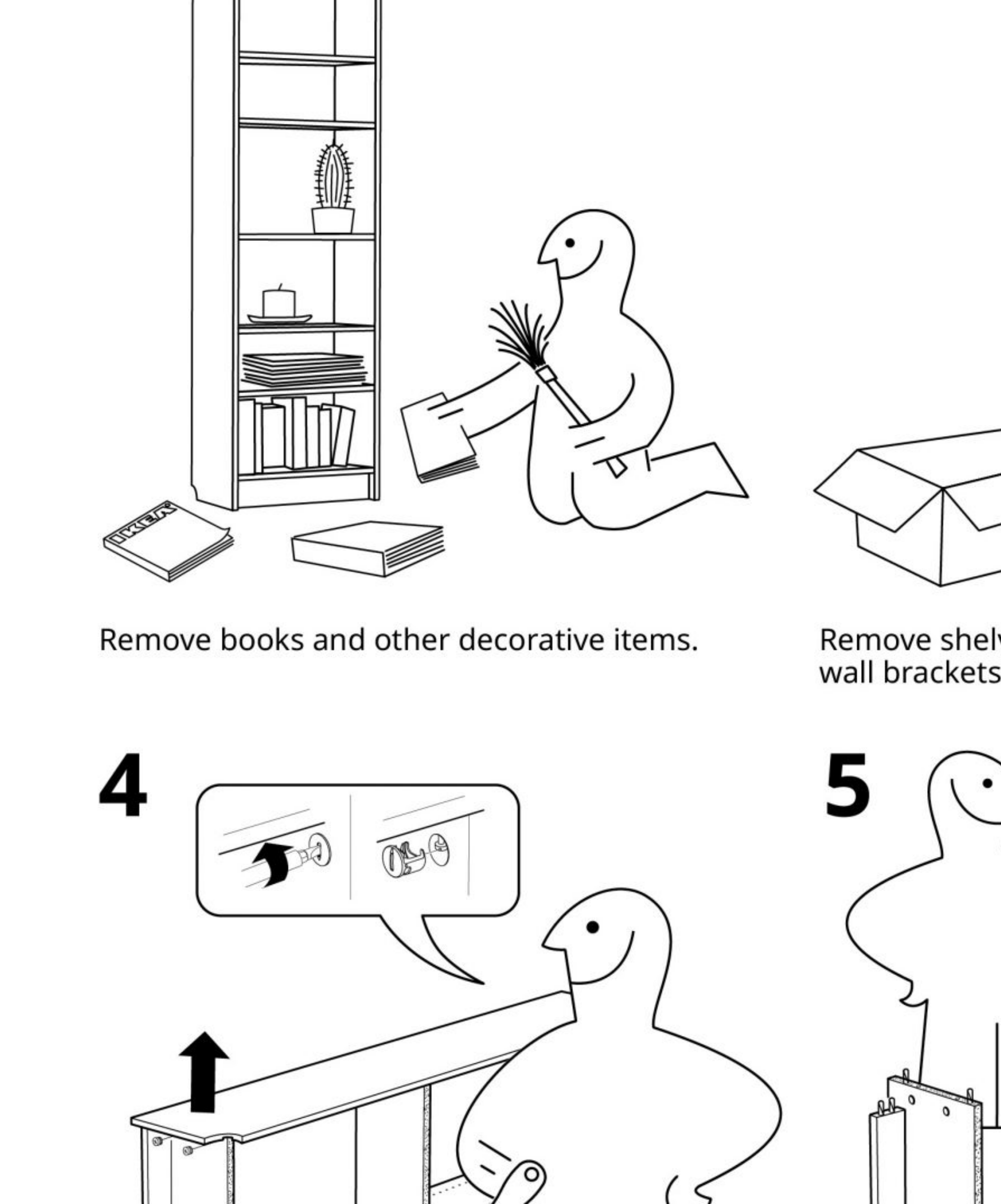
DR EDWARD ANSTEAD

LOGIC AND COMPUTER ARCHITECTURE

Overview of a simple computer
and Instruction set architecture



TODAY...

- **LO2:** Explain the architecture of standard computer hardware and how it is used to represent and calculate with data
- We will look at the principles of building a example computer system and its components, this will be followed by a description of its instruction set.
- **LO3:** Explain the methods used to represent a wide variety of types of data on a computer
- As we uncover the principles of a computer instruction set we will see its application in writing simple programs.

