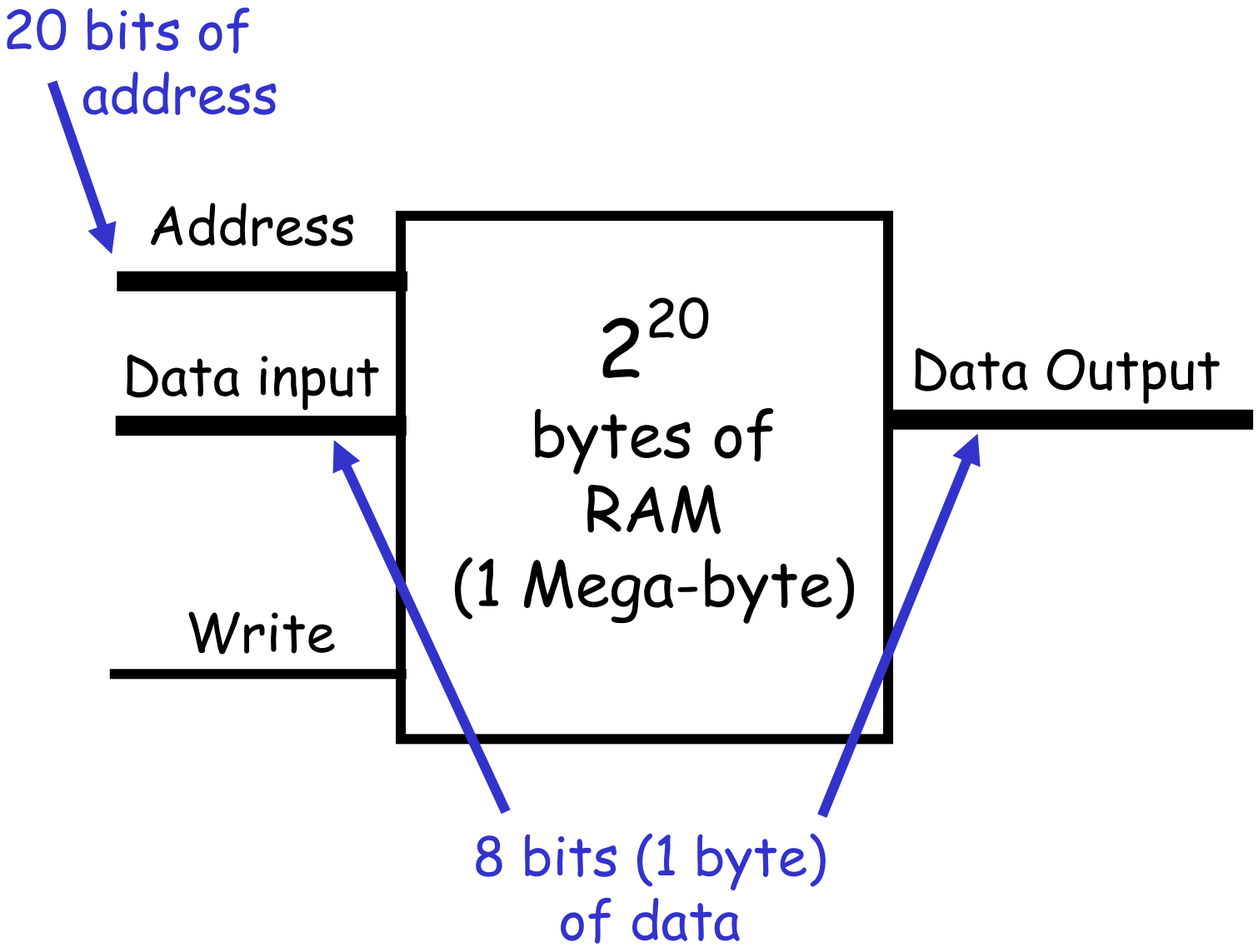
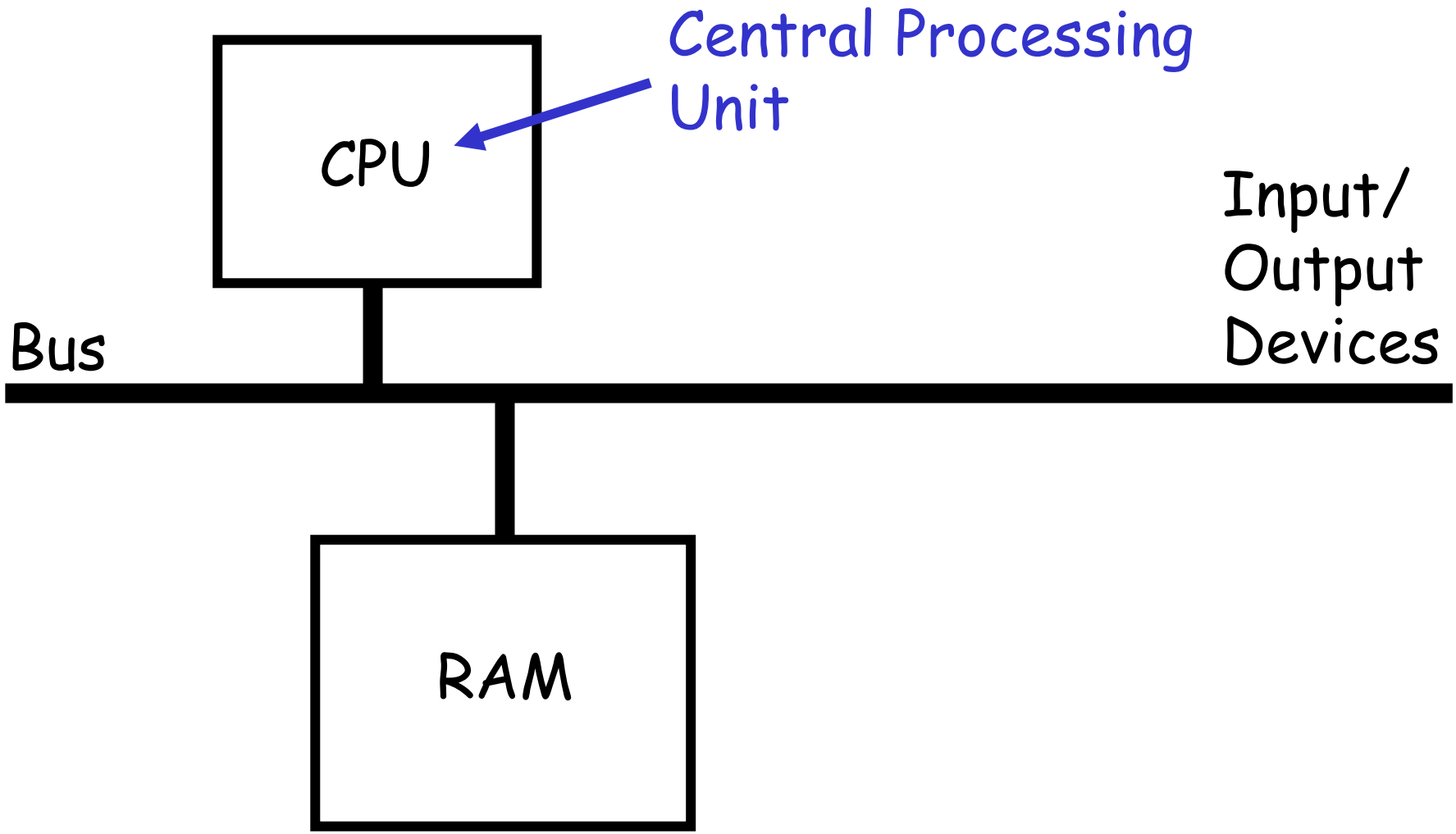
RAM (cont.)

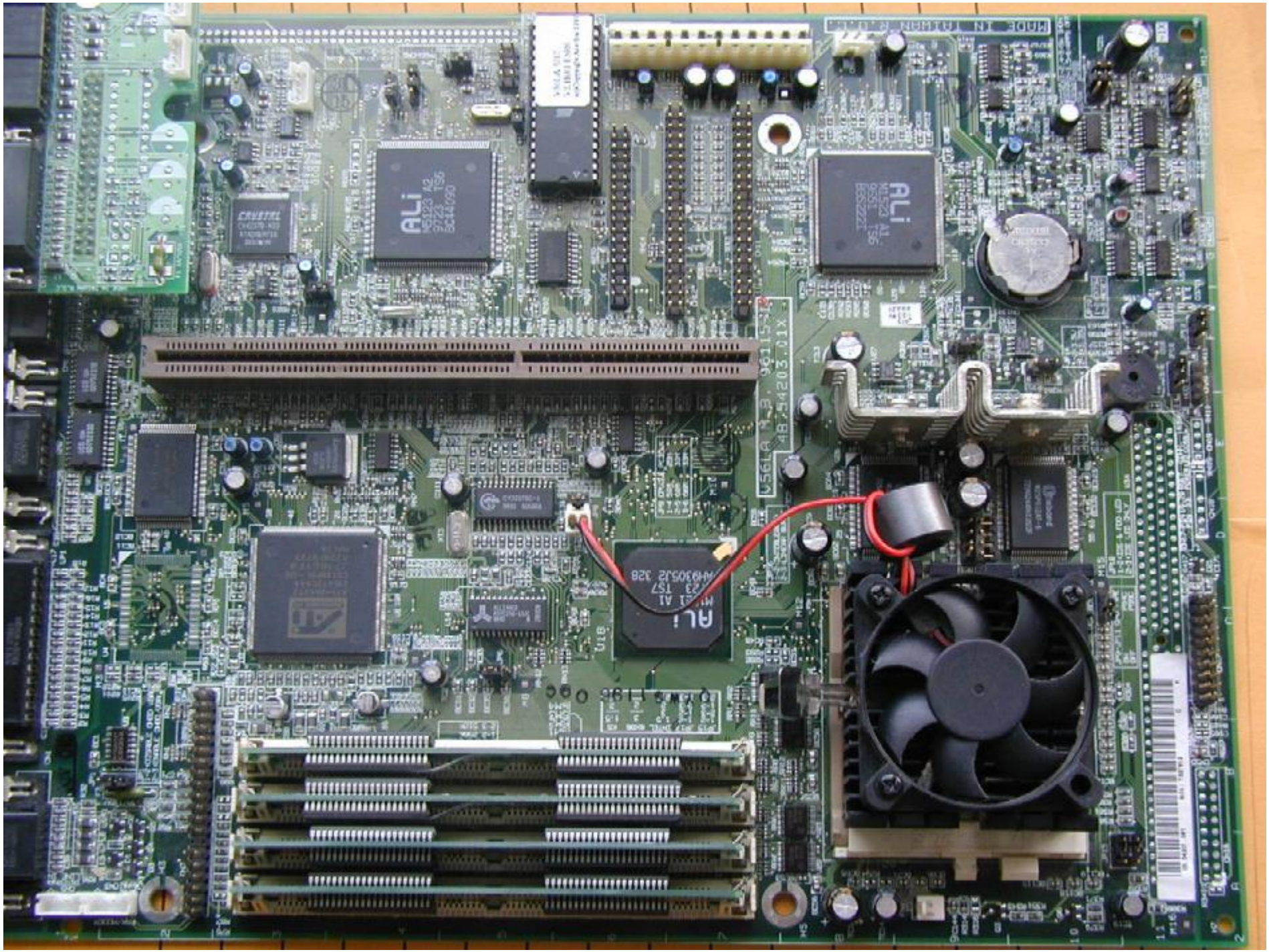

20 bits of address
Address
Data input
Write
2^{20} bytes of RAM (1 Mega-byte)
Data Output
8 bits (1 byte) of data

RAM (cont.)

