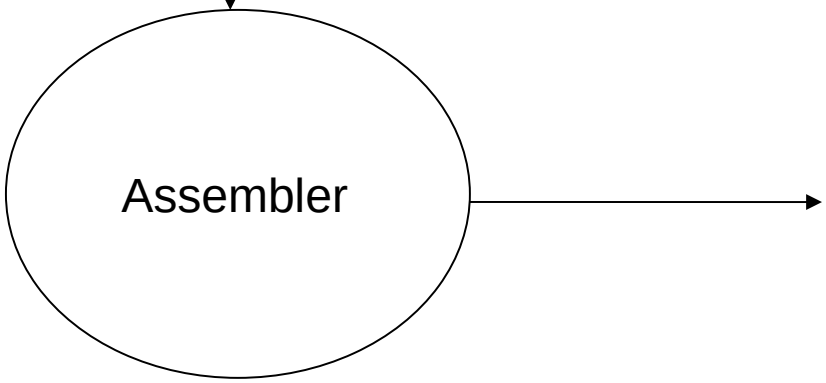
OP	ADDRESS
0001	0000 0001 0001

Assembler: translate symbolic code to executable code (binary)

Assembly Language

Load <000>
Add <001>
Store <002>
Halt

01 → LOAD
02 → ADD
03 → STORE
04 → SUB
05 → IN
06 → OUT
07 → HALT
08 → JMP
09 → SKIPZ



In binary

0001 0000 0000 0000
0010 0000 0000 0001
0011 000000000010
0111 000000000000

Assembler Directives

- The next step to improve our assembly language is the incorporation of *pseudo-ops (assembler directives)* to invoke *a special service from the assembler (pseudo-operations do not generate code)*

  .begin tell the assembler where the program starts

  .data to reserve a memory location.

  .end tells the assembler where the program ends.

  Labels are symbolic names used to identify memory locations.

Assembler Directives

This is an example of the usage of assembler directives

.begin

"*Assembly language instructions*"

halt *(return to OS)*
.data *(to reserve a memory location)*

.end **(** *tells the assembler where the program ends)*

note:
the directive .end can be used to indicate where the program starts (for example: ".end <insert label here>" _

Assembly language Programming examples

Label	opcode	address
start	.begin	
	in	x003
	store	a
	in	x003
	store	b
	load	a
	sub	TWO
	add	b
	out	x009
	halt	
a	.data	0
b	.data	0
TWO	.data	2
	.end	start

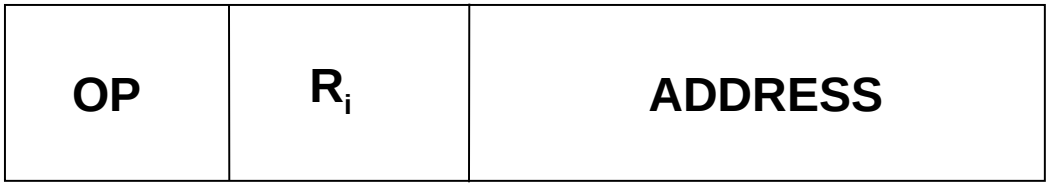
Text section (code)

Data section

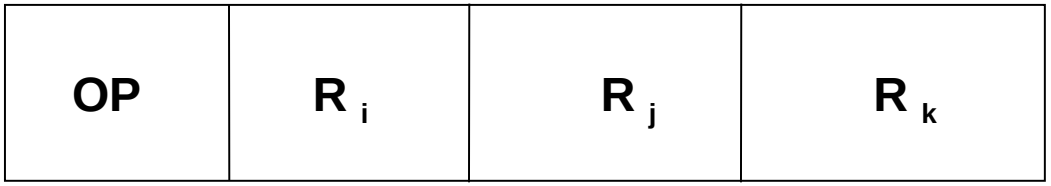
LOAD/STORE ARCHITECTURE

A load/store architecture has a “register file” in the CPU and it uses three instruction formats. Therefore, its assembly language is different to the one of the accumulator machine.