TOPICS

- Further work with the MARIE example computer
- additional instructions
- Microoperations and Register Transfer Language

MARIE EXAMPLE PROGRAM: CALCULATOR

- Multiply two values given as input
- We are going to make use of…
  - variables
  - skipcond
  - jump
  - labels

MARIE EXAMPLE PROGRAM: CALCULATOR

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  - variables
  - skipcond
  - jump
  - labels

A PROGRAMMER FRIENDLY LABEL IN THE CODE THAT IDENTIFIES A PARTICULAR LINE

SKIPCOND

`SKIPCOND` skips the next instruction according to the value of the AC.

```
If IR[11 - 10] = 00 then
     If AC < 0 then PC ← PC + 1
else If IR[11 - 10] = 01 then
     If AC = 0 then PC ← PC + 1
else If IR[11 - 10] = 10 then
     If AC > 0 then PC ← PC + 1
```

SKIPCOND

`SKIPCOND` skips the next instruction according to the value of the AC.

```
If IR[11 - 10] = 00 then
     If AC < 0 then PC ← PC + 1
else If IR[11 - 10] = 01 then
     If AC = 0 then PC ← PC + 1
else If IR[11 - 10] = 10 then
     If AC > 0 then PC ← PC + 1
```

IR 000(HEX) AC < 0
IR 400(HEX) AC = 0
IR 800(HEX) AC > 0

SKIPCOND

`SKIPCOND` skips the next instruction according to the value of the AC.

```
skipcond 000 /if the value in the AC is <0 skip next line
skipcond 400 /if the value in the AC ==0 skip next line
skipcond 800 /if the value in the AC is >0 skip next line
```

SKIPCOND

SKIPCOND skips the next instruction according to the value of the AC.

```
skipcond 000 /if the value in the AC is <0 skip next line
skipcond 400 /if the value in the AC ==0 skip next line
skipcond 800 /if the value in the AC is >0 skip next line
```

SKIP NEXT LINE - ADD 1 TO PC

JUMP

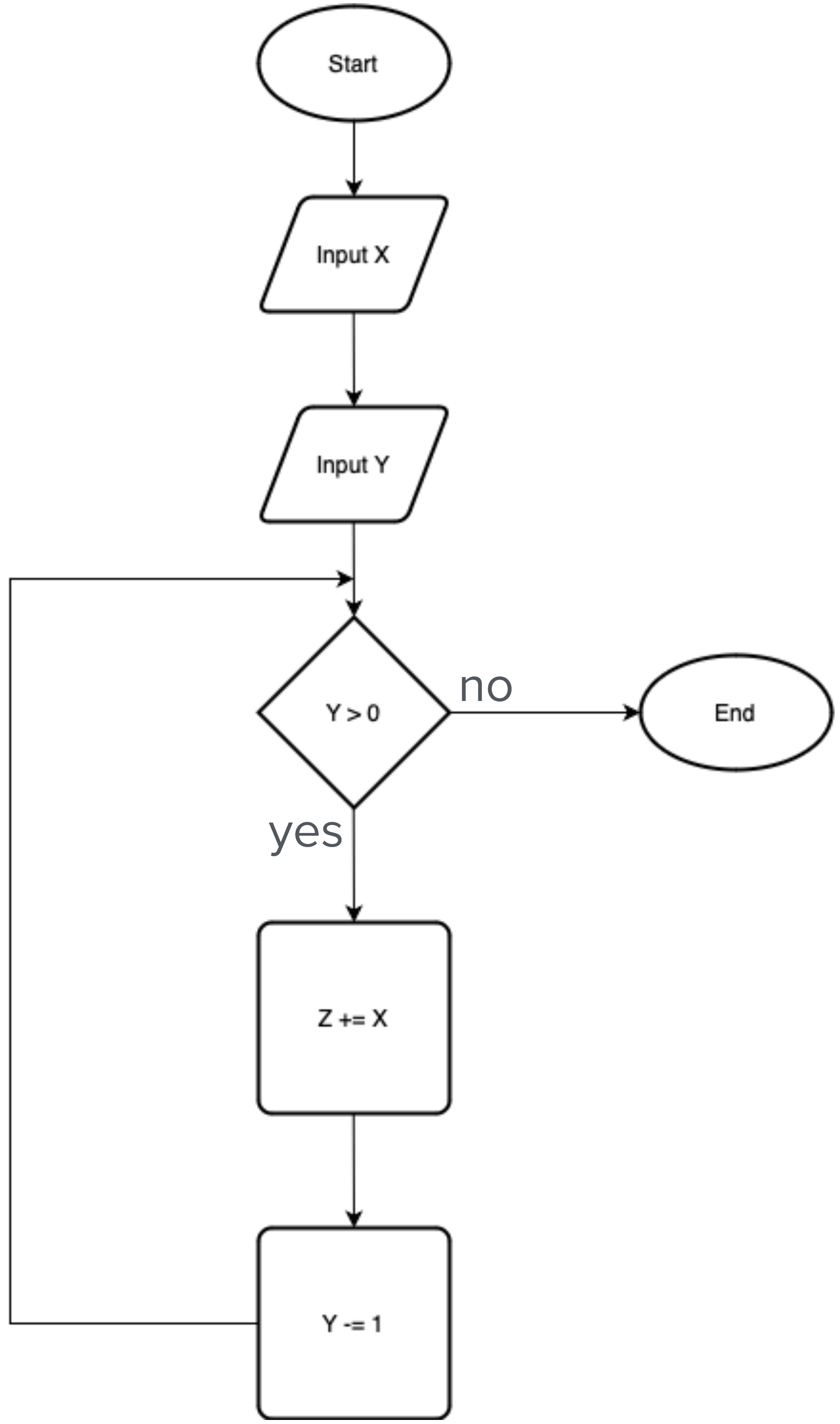
- jump to an instruction at the specified address
- We can make this much more readable with labels!

```
jump 0A1 /Jump to instruction at 0A1
jump LAB /Jump to the instruction with the label LAB
```