- When you talk about the memory of a computer, most often you're talking about its RAM.
- If a program is stored in RAM, that means that a sequence of instructions are stored in consecutively addressed bytes in the RAM.
- Data values (variables) are stored anywhere in RAM, not necessarily sequentially
- Both instructions and data are accessed from RAM using addresses
- RAM is one (crucial) part of the computer's overall architecture

Computer Architecture




ALi
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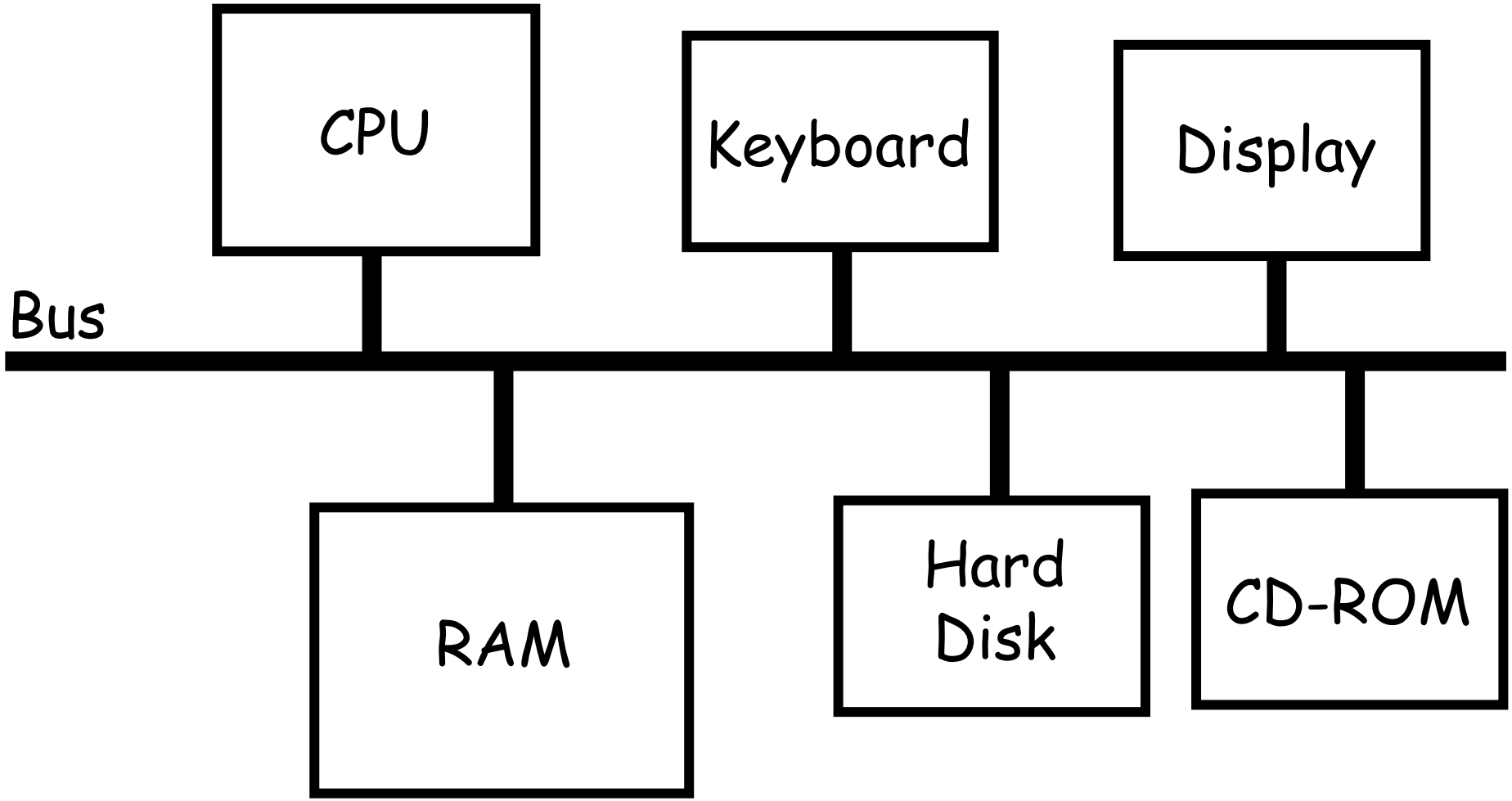
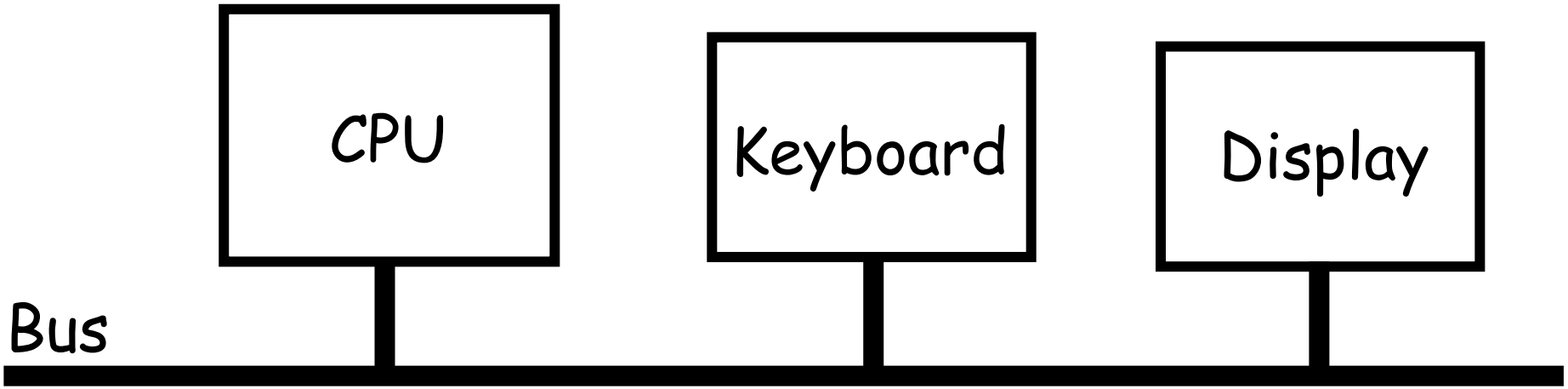
V56LA M_B 961
48.54203.01X

Computer Architecture

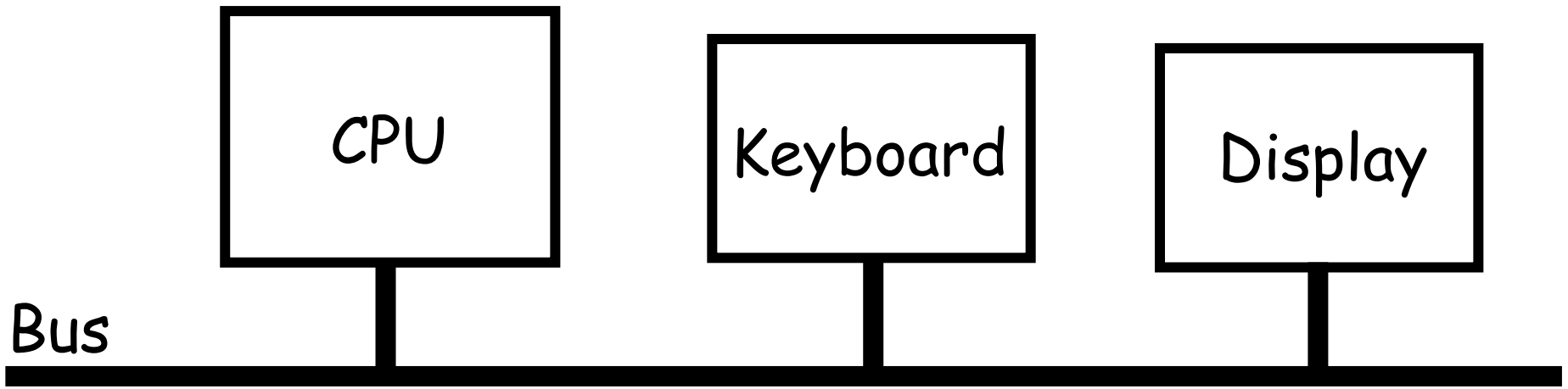


The Bus

- What is a bus?
- It is a simplified way for many devices to communicate to each other.
- Looks like a "highway" for information.
- Actually, more like a "basket" that they all share.

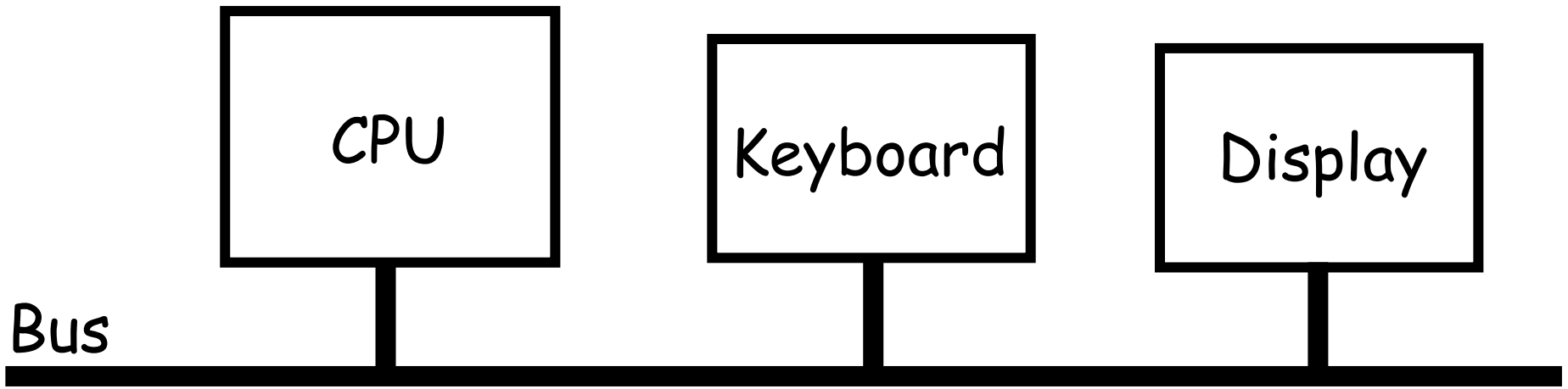


The Bus



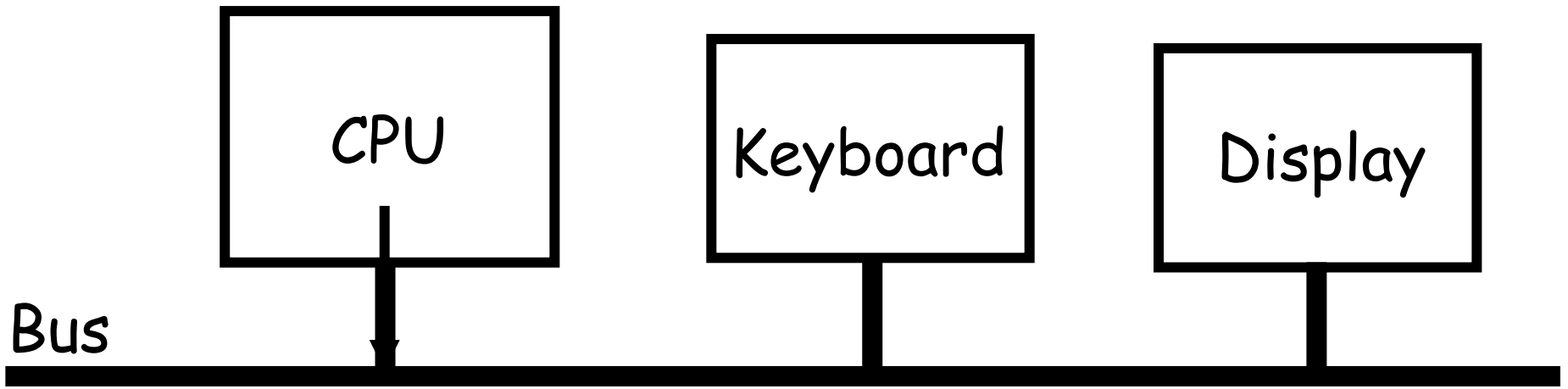
The Bus

- Suppose CPU needs to check to see if the user typed anything.



