CSD1100

Computer Architecture And Operating Systems

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The Stored Program

- Brilliant idea:
  - Build a **machine that** can **execute** certain **instructions**.
  - Then, write down different lists of instructions (programs) to accomplish different things.
- Examples:
  - Play music using Barrel Organs
  - Music boxes
  - Mechanical Pianos

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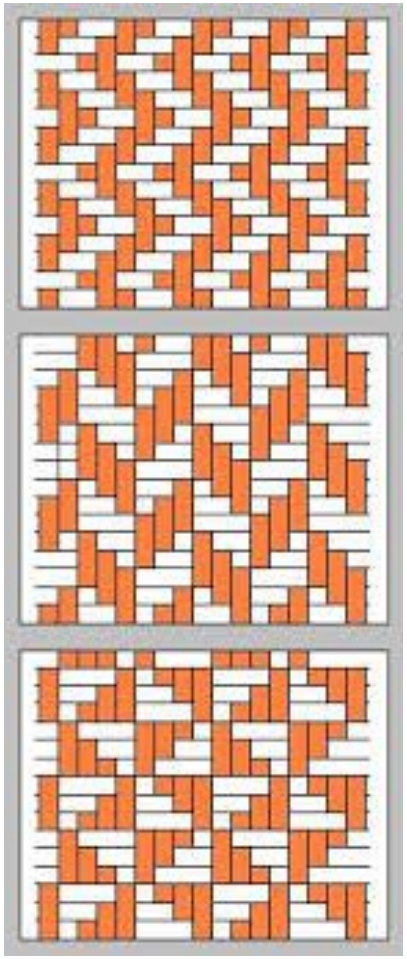
The Stored Program

- Weaving patterns using punched cards.



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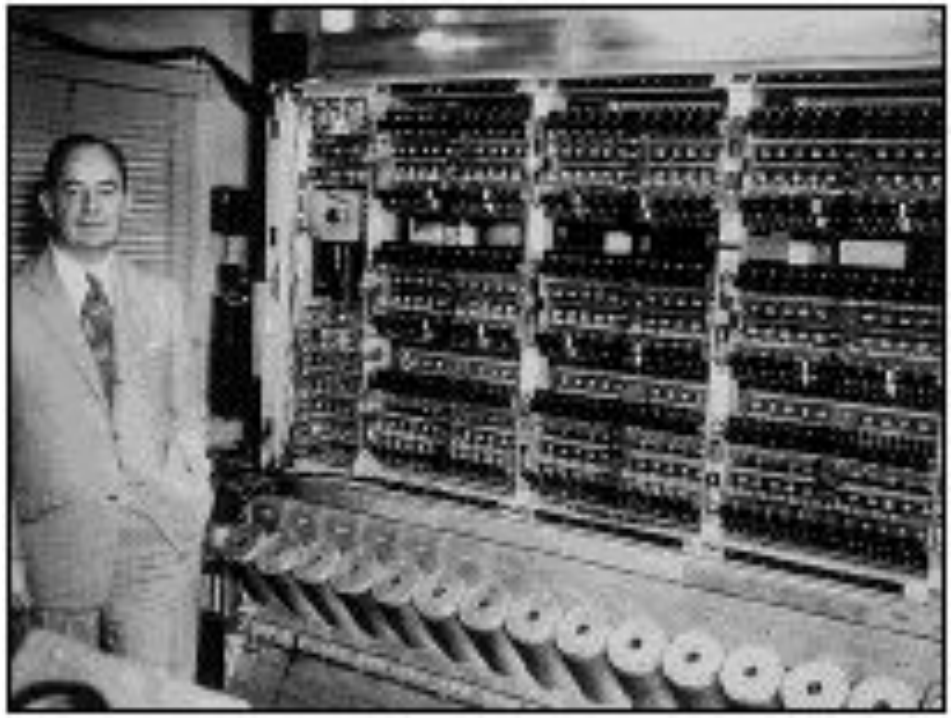
The Modern Computer

- Basic idea still the same in the modem computers.
- Machine instructions and data represented by sequences ‘low’ and ‘high’ signals.
- RAM is a place to store information while the computer is running.



John von Neumann

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John von Neumann Model

- **The instructions themselves and the data the instructions manipulate are all stored in the same memory.**
- This innovation is crucial to modern computing.
- It even allows for the possibility of programs that change themselves as they are executed.

- With great power comes great risk …
  - Computer Viruses!

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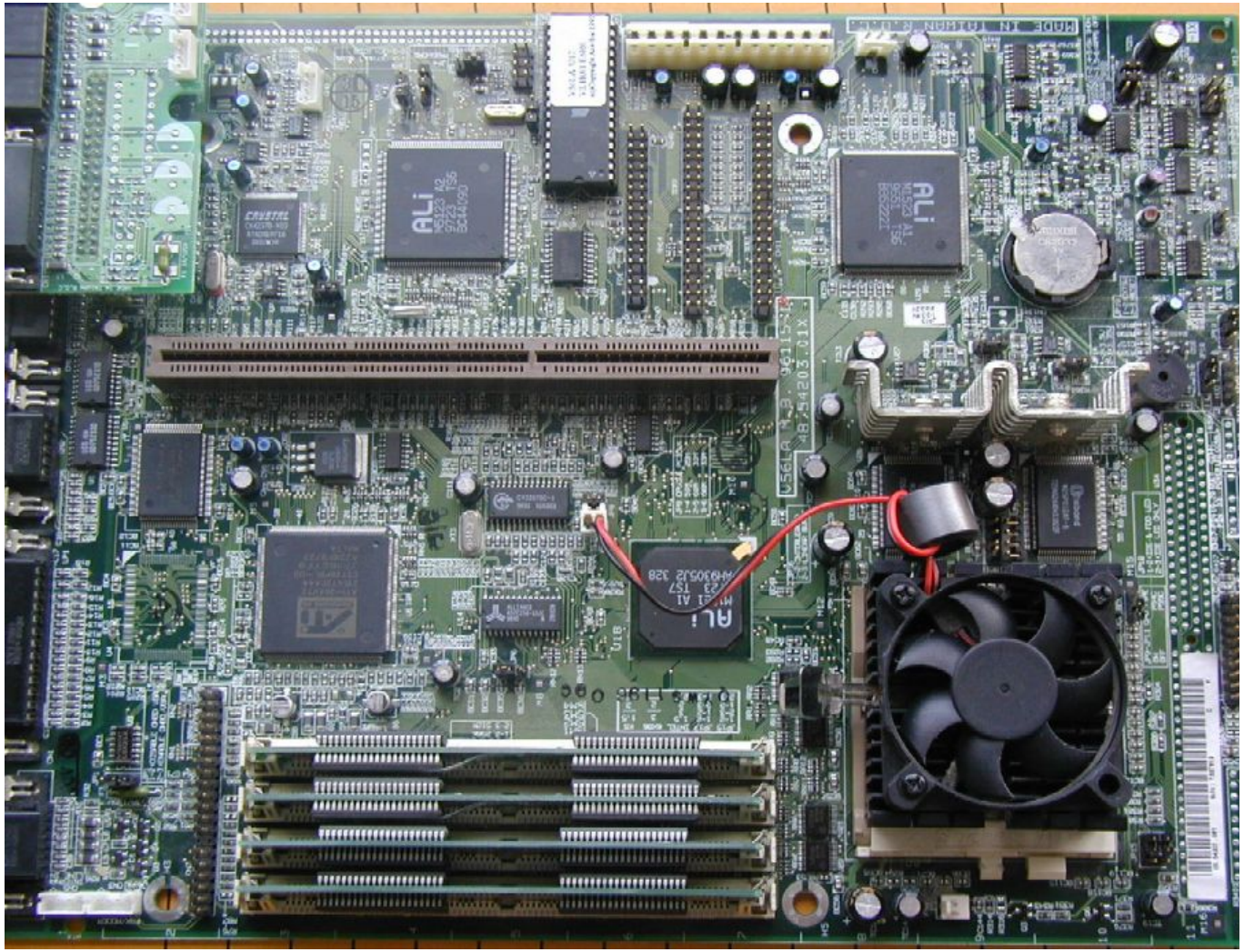
Computer Architecture - Mainboard



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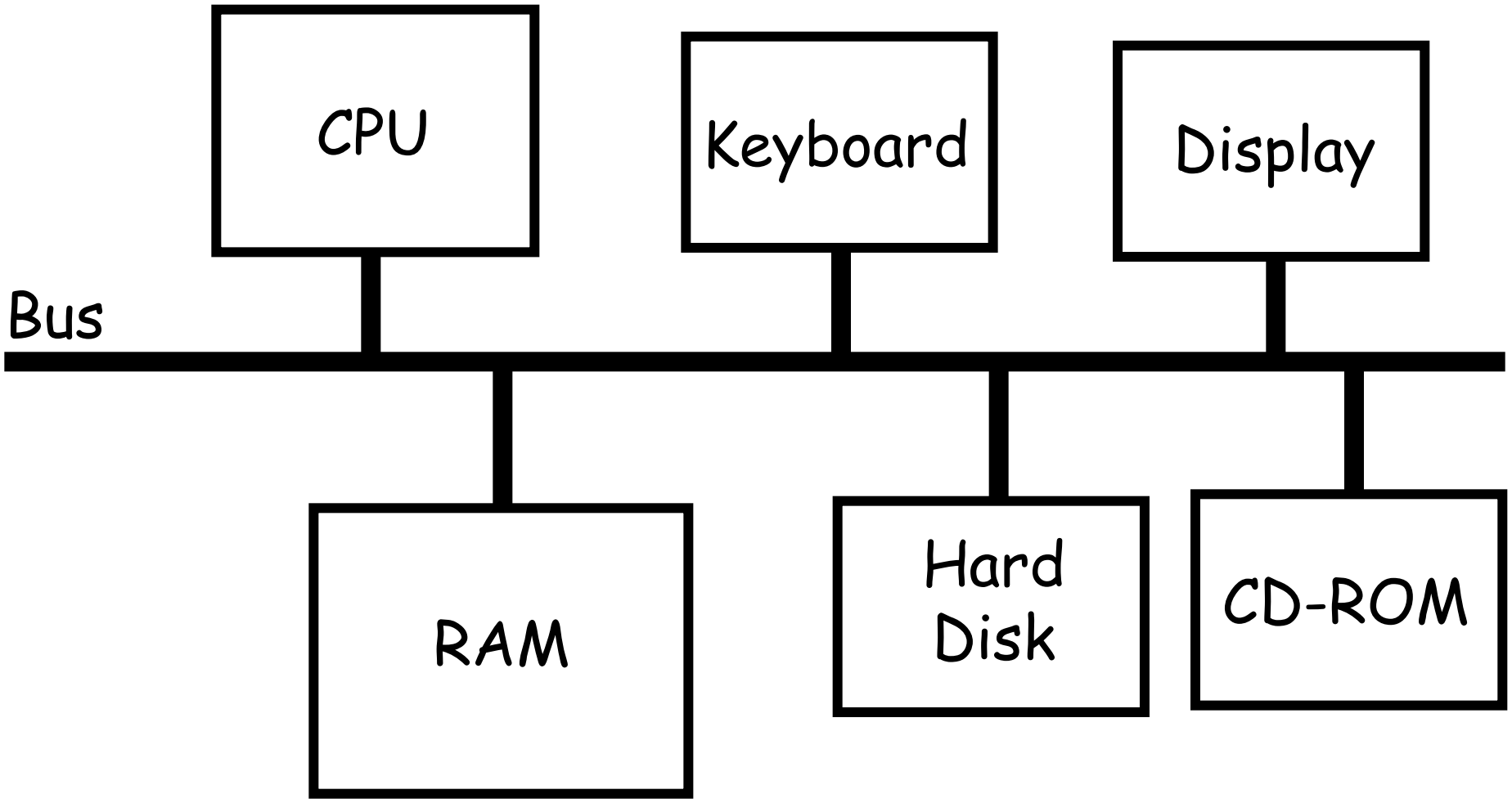
Computer Architecture