JMP <address>



Load R3, <address>



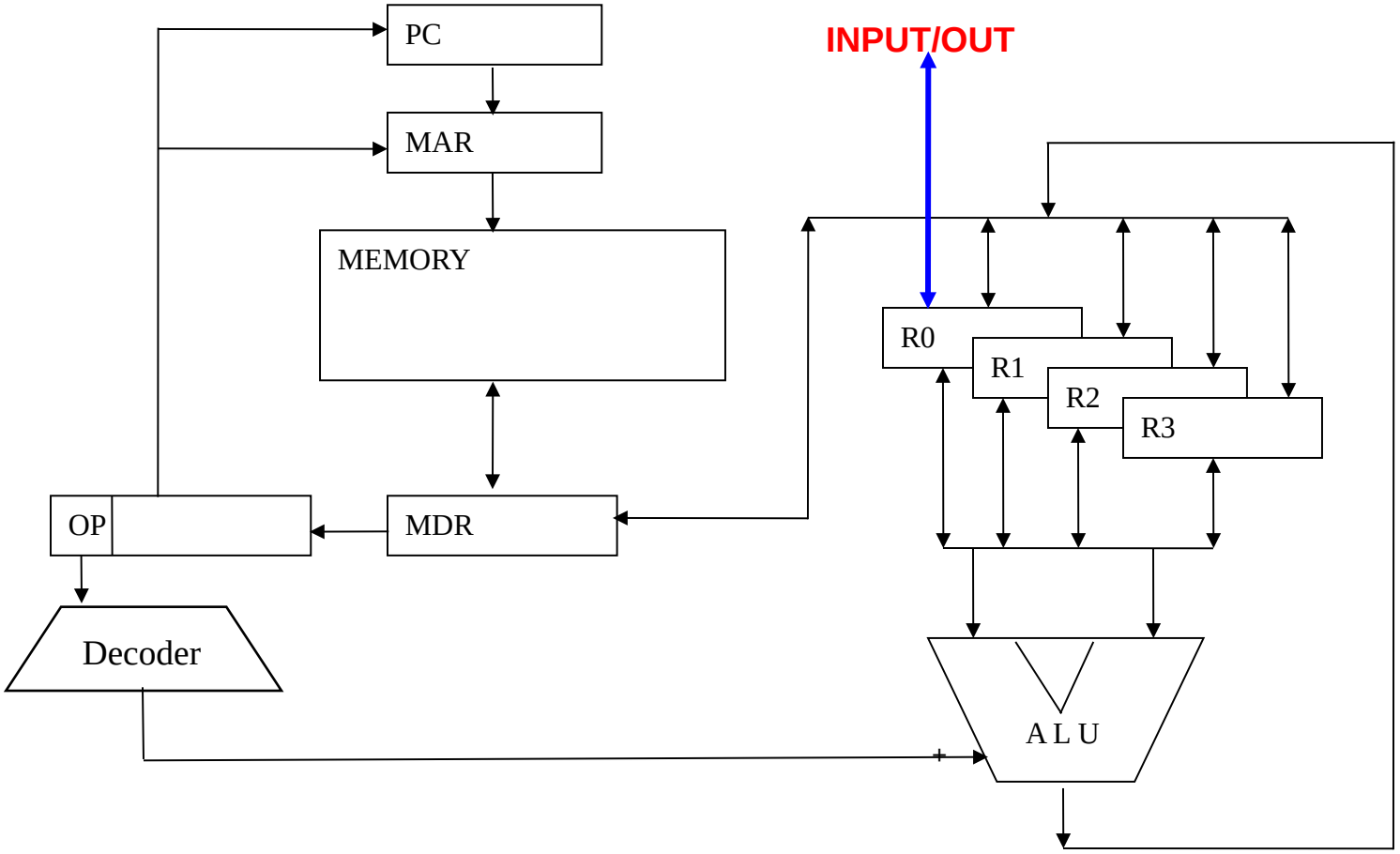
Add R3, R2, R1

ISA
Load/Store Architecture

opcode	mnemonic	meaning
0001	LOAD R0, <x>	R0 ← Mem[x]
0010	ADD R_i, R_j, R_k	R_i ← R_j + R_k
0011	STORE R0, <x>	Mem[x] ← R0
0100	SUB R_i, R_j, R_k	R_i ← R_j - R_k
0101	IN <Device_#>	R0 ← read from Device
0110	OUT <Device_#>	R0 → output to Device
0111	HALT	Stop
1000	JMP <x>	PC ← x
1001	SKIPZ	If Z = 1 Skip next instruction
1010	SKIPG	If G = 1 Skip next instruction
1011	SKIPL	If L = 1 Skip next instruction

SKIP instructions only work with register zero

Load/Store Architecture



Multiplying two numbers

```
Label                opcode   address
start                .begin
                     in             x003
                     store          a
                     in             x003
                     store          b
here                 load           result
                     add            a
                     store          result
                     load           b
                     sub            ONE
                     store          b
                     skipz
                     jmp            here
                     load           result
                     out            x009
                     halt
a                    .data          0
b                    .data          0
ONE                  .data          1
result    .data        0
                     .end           start
```

One address Architecture
(six memory access inside the loop)

```
Label                opcode   address
start                .begin
                     in             x003
                     store          R0, a
                     in             x003
                     store          R0, b
                     load           R2, result
                     load           R3, a
                     load           R0, b
                     load           R1, ONE
here                 add            R2, R2, R3
                     sub            R0, R0, R1
                     skipz
                     jmp            here
                     store          R2, result
                     load           R0, result
                     out            x009
                     halt
a                    .data          0
b                    .data          0
ONE                  .data          1
result    .data        0
                     .end           start
```

Load/Store architecture
(no memory access inside the loop)

Next time will talk about virtual machines