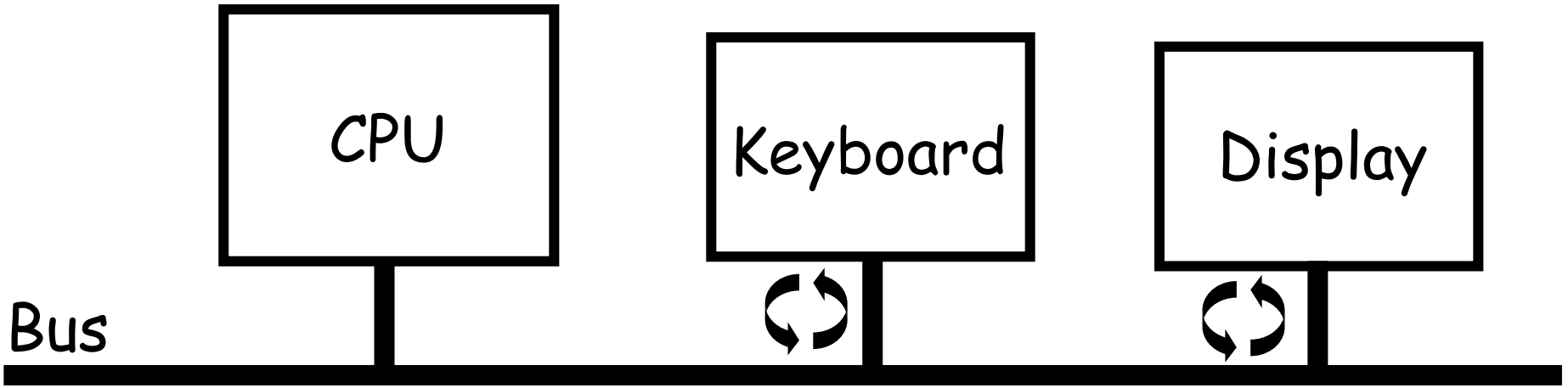
The Bus

- CPU puts "Keyboard, did the user type anything?" (represented in some way) on the Bus.



The Bus

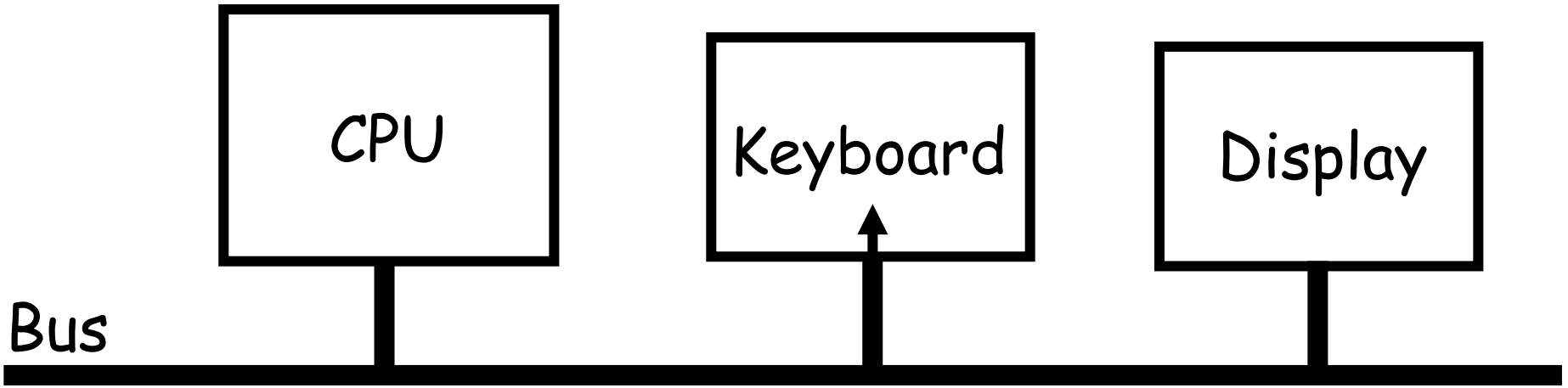
- Each device (except CPU) is a State Machine that constantly checks to see what's on the Bus.



"Keyboard, did the user type anything?"

The Bus

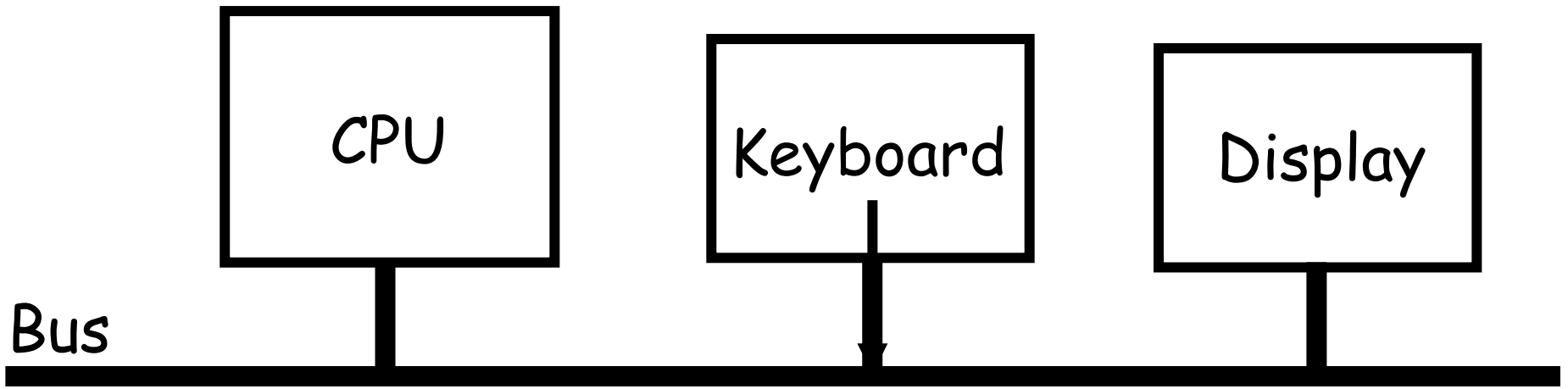
- Keyboard notices that its name is on the Bus, and reads info. Other devices ignore the info.



"Keyboard, did the user type anything?"

The Bus

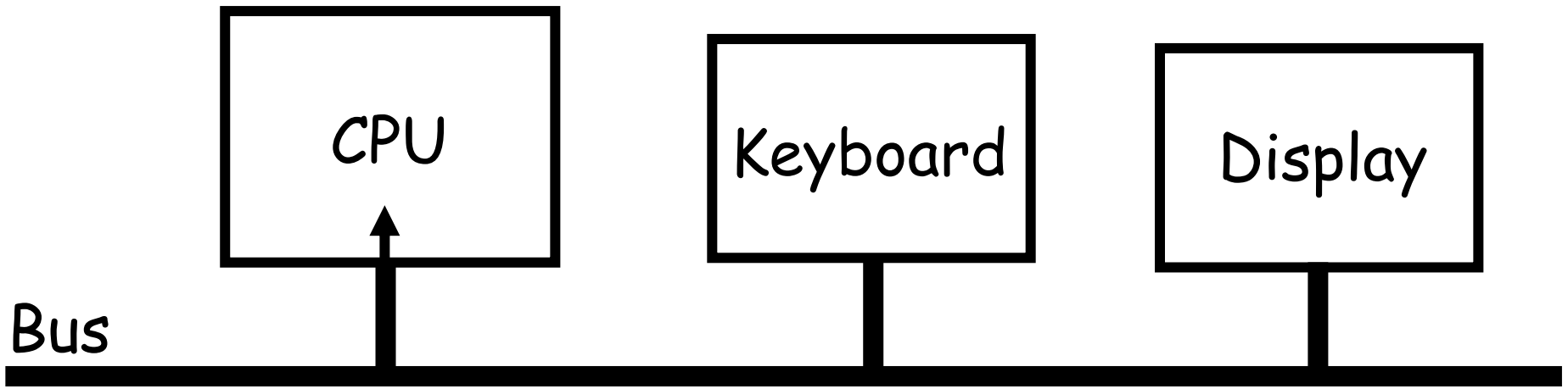
- Keyboard then writes "CPU: Yes, user typed 'a'." to the Bus.



"CPU: Yes, user typed 'a'."

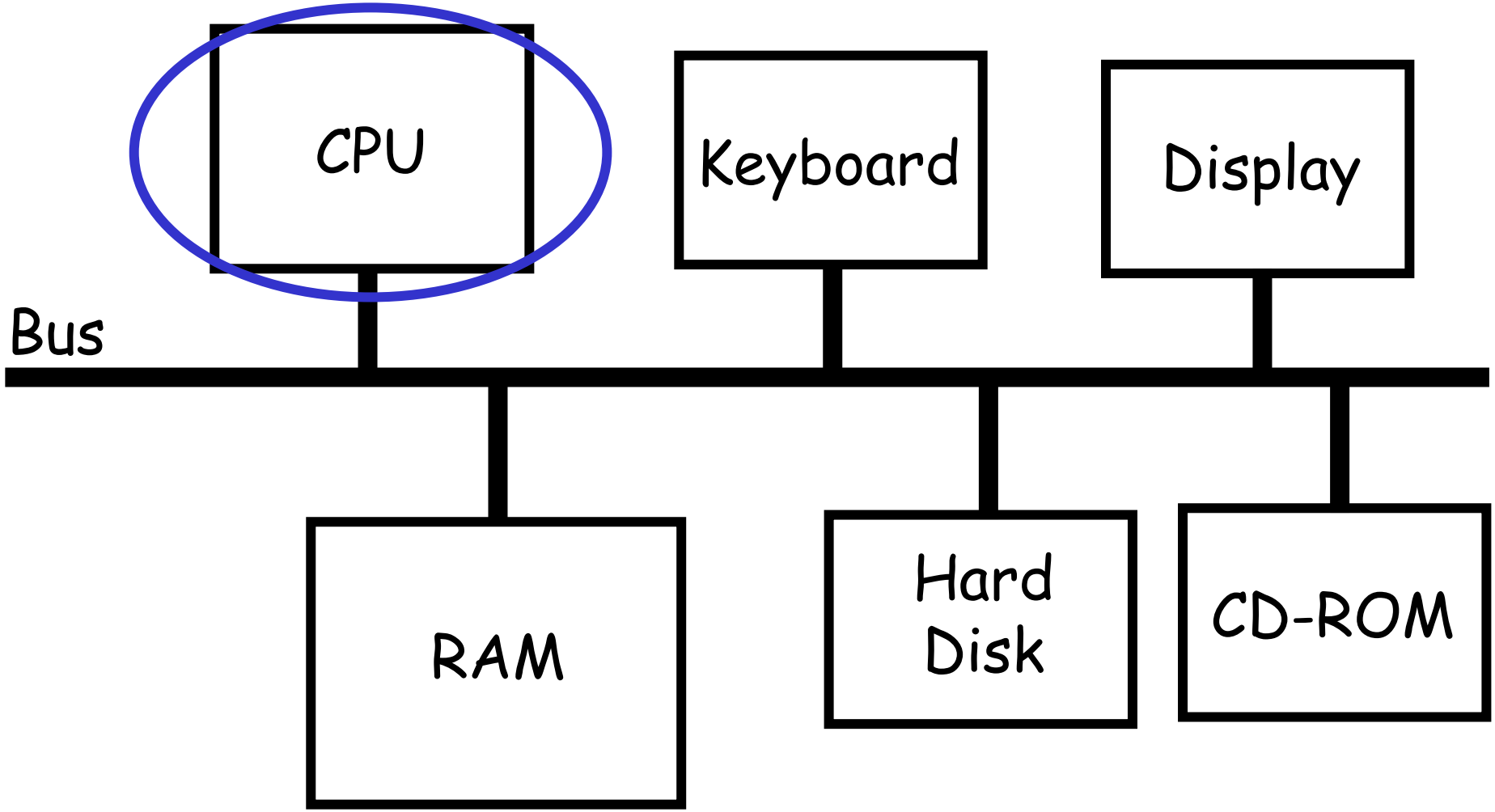
The Bus

- At some point, CPU reads the Bus, and gets the Keyboard's response.