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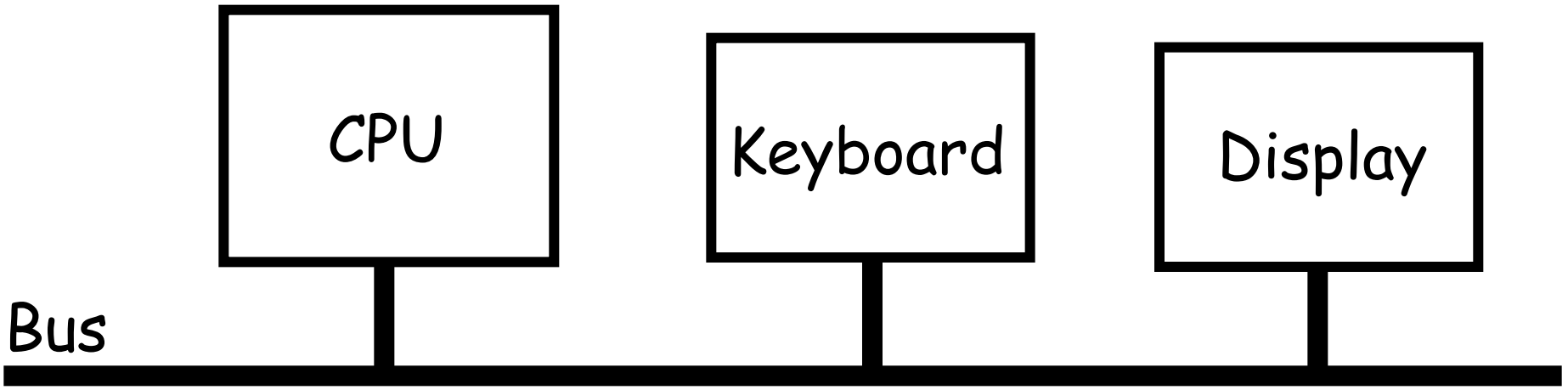
The Bus

- Bus it is a simplified way for many devices to communicate to each other
  - Bus for addresses, bus for data, and bus for controls.
- Looks like a “highway” for information.
  - Actually, more like a “basket” that they all share.



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The Bus

- Suppose CPU needs to check to see if the user typed anything.
- CPU puts “Keyboard, did the user type anything?” (represented in some way) on the Bus.
- Each device (except CPU) is a State Machine that constantly checks to see what’s on the Bus.
- Keyboard notices that its name is on the Bus, and reads info. Other devices ignore the info.
- Keyboard then writes “CPU: Yes, user typed ‘a’.” to the Bus.
- At some point, CPU reads the Bus, and gets the Keyboard’s response.

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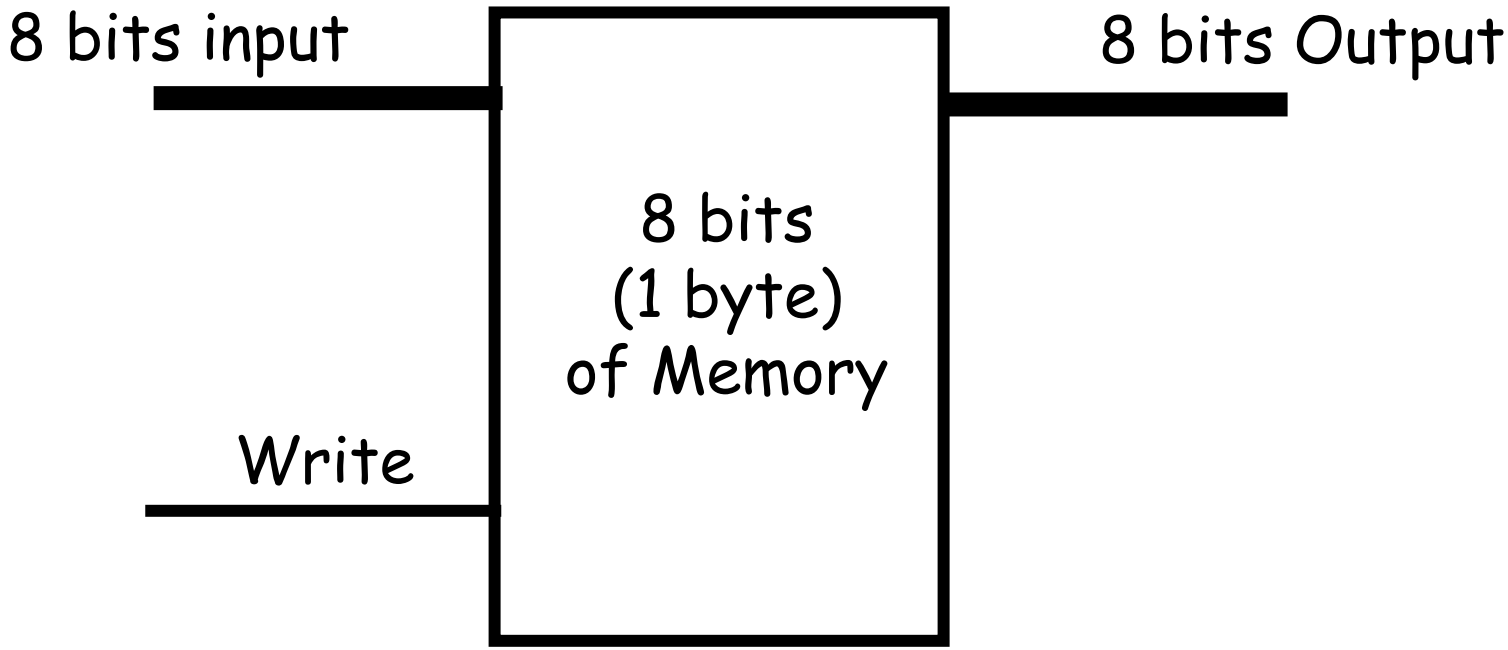
RAM

- Take a single bit of memory
- Group 8 of them together
- To have a byte of memory



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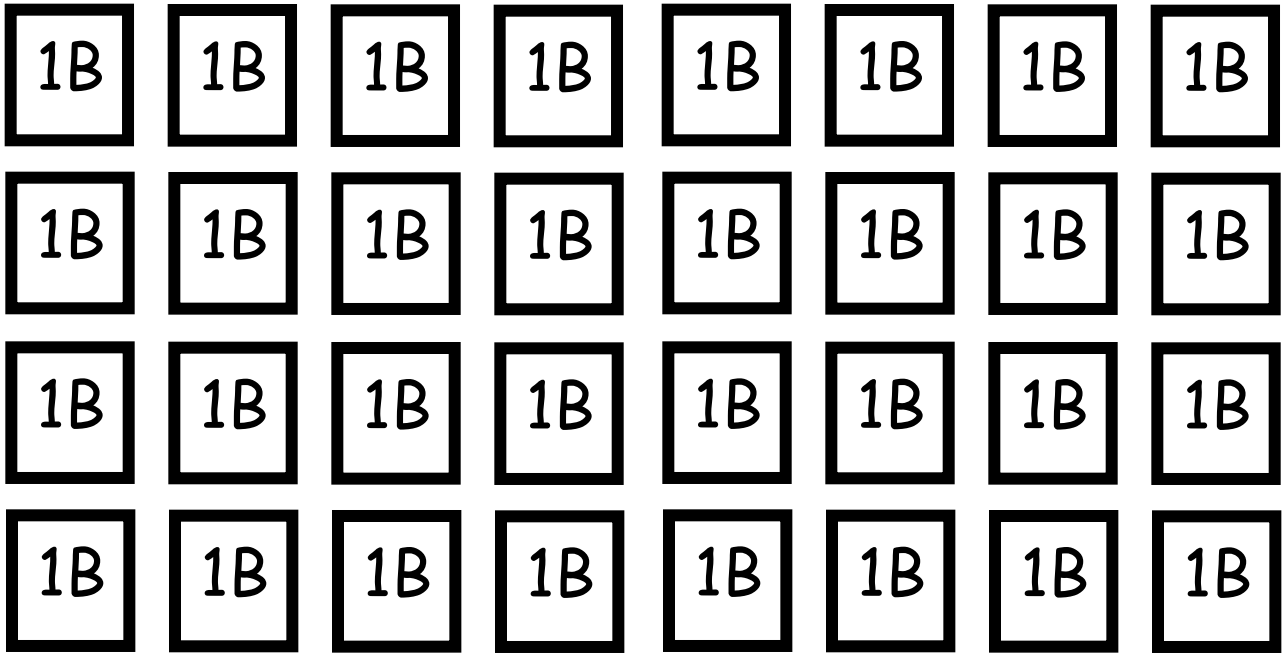
RAM

- We want a HUGE number of such 1 byte memory cells.