- By Combining jump and skipcond we can make the equivalent constructs of the loops and conditionals we are familiar with in high level programming

PROGRAM FLOWCHART

- Multiply two values given as input
- We are going to make use of…
  - variables
  - skipcond
  - jump
  - labels



EXAMPLE PROGRAM IF/ELSE

- write a program that implements the following pseudocode:

```
if X = Y then
 X = X x 2
else
 Y = Y - X
```

EXTENDING OUR INSTRUCTION SET

MARIE Instructions

Binary	Hex	Instructio	Meaning
0001	1	Load X	Load contents of address X into AC
0010	2	Store X	Store contents of AC in address X
0011	3	Add X	Add the contents of address X to AC
0100	4	Subt X	Subtract the contents of address X to AC
0101	5	Input	Input a value from the keyboard into AC
0110	6	Output	Output the value from the AC to the display
0111	7	Halt	Terminate the program
1000	8	Skipcond	Skip next instruction on condition
1001	9	Jump X	Load the value of X into the PC

MARIE Instructions

Binary	Hex	Instruction	Meaning
0000	**0**	**JnS X**	**Store the PC at address X and jump to X+1**
0001	1	Load X	Load contents of address X into AC
0010	2	Store X	Store contents of AC in address X
0011	3	Add X	Add the contents of address X to AC
0100	4	Subt X	Subtract the contents of address X to AC
0101	5	Input	Input a value from the keyboard into AC
0110	6	Output	Output the value from the AC to the display
0111	7	Halt	Terminate the program
1000	8	Skipcond	Skip next instruction on condition
1001	9	Jump X	Load the value of X into the PC
1010	**A**	**Clear**	**Put all zeros in the AC**
1011	**B**	**AddI X**	**Add Indirect: Go to address X. Use the value at X as the actual address of the data operand to add to the AC**
1100	**C**	**JumpI X**	**Jump Indirect: Go to address X. Use the value at X as the actual address of the location to jump to.**
1101	**D**	**LoadI X**	**Load indirect: Go to address X. Use the value at X as the actual address of the operand to load into the AC.**
1110	**E**	**StoreI X**	**Store Indirect: Go to the address X. Use the value at X as the destination address for storing the value in the accumulator.**