"CPU: Yes, user typed 'a'."

Computer Architecture

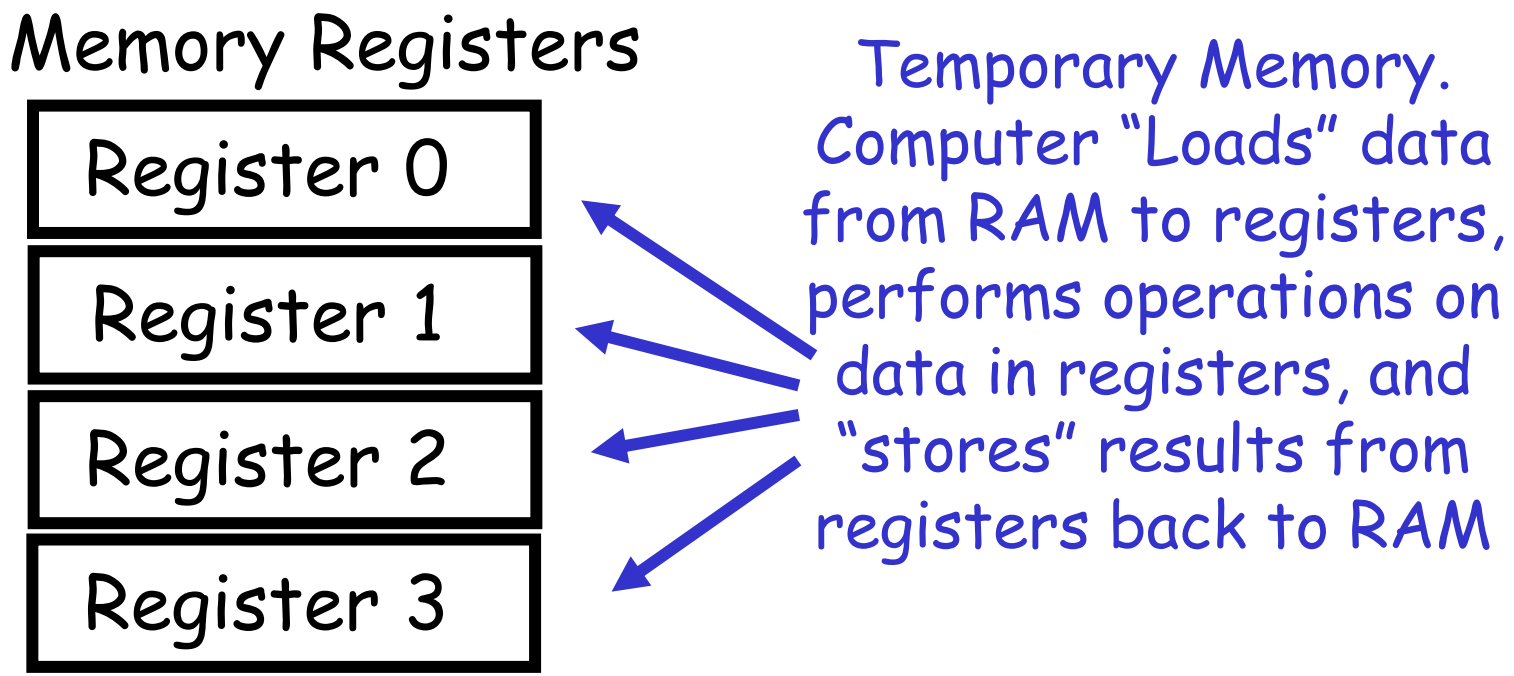


Inside the CPU

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

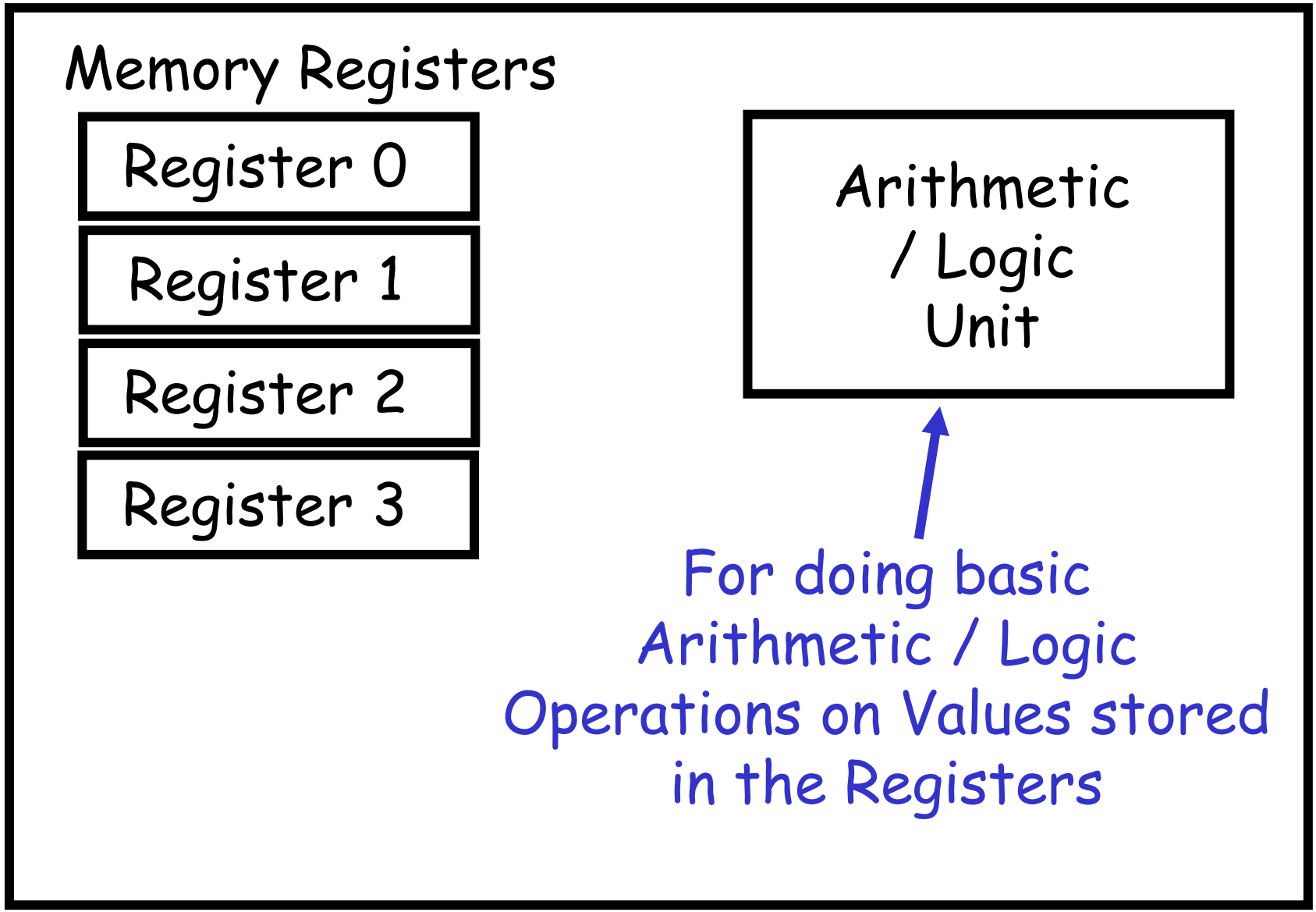
- Let's take a look inside.

Inside the CPU (cont.)

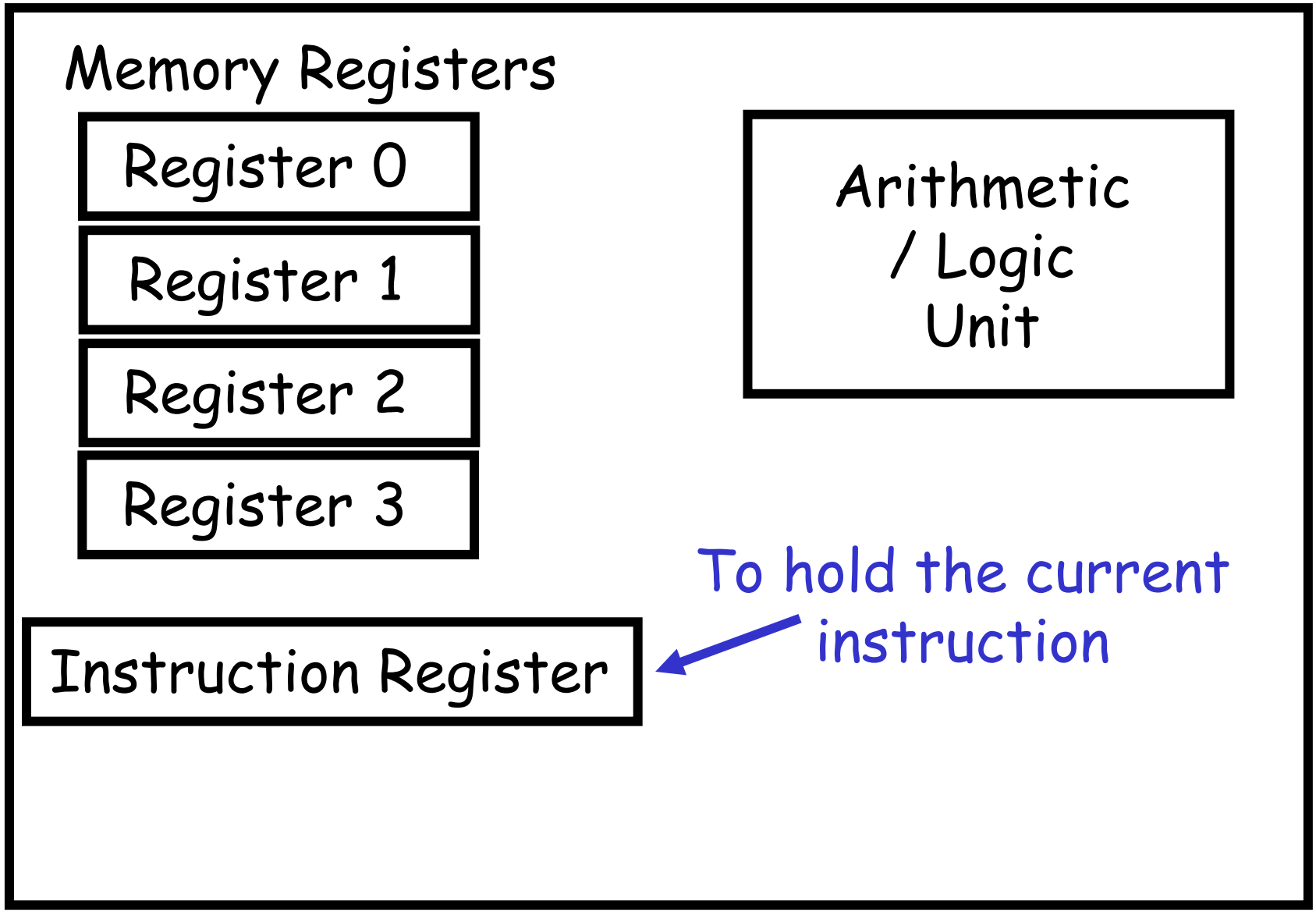


Remember our initial example: "read value of A from memory; read value of B from memory; add values of A and B; put result in memory in variable C." The reads are done to registers, the addition is done in registers, and the result is written to memory from a register.