- How do we indicate which byte of memory we want to use at any given time?

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RAM

- Answer: Assign each byte an address.
- We can number all the bytes in binary.
- Each byte's assigned number is called the byte's address in memory.
- Then, we can ask the RAM:
  - What is byte number 011010101010?
- Or tell the RAM:
  - Write "01101100" into memory at address 011010101010

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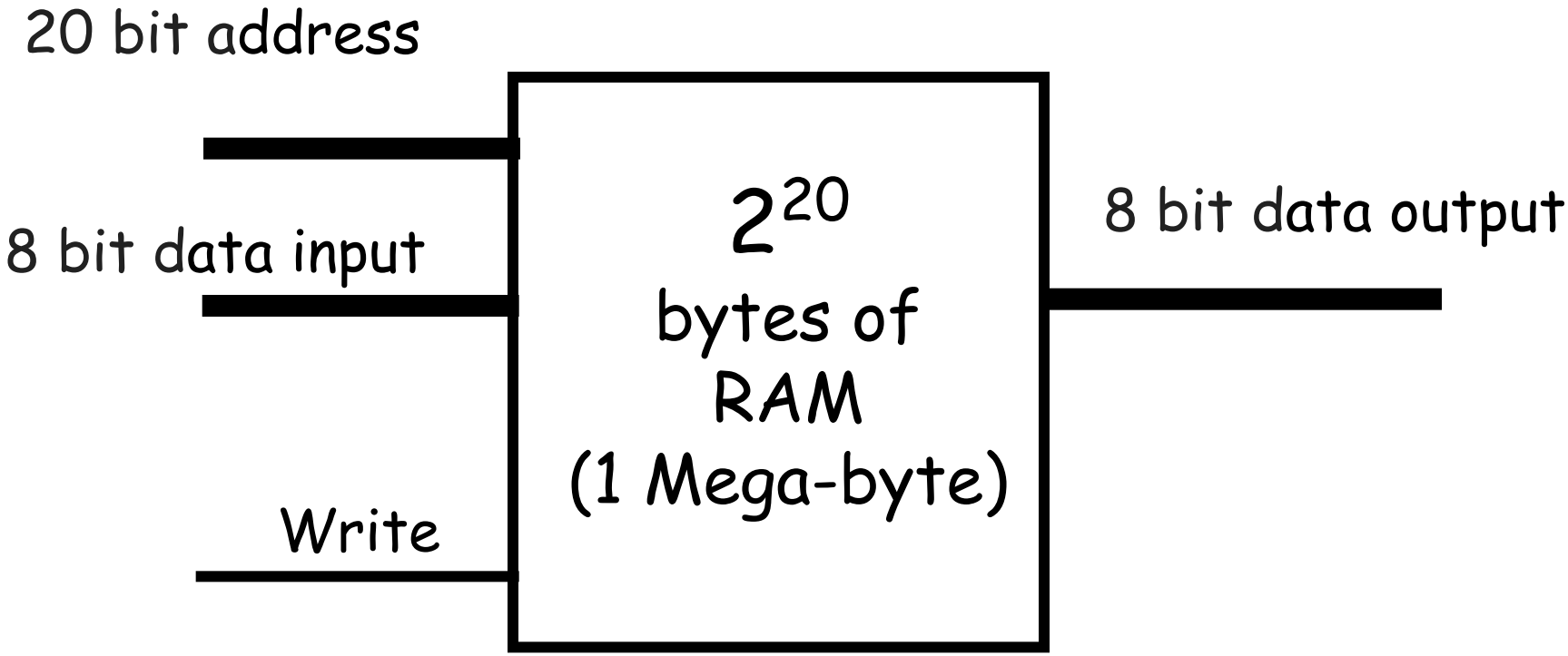
RAM



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Inside the CPU

- The CPU is the brain of the computer.
- It is the part that actually executes the instructions.

- Let’s take a look inside.



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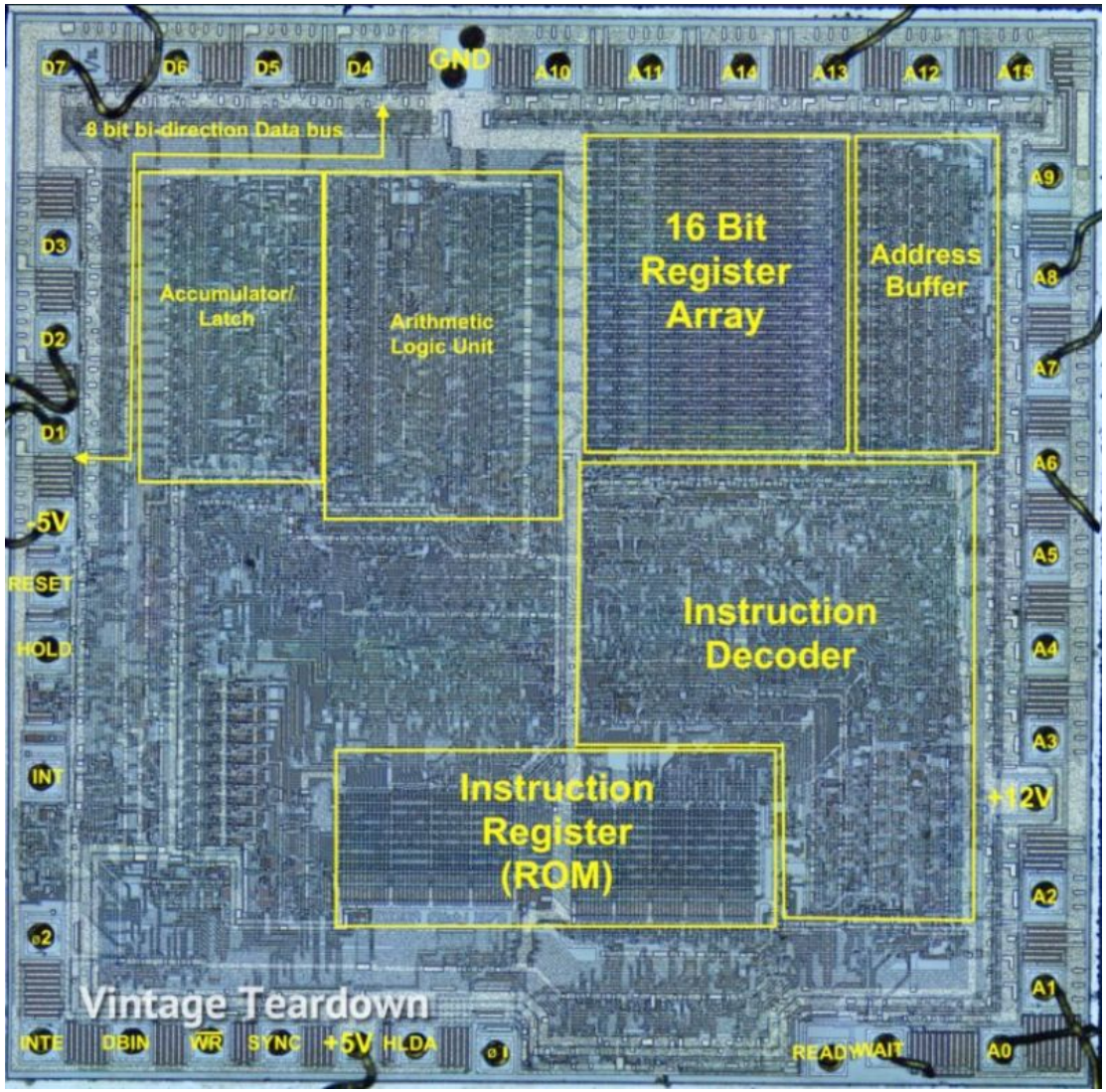
Inside the CPU



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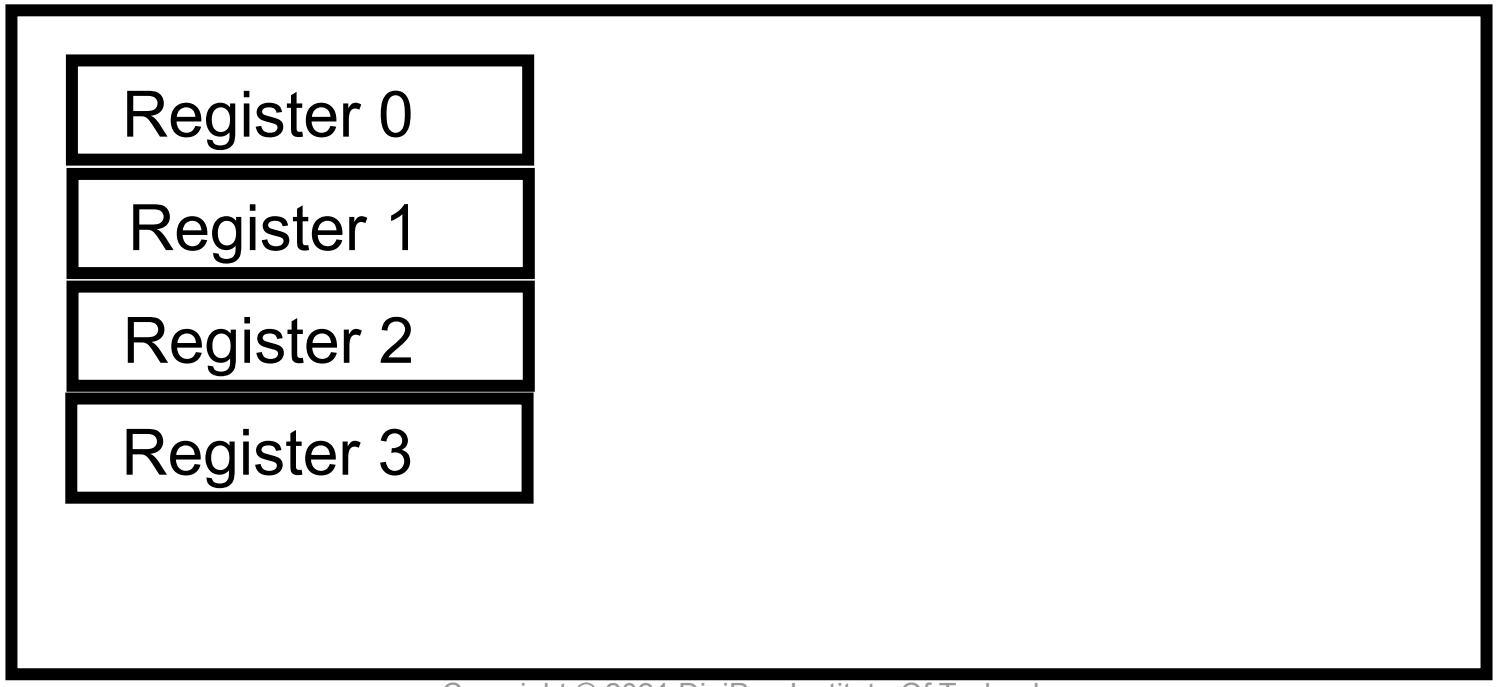
Inside the CPU: Registers

- Temporary Memory.
- Computer “Loads” data from RAM to registers, performs operations on data in registers, and “stores” results from registers back to RAM



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Inside the CPU: General Purpose Registers

- GPR - registers that can be used to hold data for the purpose of computation.
  - For example, if we have a statement in C like “ a = b+c+z;”, where a, b, c and z are locations in memory.
  - Usually, the ALU can only perform additions for 2 values at a time.
  - That means that the intermediate results of b+c needs to be saved somewhere.
  - The usual practice is to use the GPRs instead of memory locations to store these intermediate results for quick access purposes.