EXAMPLE PROGRAM: NUMBER TOTALISER

- Add together a series of numbers stored in the machines memory
- To do this we will use
  - variables
  - labels
  - add indirect
  - Jump
  - skipcond

EXAMPLE PROGRAM: STRING OUTPUT

- Output a string from the computers memory.
- To do this we will use
  - variables
  - labels
  - load indirect
  - Jump
  - skipcond

MICRO INSTRUCTIONS

- We have seen the operations of a simple computer simulator using machine code instructions.
  - Each of these instructions is built from a series of smaller units.
    - **micro-instructions**
  - Understanding this will help to conceptualise the operation of the control unit.
  - We can see the micro-instructions for MARIE from the simulator

Program execution

Figure adapted from Stallings 2022 Chapter 19

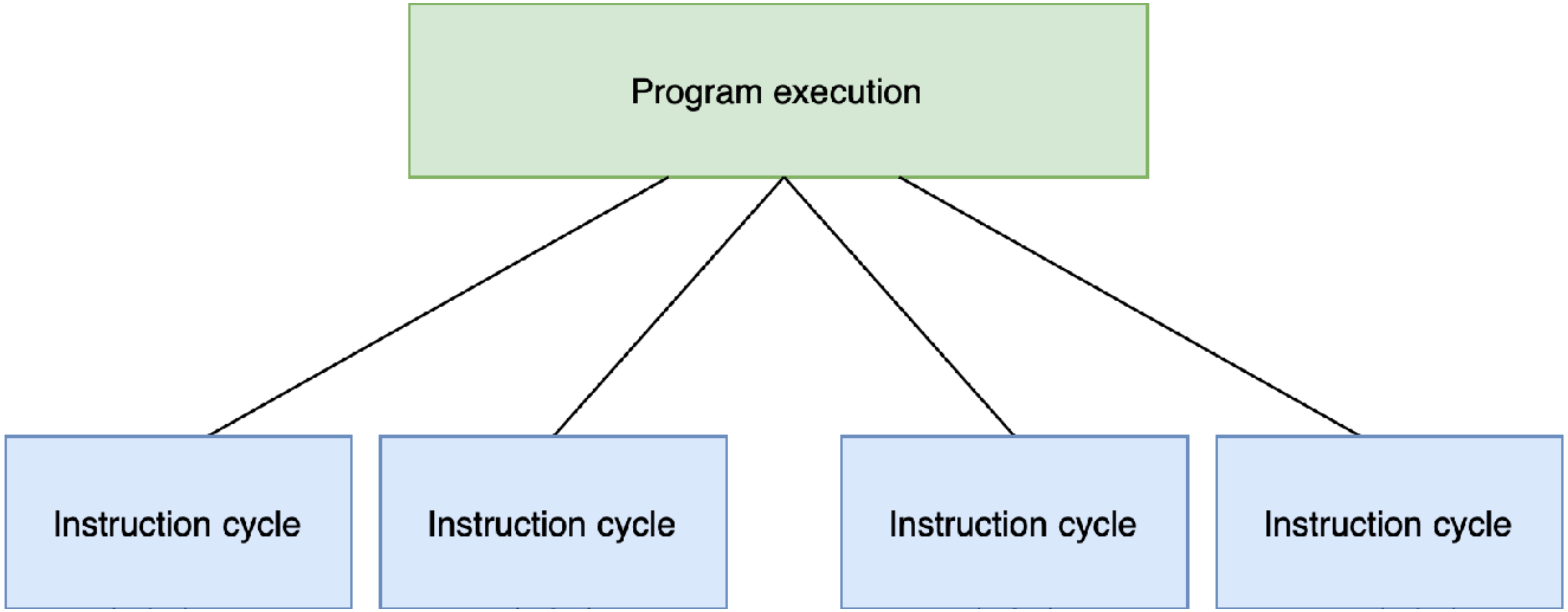
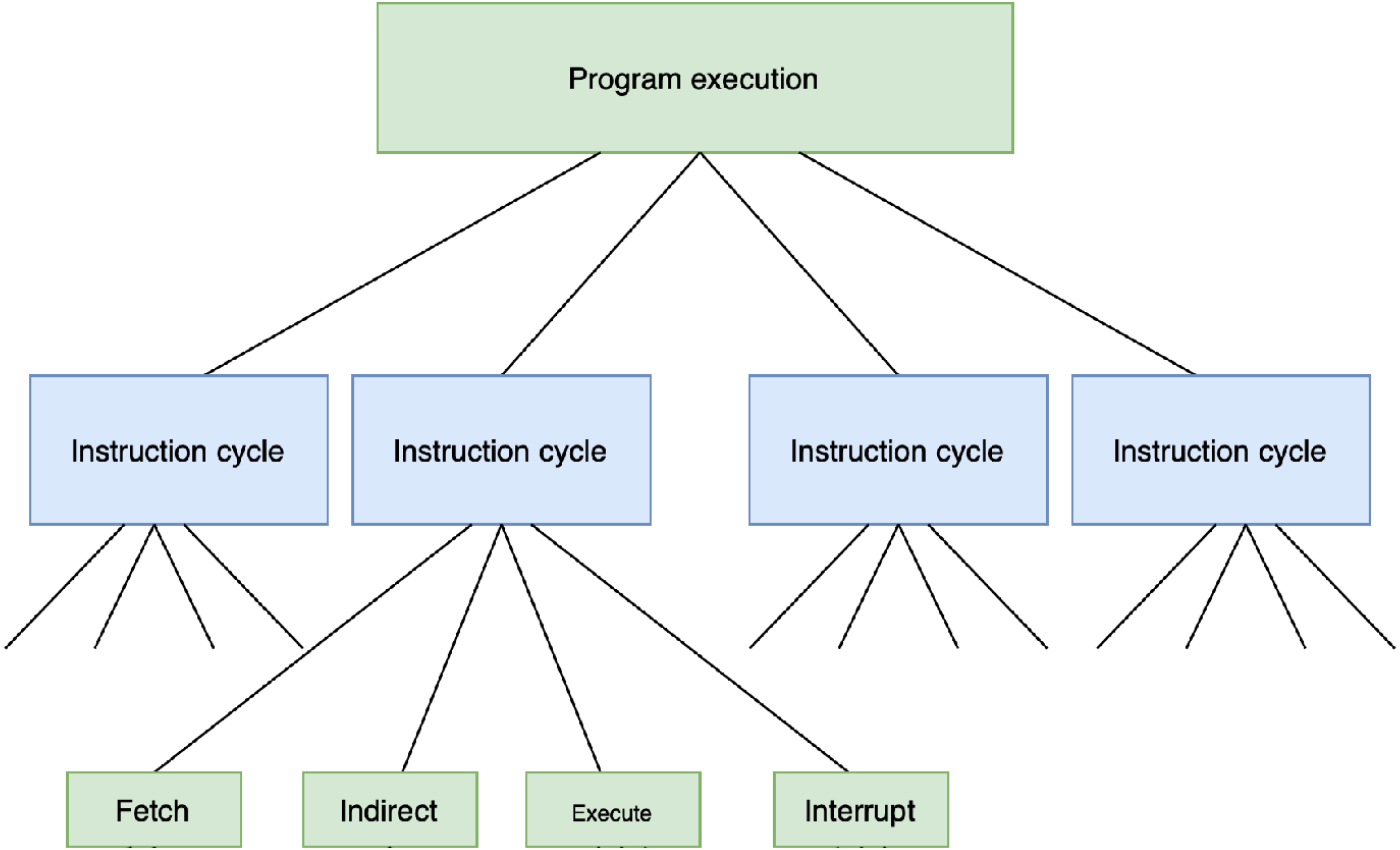