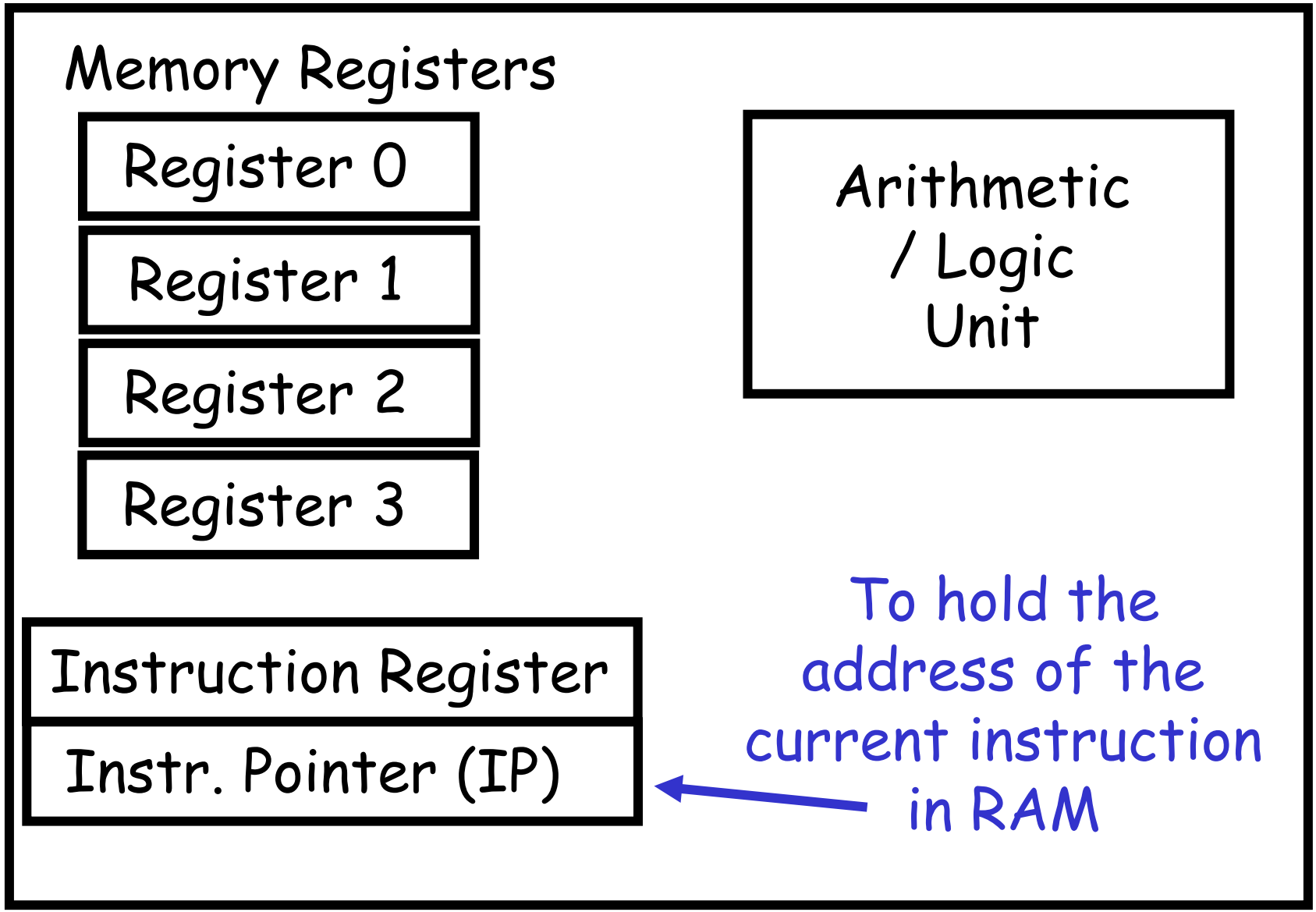
Inside the CPU (cont.)



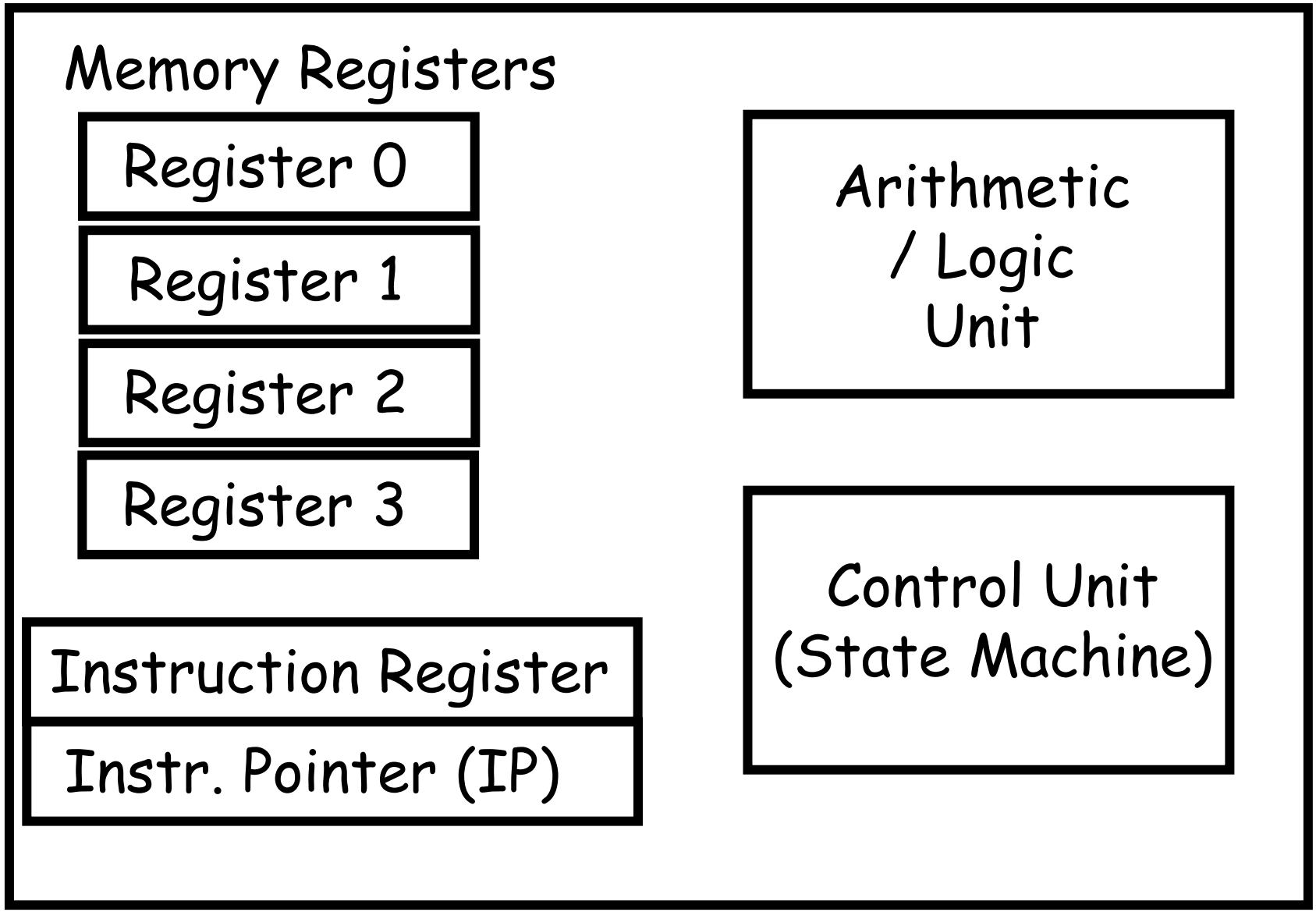
Inside the CPU (cont.)



Inside the CPU (cont.)



Inside the CPU (cont.)



The Control Unit

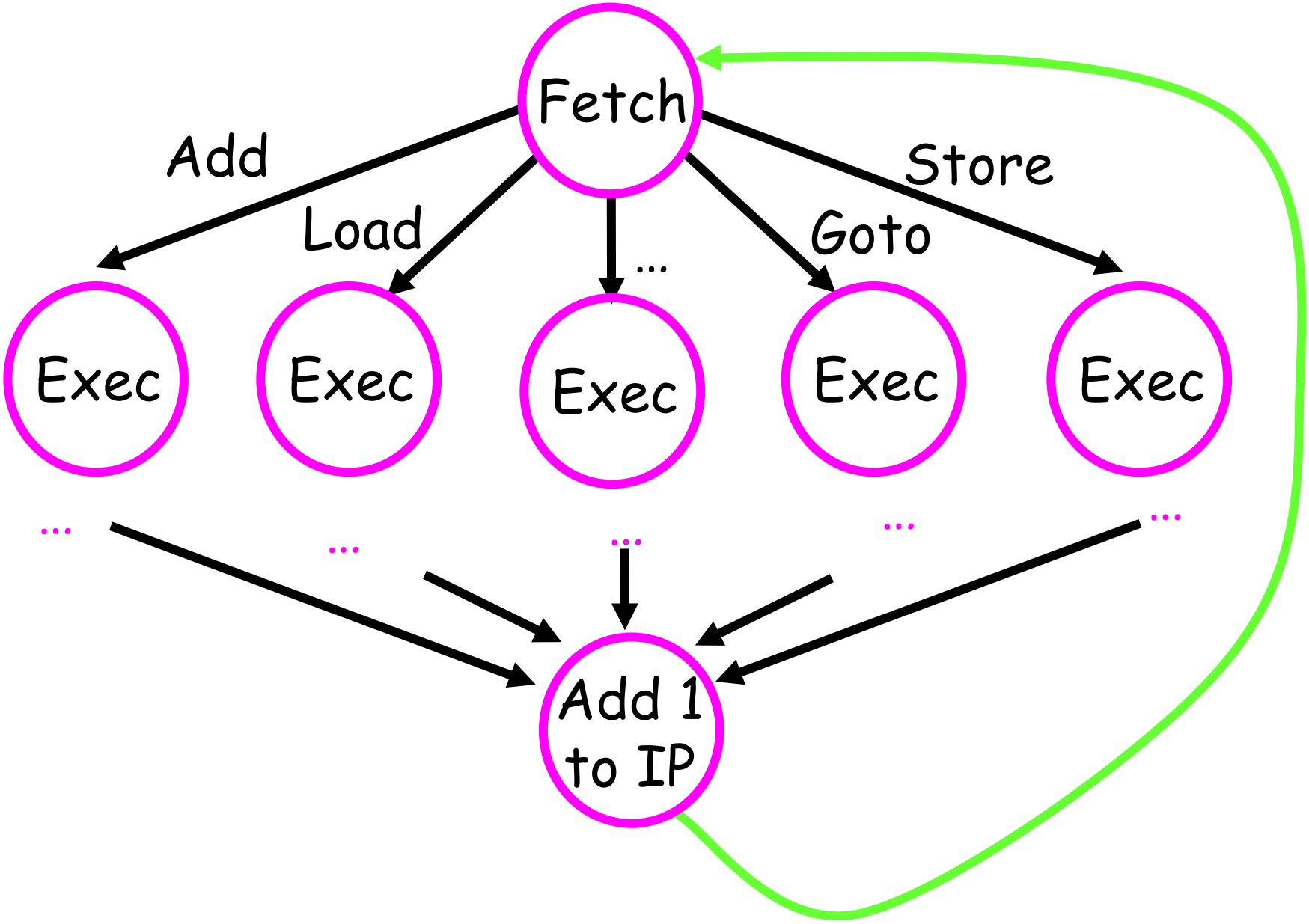
- It all comes down to the Control Unit.
- This is just a State Machine.