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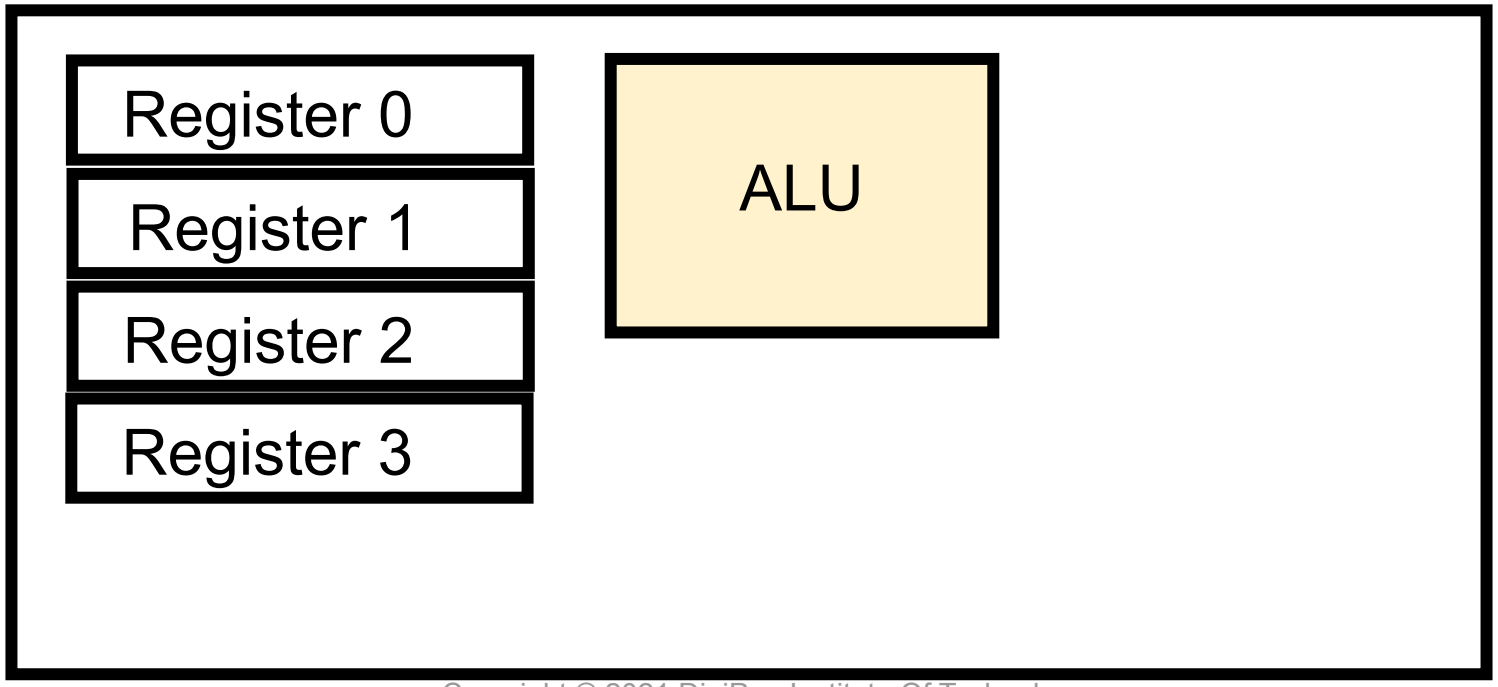
Inside the CPU: ALU

- For doing basic Arithmetic / Logic
- Operations on values stored in the Registers



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Inside the CPU: ALU

- Instructions performed in the ALU can be divided into two categories depending on the location of operands:
  - Register-Register or Register-Memory instructions allow memory words to be fetched into registers, where they can be used as ALU inputs, perform some operations on them, and then store the result back in a register.
  - A Memory-Memory instruction fetches its operands from the memory into the ALU inputs registers, performs its operation, and then writes the result back into memory.

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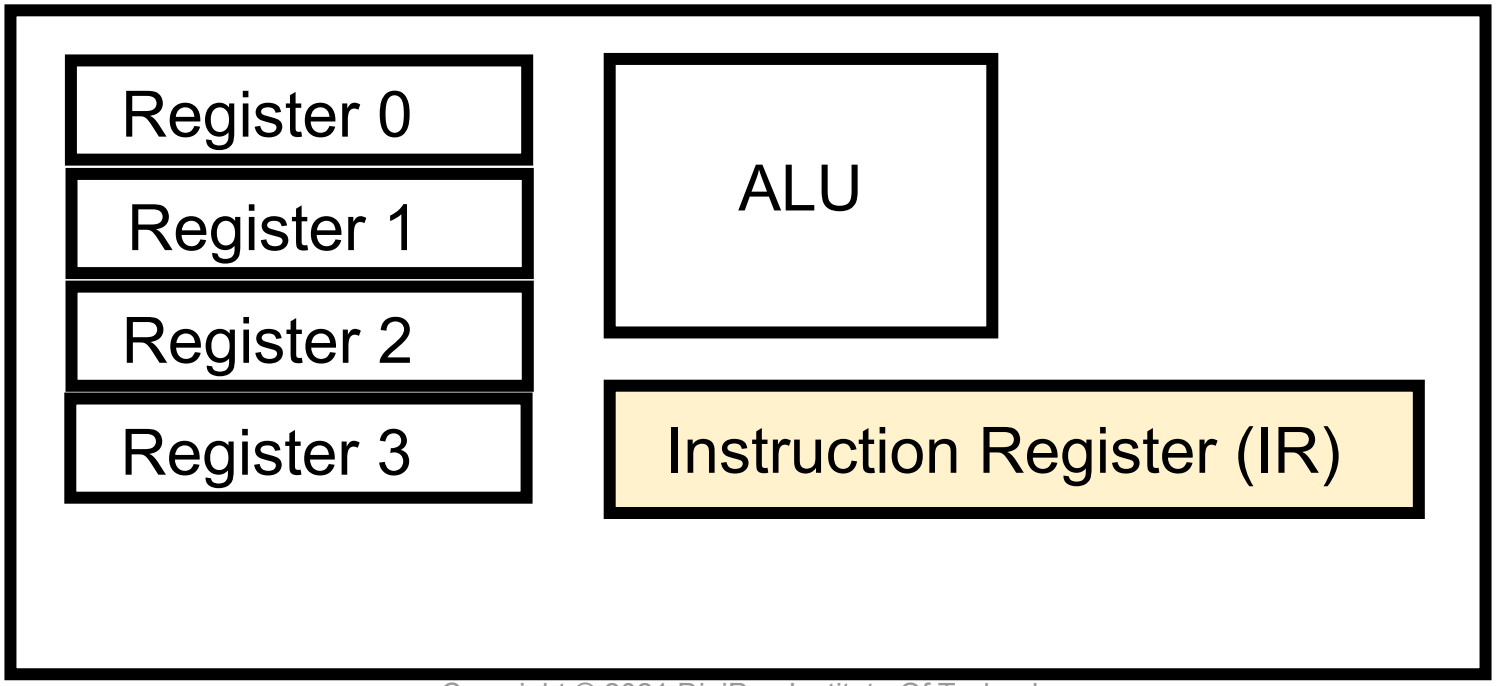
Inside the CPU: Instruction Register (IR)

- Holds the instruction currently being decoded and executed
- Can be more IR than 1, bcs decoding on several instructions can be done in parallel.



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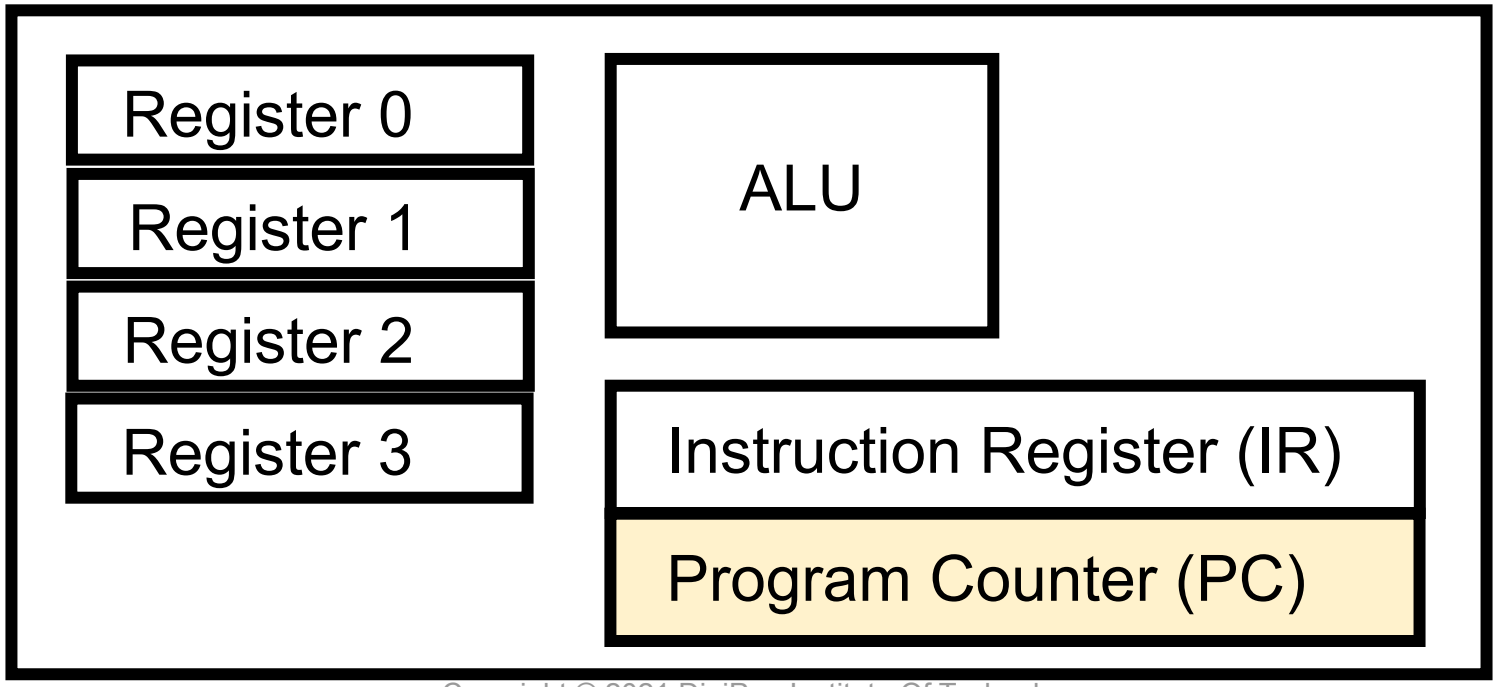
Inside the CPU: Program Counter (PC) / Instruction Pointer