Figure adapted from Stallings 2022 Chapter 19



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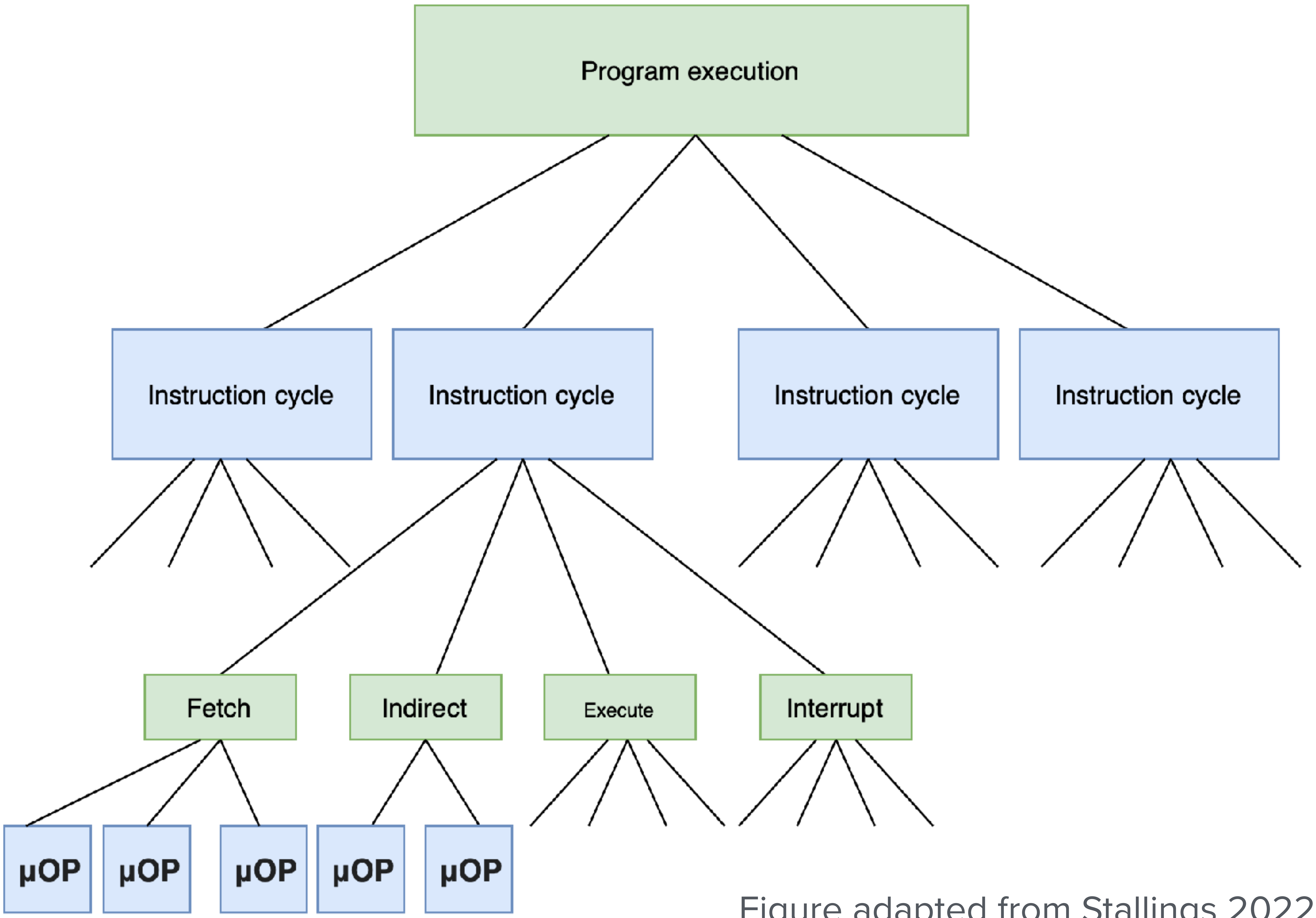

Figure adapted from Stallings 2022 Chapter 19

REGISTER TRANSFER LANGUAGE / NOTATION

- Micro operations are represented in register transfer language (sometimes register transfer notation)
- RTL shows the transfer of data between registers and memory in an operation

RTL	Description
MAR ← PC	load address from PC into MAR
MBR ← M[MAR]	Load data at memory location stored in MAR into MBR
IR ← MBR	Load data from MBR into IR
PC ← PC + 1	set value of PC to be PC + 1

FETCH CYCLE

- The beginning phase of an instructions execution
- During the fetch cycle an instruction is read from memory
- In MARIE four registers are involved in the fetch cycle.
  - Memory address register (MAR)
  - Memory buffer register (MBR)
  - Program counter (PC)
  - Instruction register (IR)
- The fetch cycle is the same for all operations