- How does it work?

The Control Unit

- Control Unit State Machine has very simple structure:
  - 1) Fetch: Ask the RAM for the instruction whose address is stored in IP.
  - 2) Execute: There are only a small number of possible instructions. Depending on which it is, do what is necessary to execute it.
  - 3) Repeat: Add 1 to the address stored in IP, and go back to Step 1 !

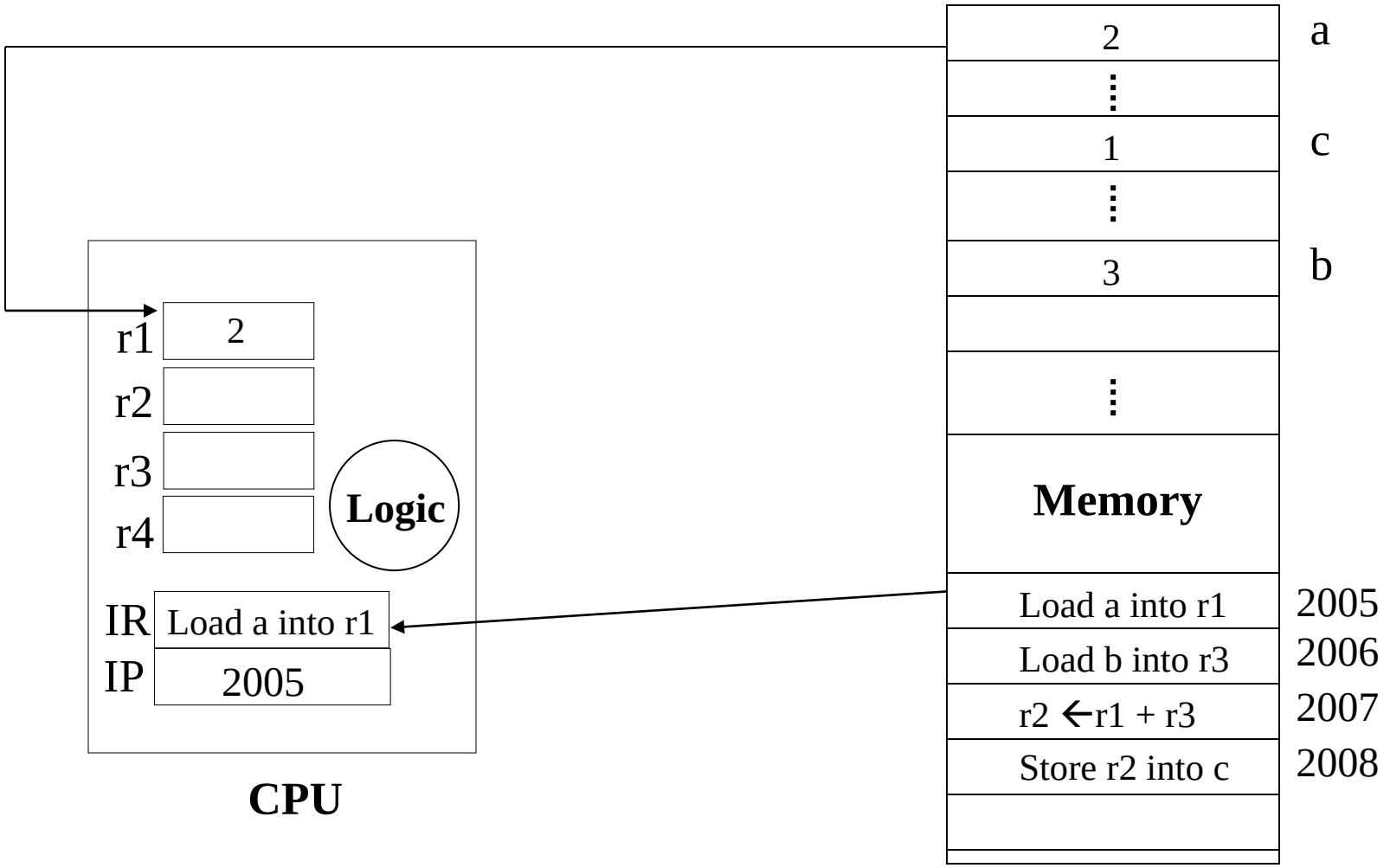
The Control Unit is a State Machine



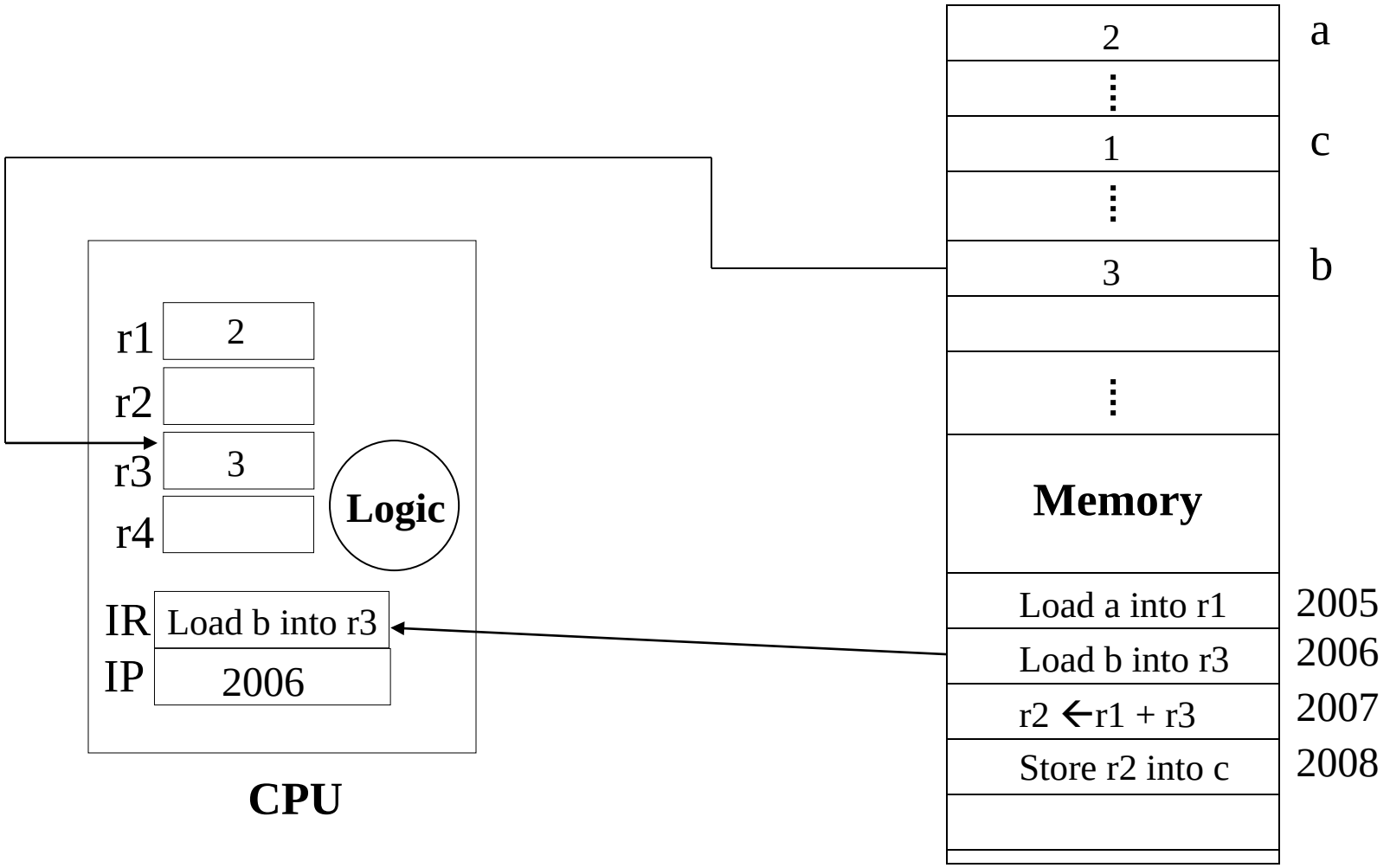
A Simple Program

- Want to add values of variables a and b (assumed to be in memory), and put the result in variable c in memory, I.e. c ← a+b
- Instructions in program
  - Load a into register r1
  - Load b into register r3
  - r2 ← r1 + r3
  - Store r2 in c