- To hold the address of the current instruction in RAM



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Other Registers

- Status register
  - Status register also referred to as the condition code or flag, is used to make decisions depending on the value of flags. Those flags are set depending on the result of the last operation.
  - The most important status register flags are:
    - Zero flag: ZF
    - Overflow flag: OF
    - Sign flag: SF
    - Carry flag: CF

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Other Registers

- Memory Address Register (MAR)
  - The memory address register (MAR) holds the address of the memory where data should be stored.
- Memory Data Register (MDR)
  - The memory data register (MDR) stores the results of an instruction.

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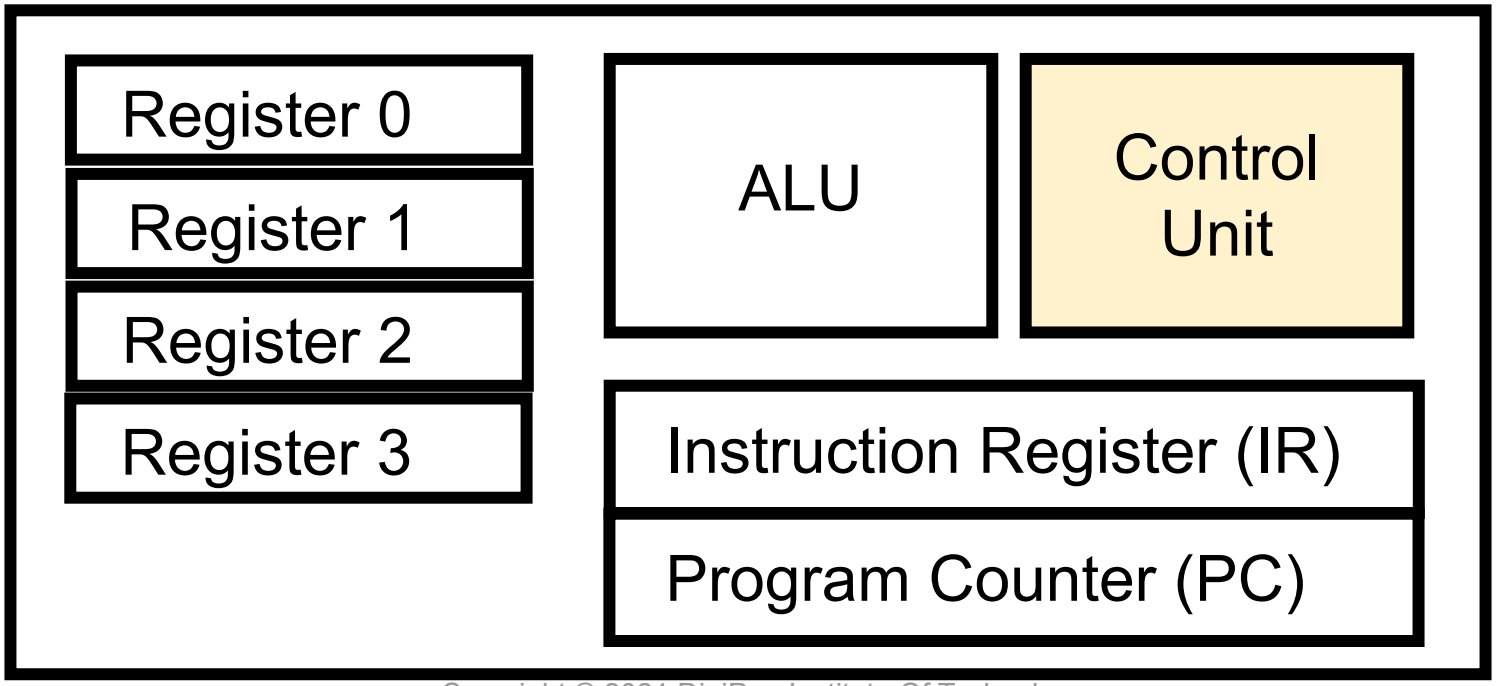
Inside the CPU: The Control Unit

- It all comes down to the Control Unit.
- CU makes sure that everything is running smoothly and in order.



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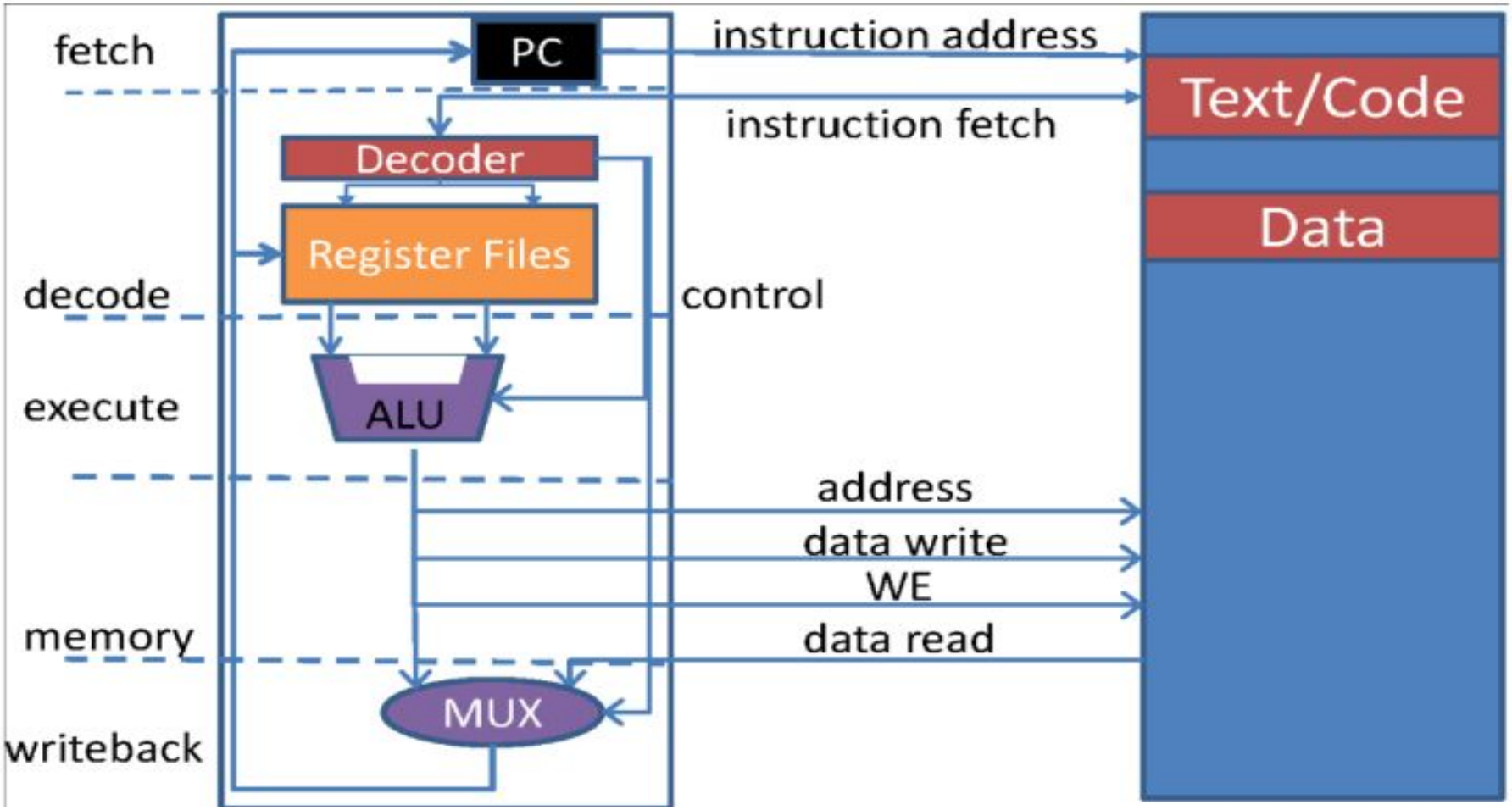
Datapath



- Multiplexer(MUX) - a device that selects one of several digital input signals and forwards the selected input into a single line

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Fetch-Decode-Execute-Writeback

- Fetch Stage
  - The value stored in the PC is the address of the instruction we want to fetch. That instruction is fetched into the instruction register which is an input into the decoder.
- Decode Stage
  - The decoder extracts the following from the instruction stored in the instruction register
    - Operands involved for the current operation,
    - What operation the ALU needs to do
    - Desired effect of the operation.

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Fetch-Decode-**Execute**-Writeback

- Execute Stage
  - The ALU performs the operation based on the inputs given from the register file (collection of registers that can be accessed by programmers) and the decoder.
  - The control line of the decoder indicates the desired operation (addition/subtraction/etc) while the input from the register files are the operands of the operation.