FETCH CYCLE

Time unit	RTL
t1	MAR ← PC
t2	MBR ← M[MAR]
t3	PC ← PC+1
t4	IR ← MBR

FETCH CYCLE

Time unit	RTL
t1	MAR ← PC
t2	MBR ← M[MAR]
t3	PC ← PC+1
t4	IR ← MBR

Register	Data
MAR	
MBR	
PC	0000 0000 1010
IR	
AC	
Input	
Output	

FETCH CYCLE

Time unit	RTL
t1	**MAR ← PC**
t2	MBR ← M[MAR]
t3	PC ← PC+1
t4	IR ← MBR

Register	Data
MAR	0000 0000 1010
MBR	
PC	0000 0000 1010
IR	
AC	
Input	
Output	

FETCH CYCLE

Time unit	RTL
t1	MAR ← PC
t2	**MBR ← M[MAR]**
t3	PC ← PC+1
t4	IR ← MBR

Register	Data
MAR	0000 0000 1010
MBR	0010 0000 0000 1100
PC	0000 0000 1010
IR	
AC	
Input	
Output	

FETCH CYCLE

Time unit	RTL
t1	MAR ← PC
t2	MBR ← M[MAR]
t3	**PC ← PC+1**
t4	IR ← MBR

Register	**Data**
MAR	0000 0000 1010
MBR	0010 0000 0000 1100
PC	0000 0000 1011
IR	
AC	
Input	
Output	

FETCH CYCLE

Time unit	RTL
t1	MAR ← PC
t2	MBR ← M[MAR]
t3	PC ← PC+1
t4	**IR ← MBR**

Register	**Data**
MAR	0000 0000 1010
MBR	0010 0000 0000 1100
PC	0000 0000 1011
IR	0010 0000 0000 1100
AC	
Input	
Output	

INDIRECT CYCLE

- After fetching The operands of the instruction need obtaining from memory
- If this is indirectly addressed an extra step is required.

INDIRECT CYCLE

Time unit	RTL
t1	MAR ← IR[Address]
t2	MBR ← M[MAR]
t3	MAR ← MBR[Address]

Register	Data
MAR	0000 0000 1010
MBR	1101 0000 0000 1100
PC	0000 0000 1011
IR	1101 0000 0000 1100
AC	
Input	
Output	

INDIRECT CYCLE

Time unit	RTL
t1	**MAR ← IR[Address]**
t2	MBR ← M[MAR]
t3	MAR ← MBR[Address]

Register	**Data**
MAR	0000 0000 1100
MBR	1101 0000 0000 1100
PC	0000 0000 1011
IR	1101 0000 0000 1100
AC	
Input	
Output	

INDIRECT CYCLE

Time unit	RTL
t1	MAR ← IR[Address]
t2	**MBR ← M[MAR]**
t3	MAR ← MBR[Address]

Register	Data
MAR	0000 0000 1100
MBR	0000 0000 0010 1011
PC	0000 0000 1011
IR	1101 0000 0000 1100
AC	
Input	
Output	

INDIRECT CYCLE

Time unit	RTL
t1	MAR ← IR[Address]
t2	MBR ← M[MAR]
t3	**MAR ← MBR[Address]**

Register	**Data**
MAR	0000 0010 1011
MBR	0000 0000 0010 1011
PC	0000 0000 1011
IR	1101 0000 0000 1100
AC	
Input	
Output	

INDIRECT CYCLE - VARIATION (AS DETAILED IN STALLINGS 2022)

Time unit	RTL
t1	MAR ← IR[Address]
t2	MBR ← M[MAR]
t3	**IR(Address) ← MBR[Address]**

Register	**Data**
MAR	0000 0000 1100
MBR	0000 0000 0010 1011
PC	0000 0000 1011
IR	1101 **0000 0010 1011**
AC	
Input	
Output	

EXECUTE AND INTERRUPT CYCLES

- Execute Cycle
  - Each opcode will have unique micro-operations for execution. We can see these in the RTL output in the MARIE simulator.
- Interrupt Cycle
  - MARIE doesn't support interrupts
  - A simple process might involve:

t1: MBR ← PC
t2: MAR ← [A free memory address]
t3: PC ← [Interrupt routine address]
t4: M ← (MBR)

MICRO-OPERATION SUMMARY

- Micro-operations perform one of the following
  - Transfer data between registers
  - transfer data from a register to an external interface (system bus)
  - transfer data from an external interface to a register
  - perform an arithmetic or logical operation using registers