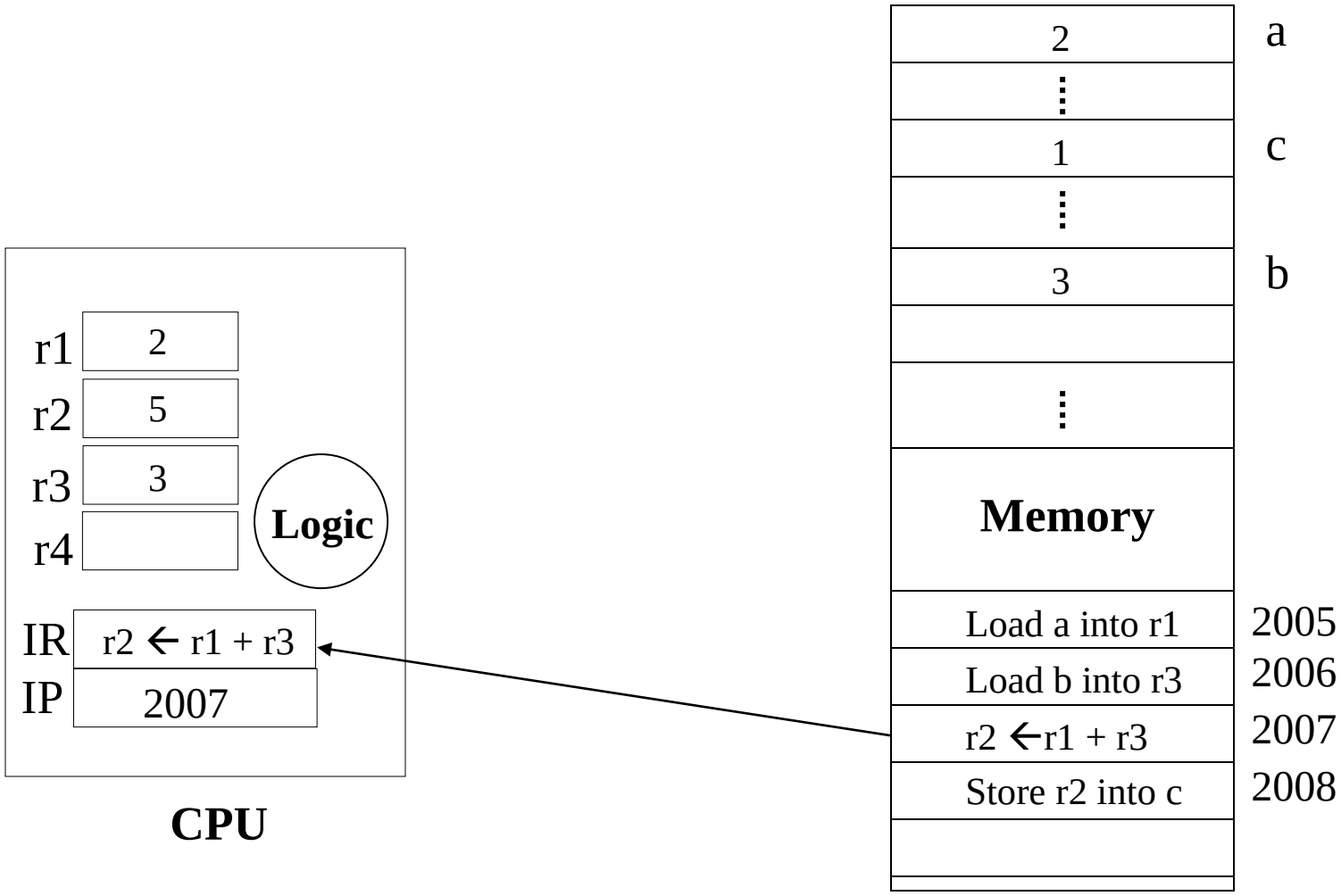
Running the Program



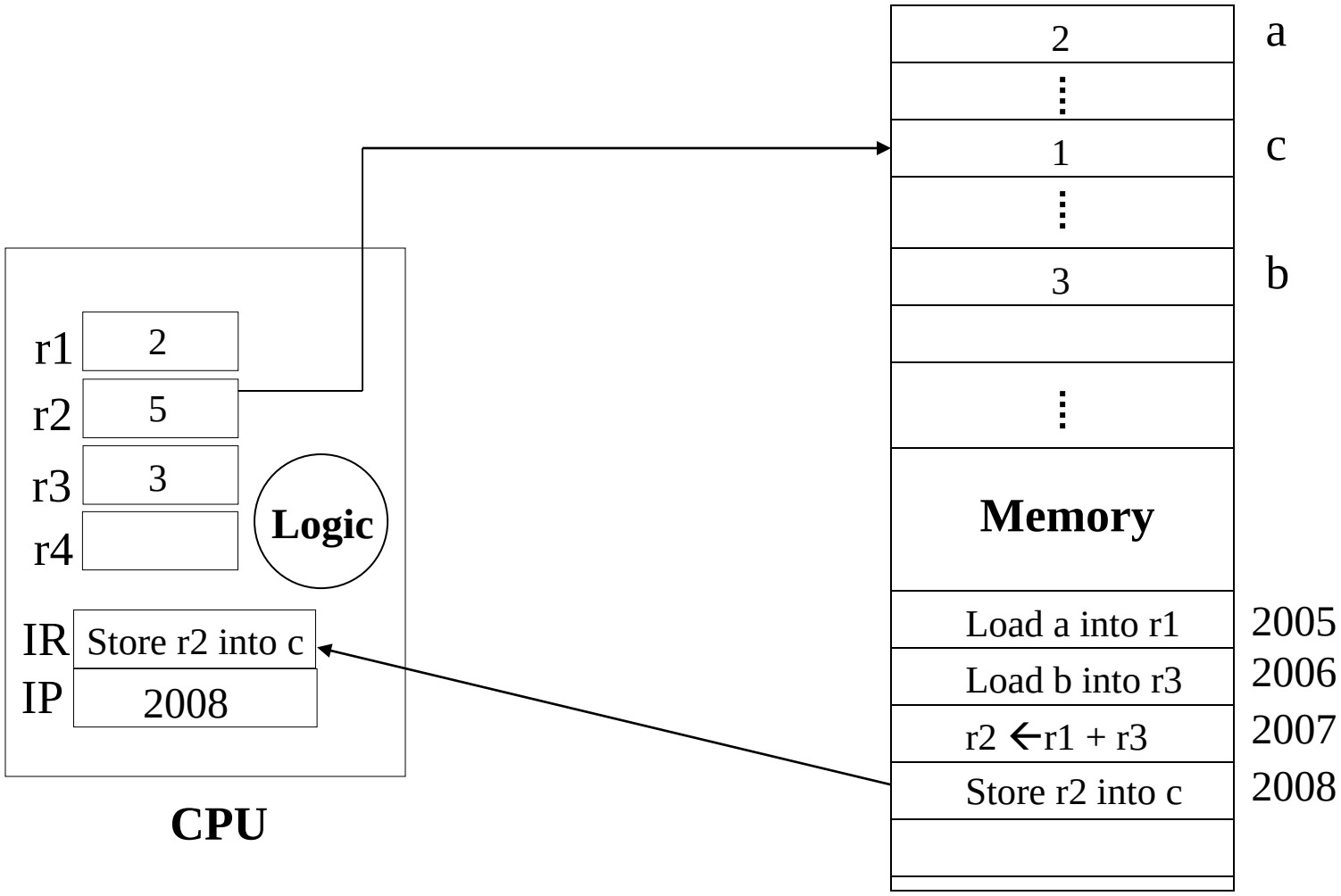
Running the Program



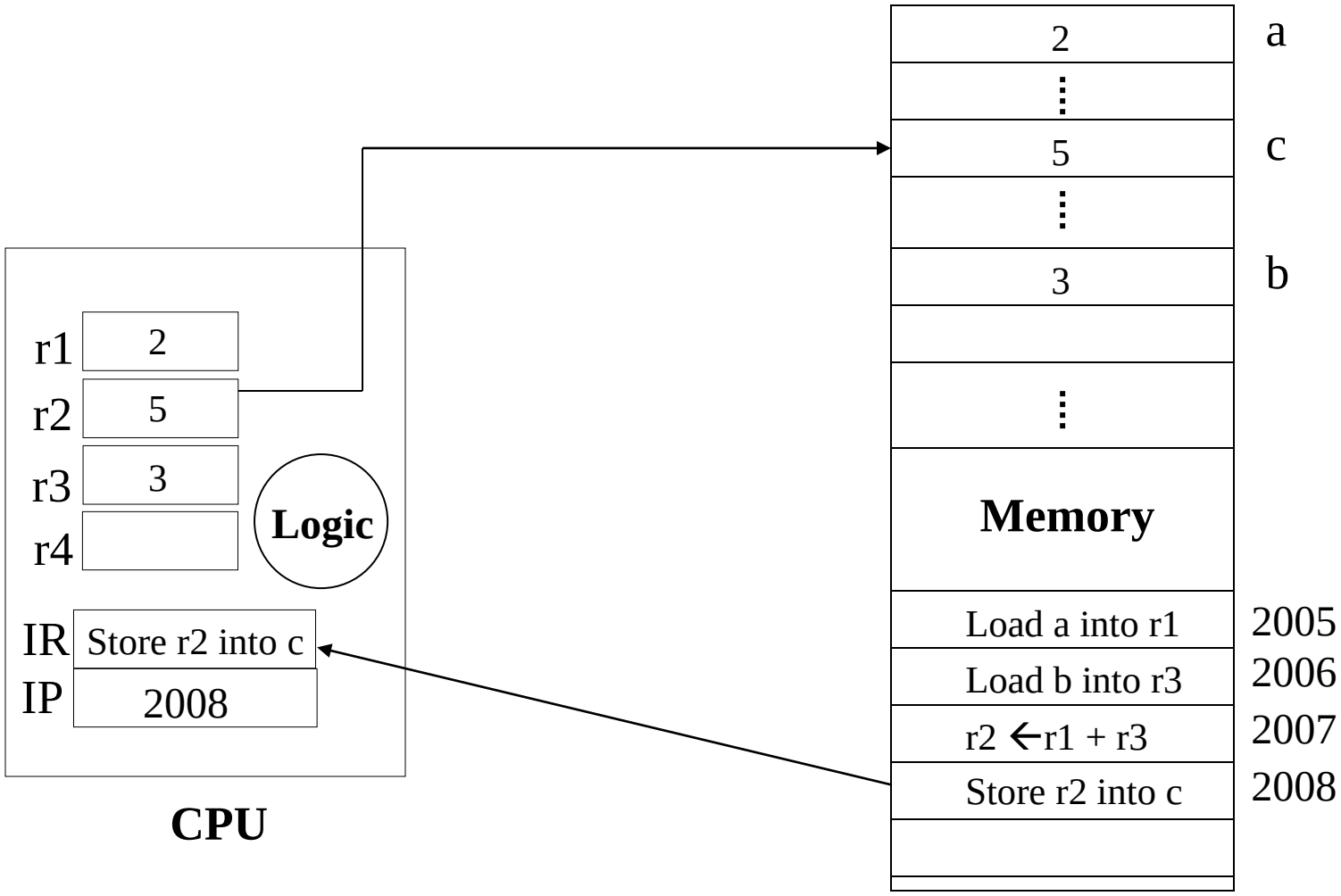
Running the Program



Running the Program

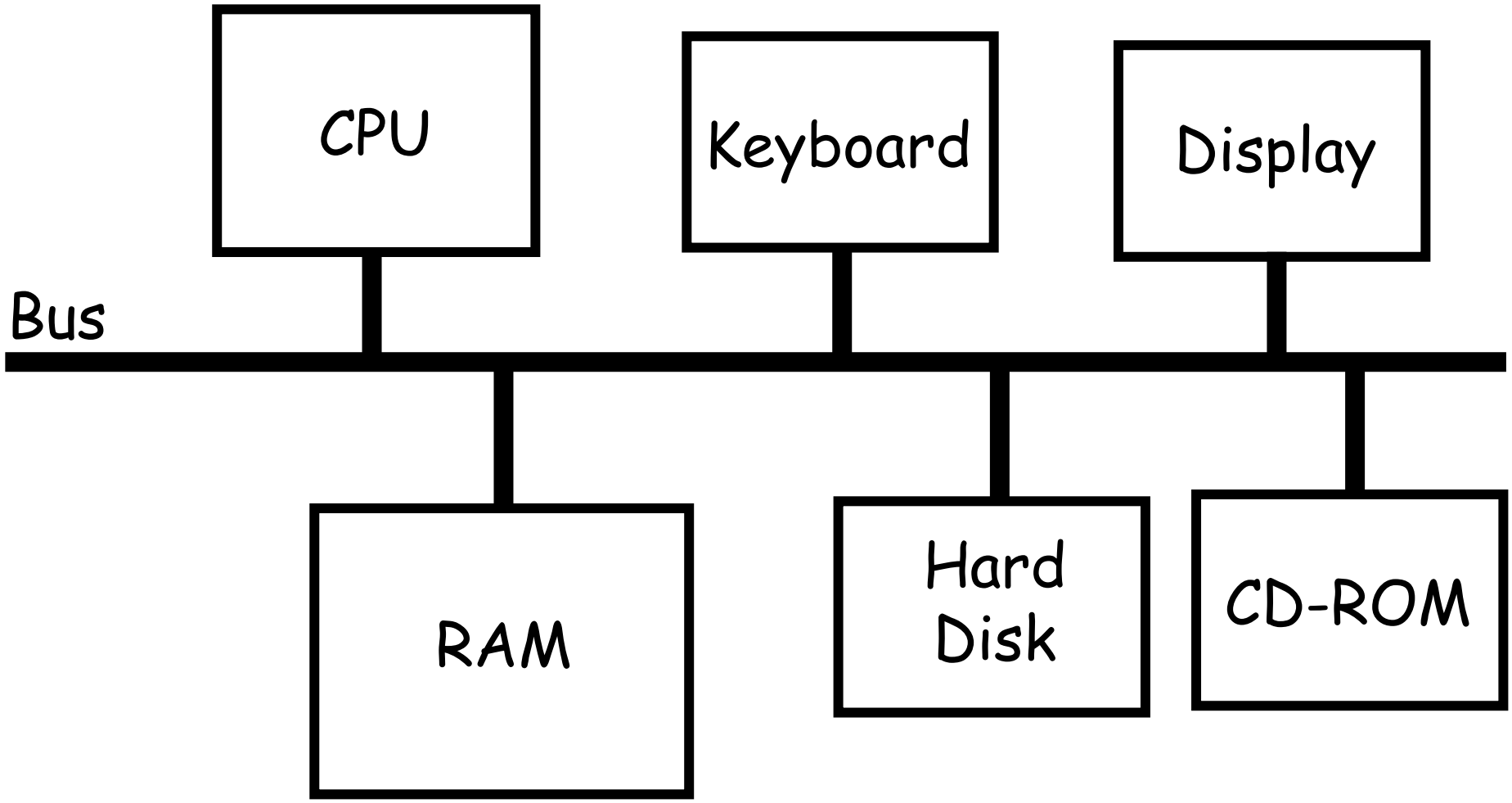


Running the Program



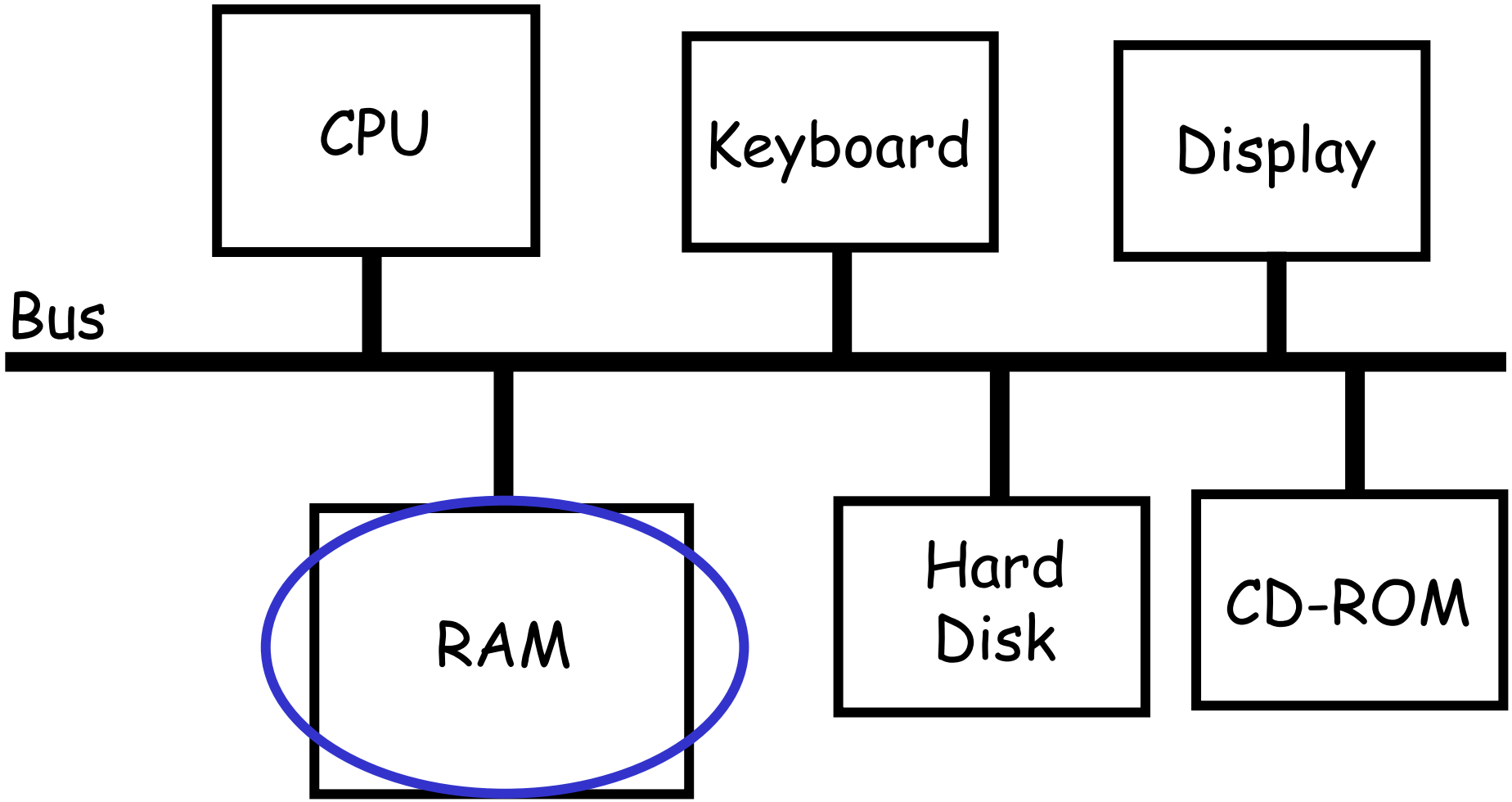
Putting it all together