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Fetch-Decode-Execute-**Writeback**

- Writeback Stage
  - Again, the input from the decoder determines what happens during this stage.
  - Depending on the instruction that is decoded
    - the result of the ALU may be written back into memory,
    - a value may be loaded onto the register from the memory or
    - the result of the ALU may be written back into the register file immediately.

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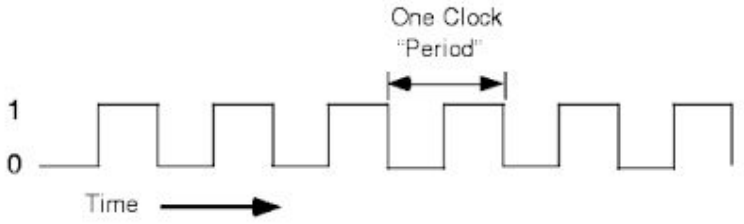
System Clock

- Every computer contains an **system** (AKA internal) **clock** that regulates the rate at which instructions are executed and synchronizes all the various computer components
- The clock signal consists of clock cycles (every clock cycle is called the clock period) that are generally represented by a square wave.



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System Clock

- Now in order to specify the clock speed or cycle, we use the **clock frequency** that is calculated using the inverse of the clock period (the duration of time of one cycle).
- We measure the clock frequency in Hz and it represents one cycle/second.
- Top CPU: Intel Core i7-8700K
  - Base clock: 3.7GHz
  - Boost clock: 4.7GHz
- GHz = 10^9 clock cycles per second.

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I/O Devices

- Man readable
  - Printers, graphical terminals, screen, keyboard, mouse, pointing devices,…
- Machine readable
  - Disks, tapes, sensors, controllers, actuators
- Communication
  - Modems

- So different, so need **a uniform approach to I/O as seen from the user and from the operating system point of view**

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I/O Devices. **Special Instructions**

- Besides arithmetic and memory instructions, we include special instructions for interacting with I/O.
- Can be done using dedicated I/O processors (channels) which execute their own instructions

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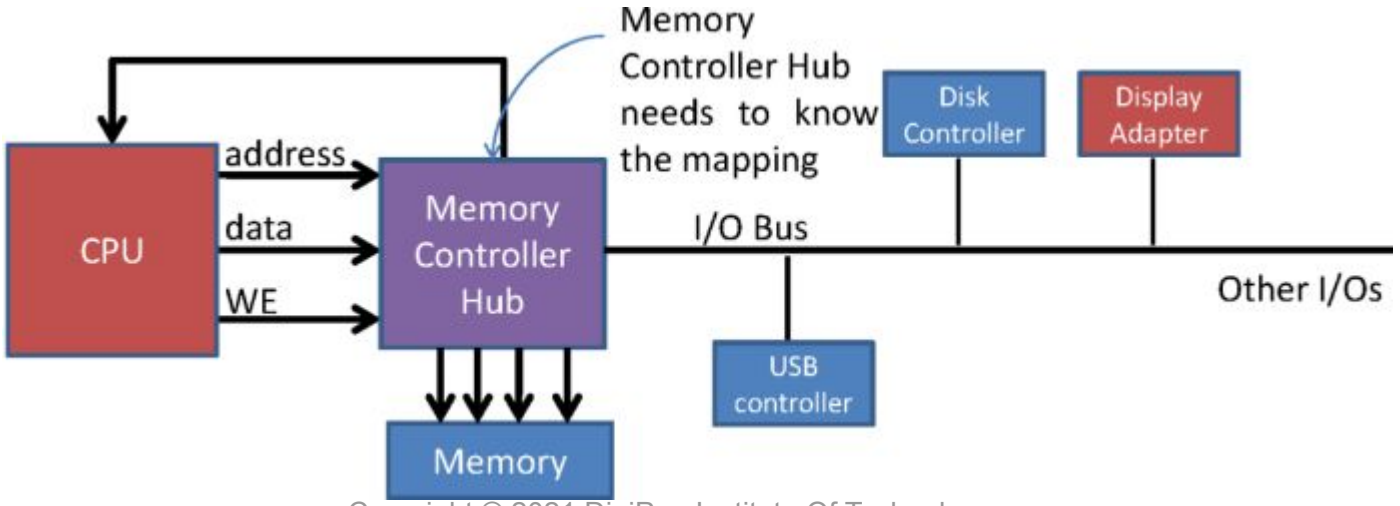
I/O Devices. **Memory-Mapped Instructions**

- Idea is to uses the same address space to address both memory and I/O devices to make some special addresses correspond to specific I/Os.
- This mapping is dependent on the motherboard and the computer architecture and is achieved through using a **memory controller hub** which is like a postman who delivers letters to the correct household.



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I/O Devices. **Memory-Mapped Instructions**

- Thus when the addresses are those mapped to the RAM, the RAM is accessed. Otherwise, the information is passed onto the I/O bus for the specific I/O device.
- This way, from the CPU point of view, **communication with I/O is just like reading or writing to memory**.

A sample system memory map

Address range (hexadecimal)	Size	Device
0000–7FFF	32 KiB	RAM
8000–80FF	256 bytes	General-purpose I/O
9000–90FF	256 bytes	Sound controller
A000–A7FF	2 KiB	Video controller/text-mapped display RAM
C000–FFFF	16 KiB	ROM

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I/O Devices. **Polling**

- Polling can be used to inform CPU of an I/O event happening
- The CPU executes instructions to keep on checking whether a desired I/O operation is done or not.
- Pros:
  - Simple
- Cons
  - Wastes CPU cycles that can be used to do other useful tasks.

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I/O Devices. **Interrupts**

- Enable the I/O devices to signal the CPU electronically when a task is completed.
- Pros
  - Increased CPU utilization
- Cons
  - Complex procedures need to be put in place in order to handle interrupts.

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Programs and Instructions

- Programs are made up of instructions
- CPU executes one instruction every clock cycle
  - Modern CPUs do more, but we ignore that
- Specifying a program and its instructions:
  - Lowest level: Machine language
  - Intermediate level: Assembly language
  - Typically today: High-level programming language

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Programs and Instructions

- High-level programs: each statement translates to many instructions
  - int c = a + b;
- Assembly language: specify each machine instruction, using mnemonic form
  - add rax, a
- Machine language: specify each machine instruction, using bit patterns
  - 1101101000001110011

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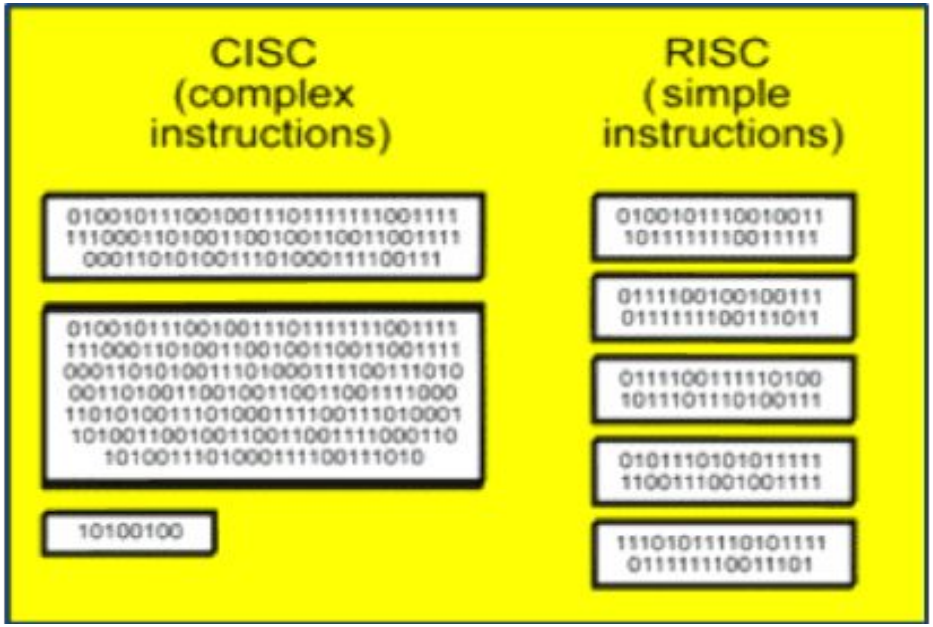
Complex vs Simple Instructions

- Processors can be
  - Complex Instruction Set Computer (CISC)
  - Reduced Instruction Set Computer (RISC)



- RISC utilizes small and highly optimized set of instructions.
- The main intent of the CISC processor architecture is to complete task by using less number of assembly lines

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Typical Assembly Instructions

- Some common assembly instructions include:
  - “Load” – Load a value from RAM into one of the registers
  - “Add” – Add the contents of two registers and put the result in a third register
  - “Compare” – If the value in a specified register is larger than the value in a second register, put a “0” in Register r0
  - “Jump” – If the value in Register r0 is “0”, change IP to the value in a given register

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Example: A Simple Program

- Want to add values of variables a and b (assumed to be in memory), and put the result in variable c in memory

- Instructions in program
  - Load a into register r1
  - Load b into register r3
  - r2 ← r1 + r3
  - Store r2 in c

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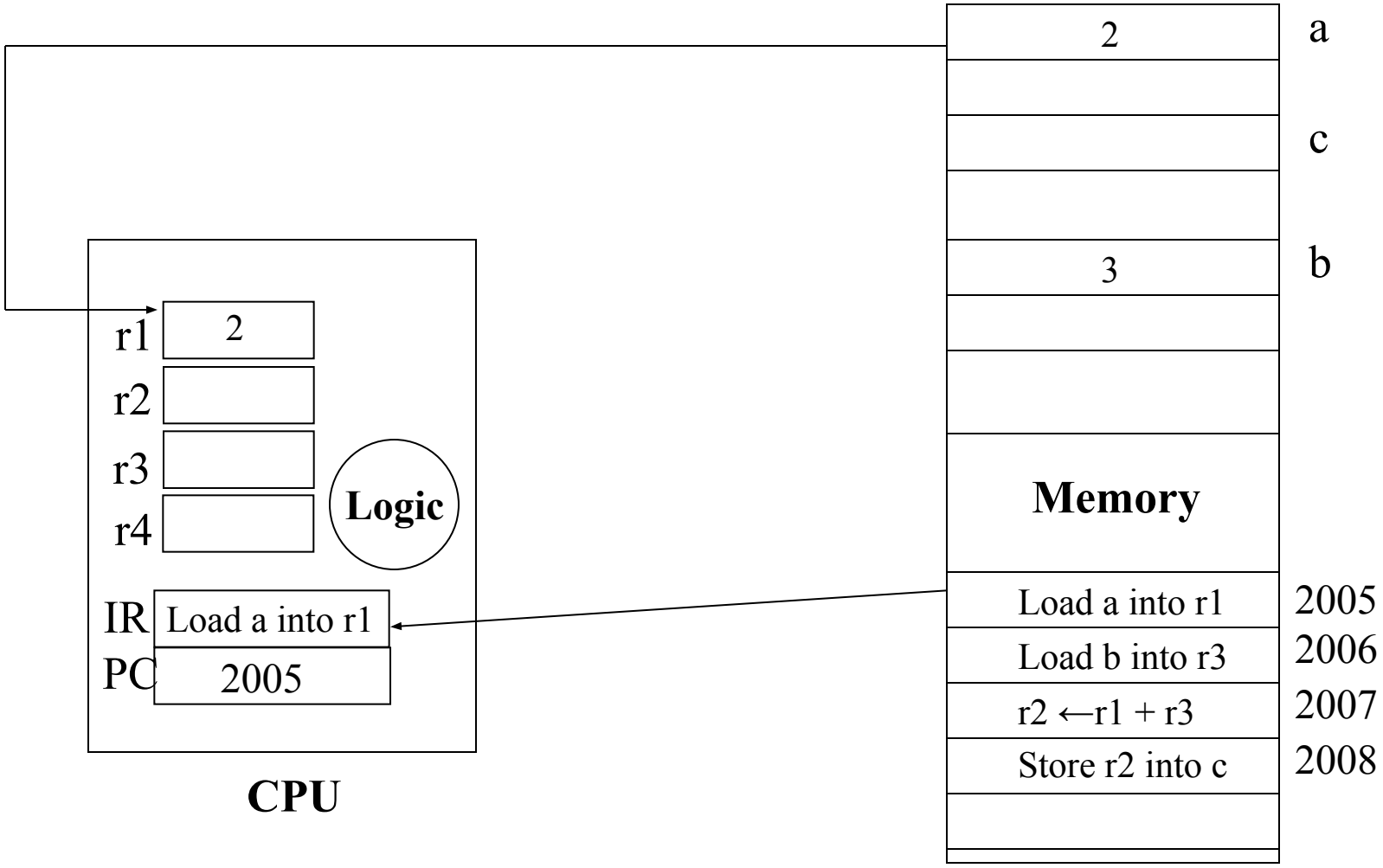
A Simple Program: Running



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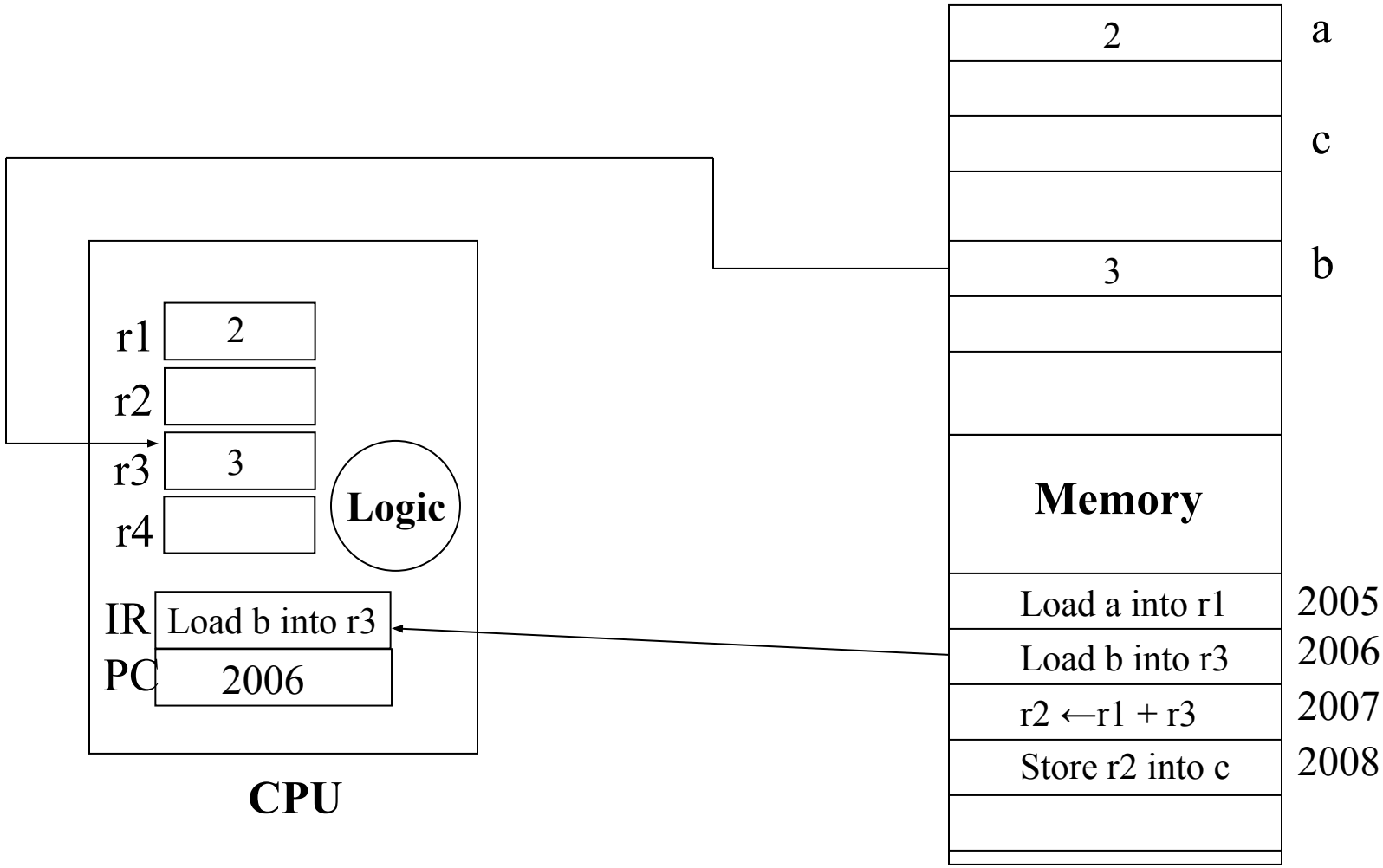
A Simple Program: Running



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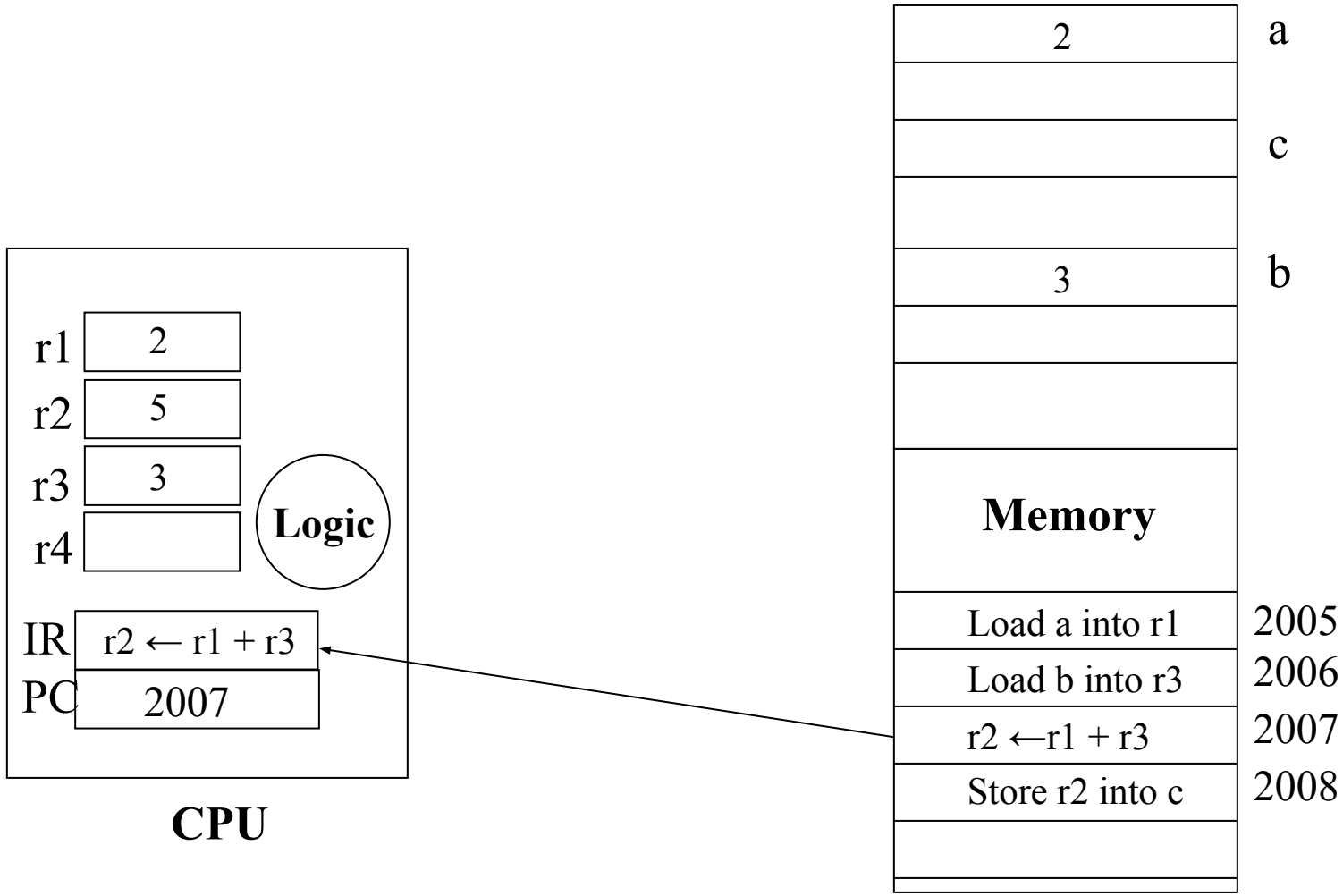
A Simple Program: Running



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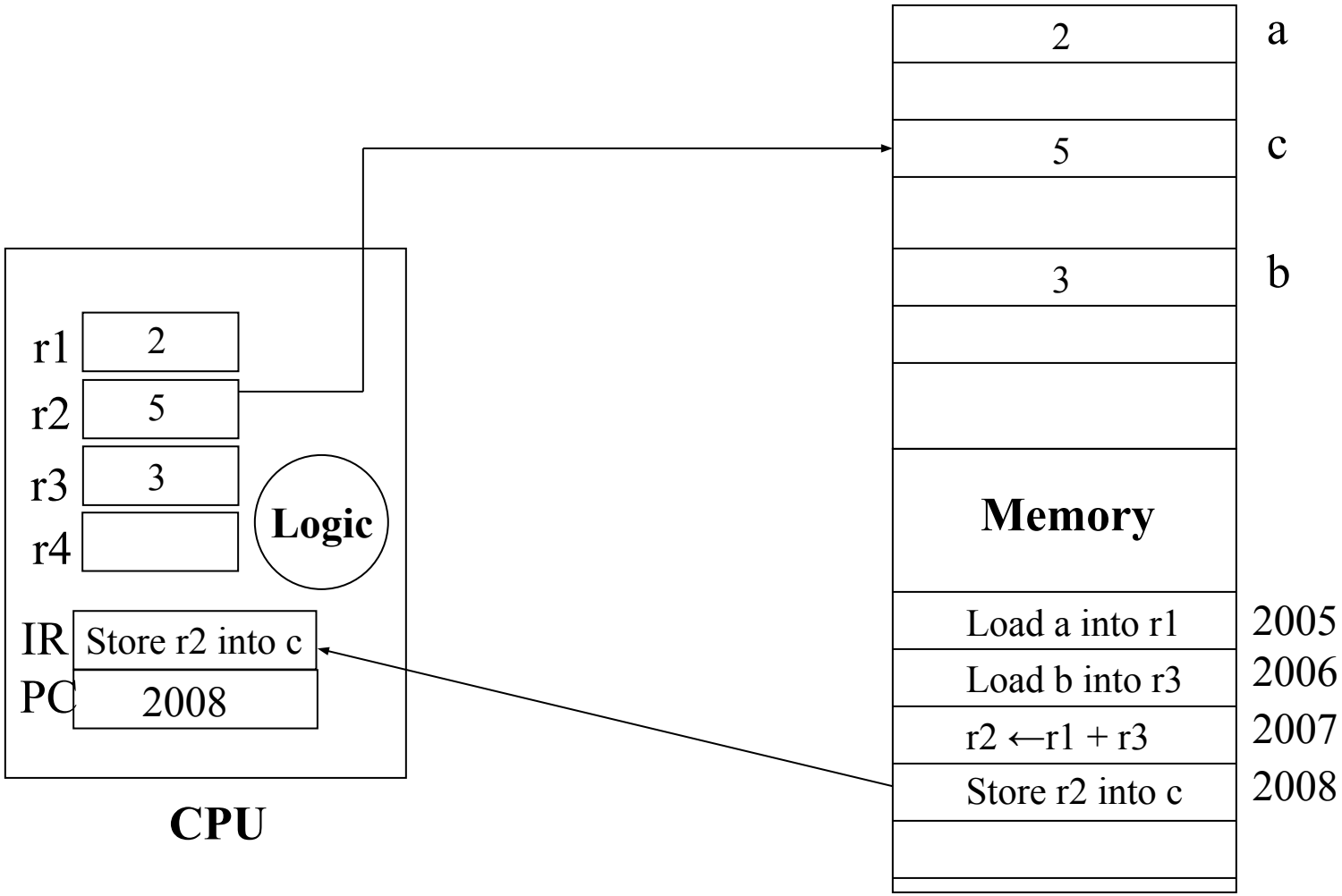
A Simple Program: Running



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Program execution

- So how does a program execute?
- Naïve answer:
  - load the program into memory and point the PC to the start of the program.

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Loading a Program

- Need a program called a **loader**
  - Able to read the executable format
  - Copy the text and data segments into the correct memory addresses.
  - Allocate space for Stack and heap for the new running program
  - Set the Program Counter value to the address of the starting instruction of the loaded program.
  - The newly loaded program runs

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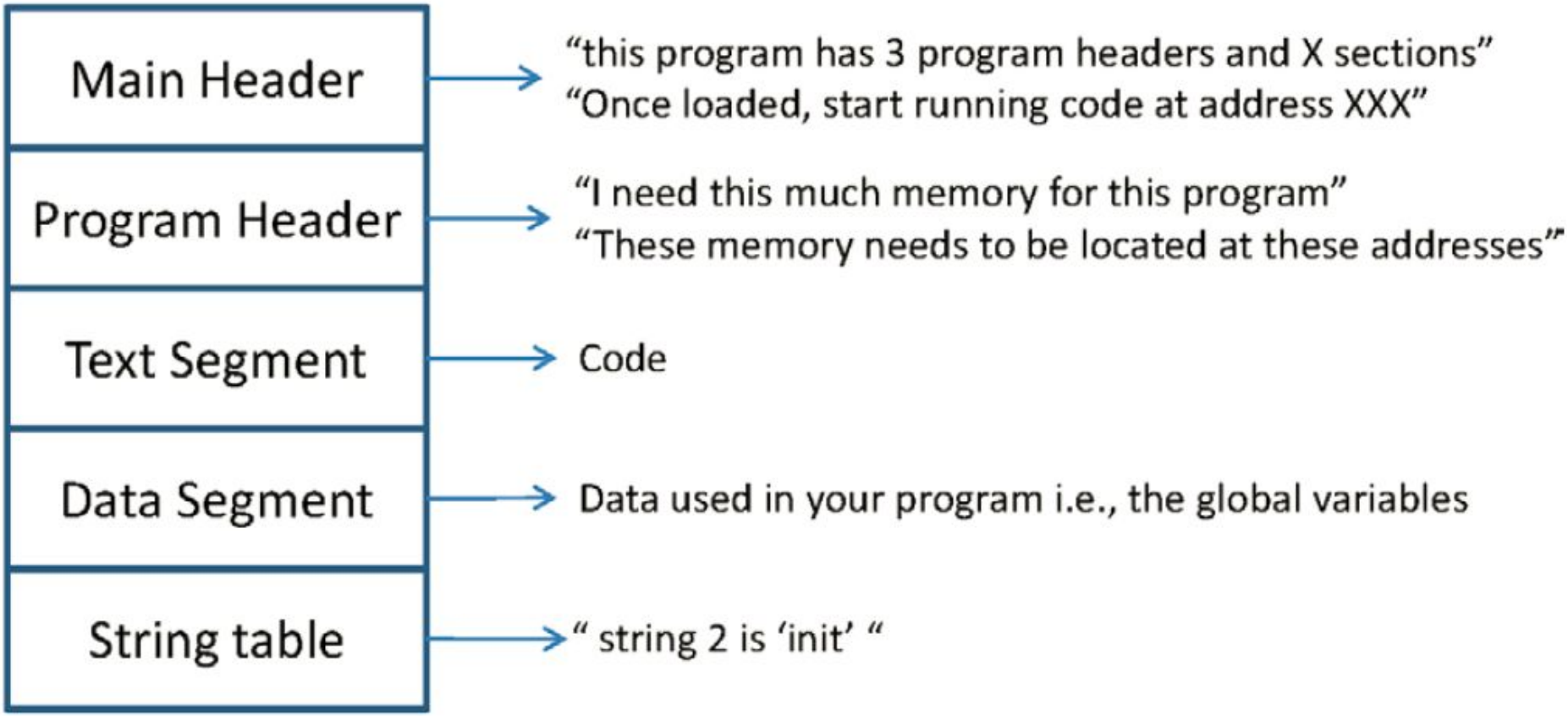
Layout of an executable



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Loader

- Chicken and egg problem
- Who loads the loader?
- Need to talk about the boot sequence:
  1. Power-On
  2. Run Basic I/O System (BIOS)
  3. BIOS load and run Master Boot Record (MBR) in HDD/SSD
  4. MBR loads an OS Boot Loader (BL)
  5. BL loads and run OS

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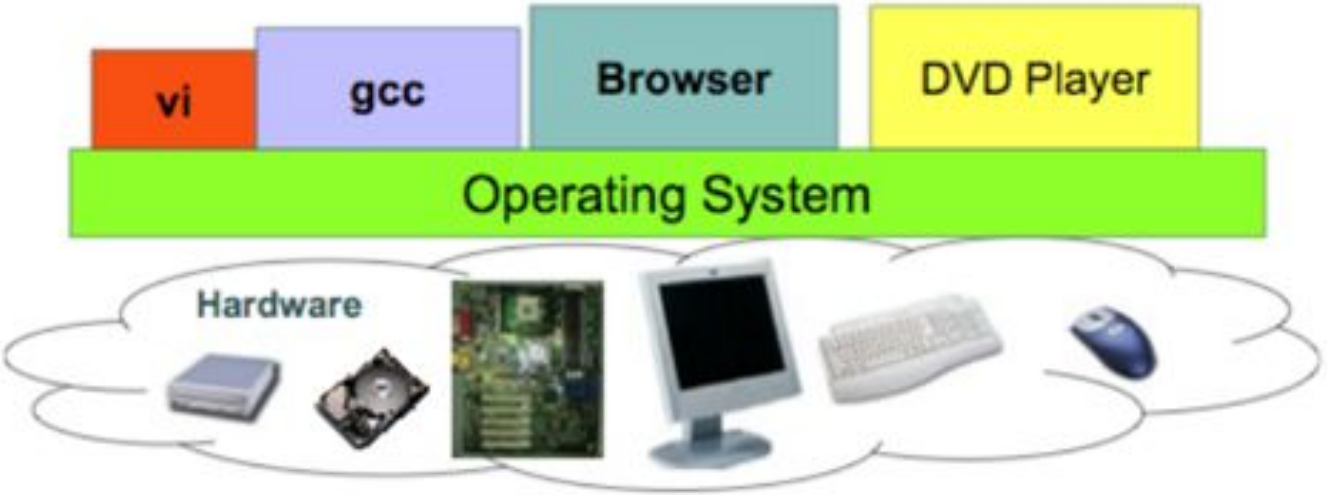
What is an OS?



- OS is a key part of a computer system, an interface between your hardware and software.
- OS understands how computers work under the hood
- Combine languages, hardwares, data structures, and algorithms.

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What does an OS do?

- Manages execution of programs/applications
- Abstraction for programmers
  - API removes need for low-level details
- Portability
- Resource Management
  - Virtualization
- Security

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