- Computer has many parts, connected by a Bus:



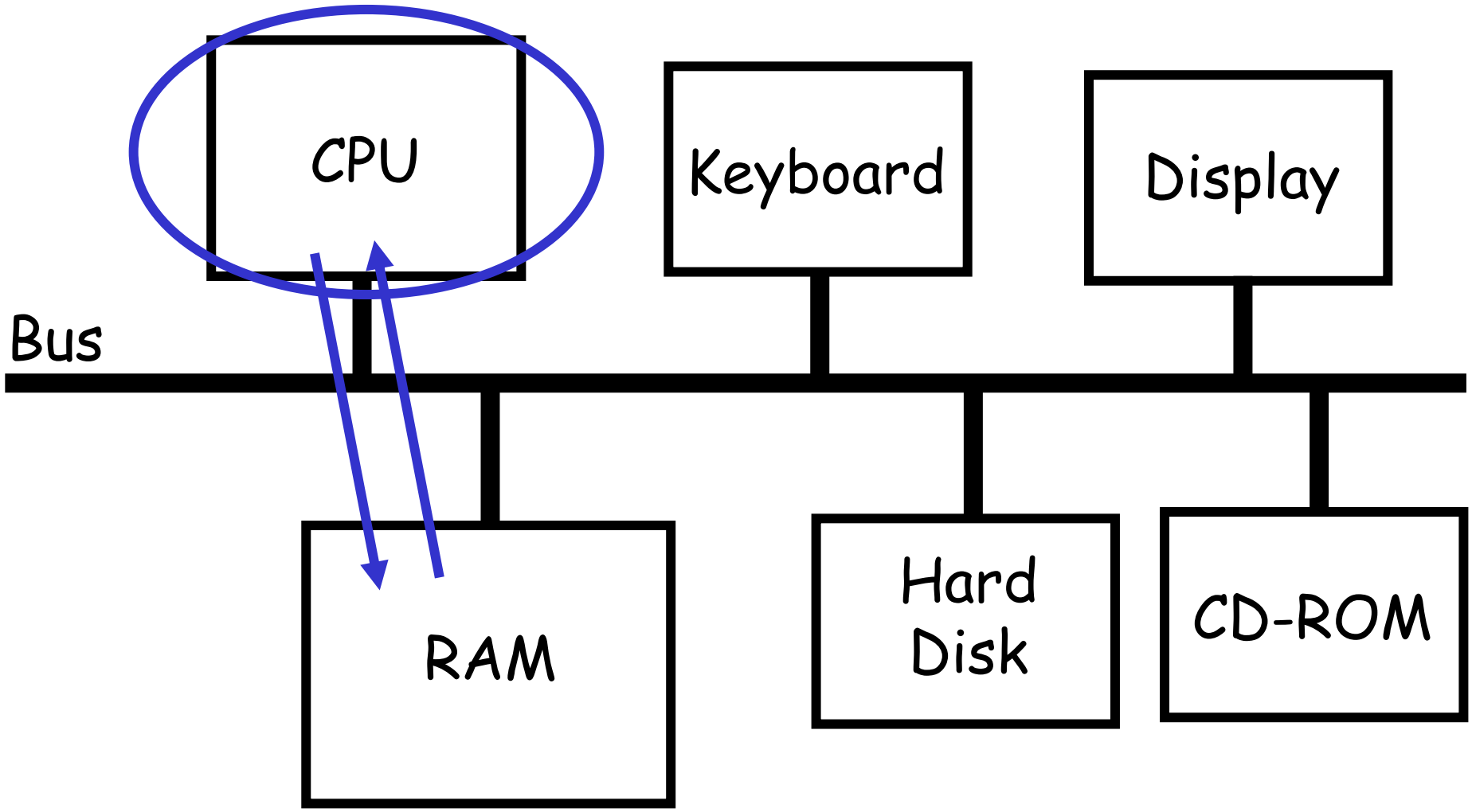
Putting it all together

- The RAM is the computer's main memory.
- This is where programs and data are stored.



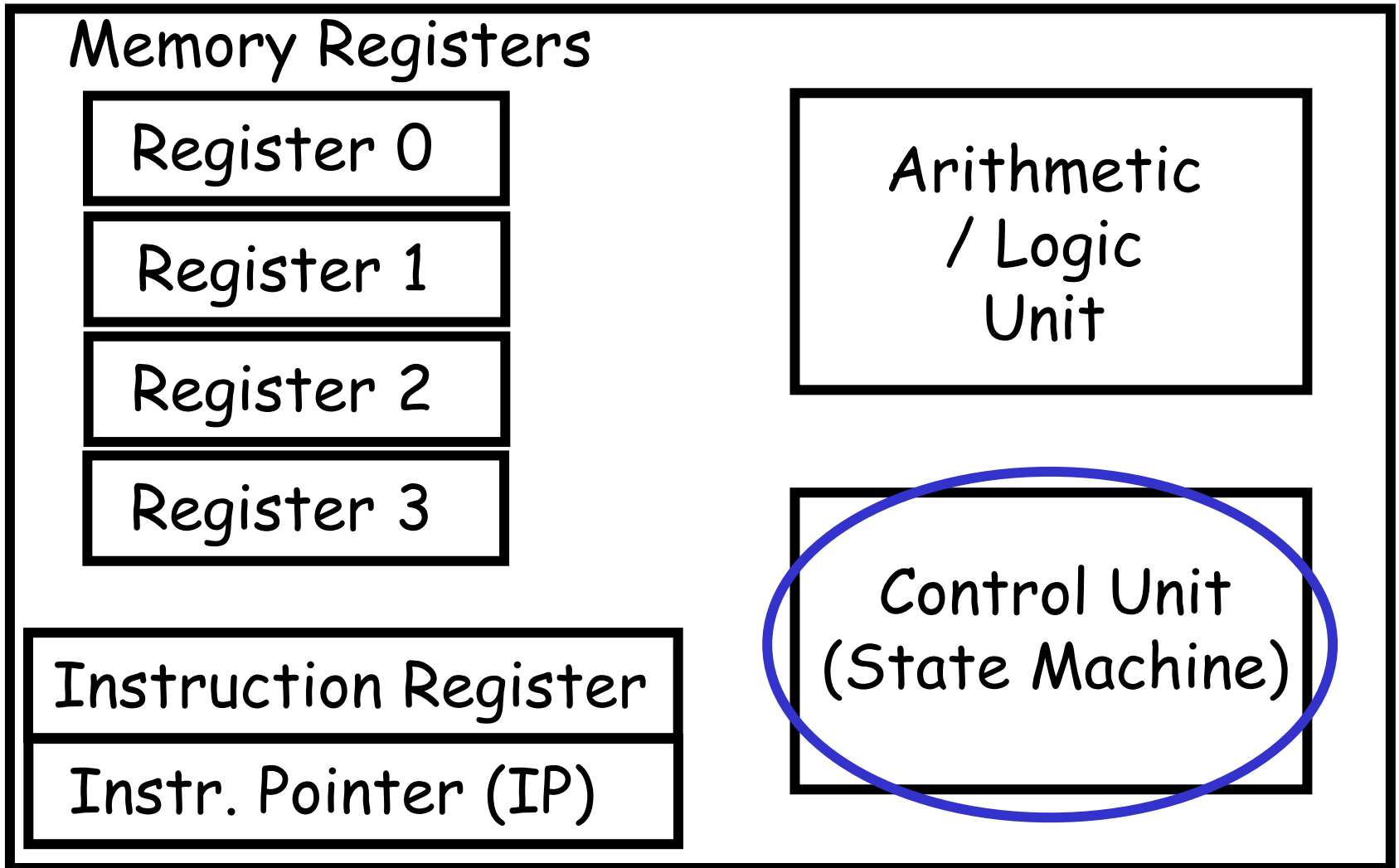
Putting it all together

- The CPU goes in a never-ending cycle, reading instructions from RAM and executing them.



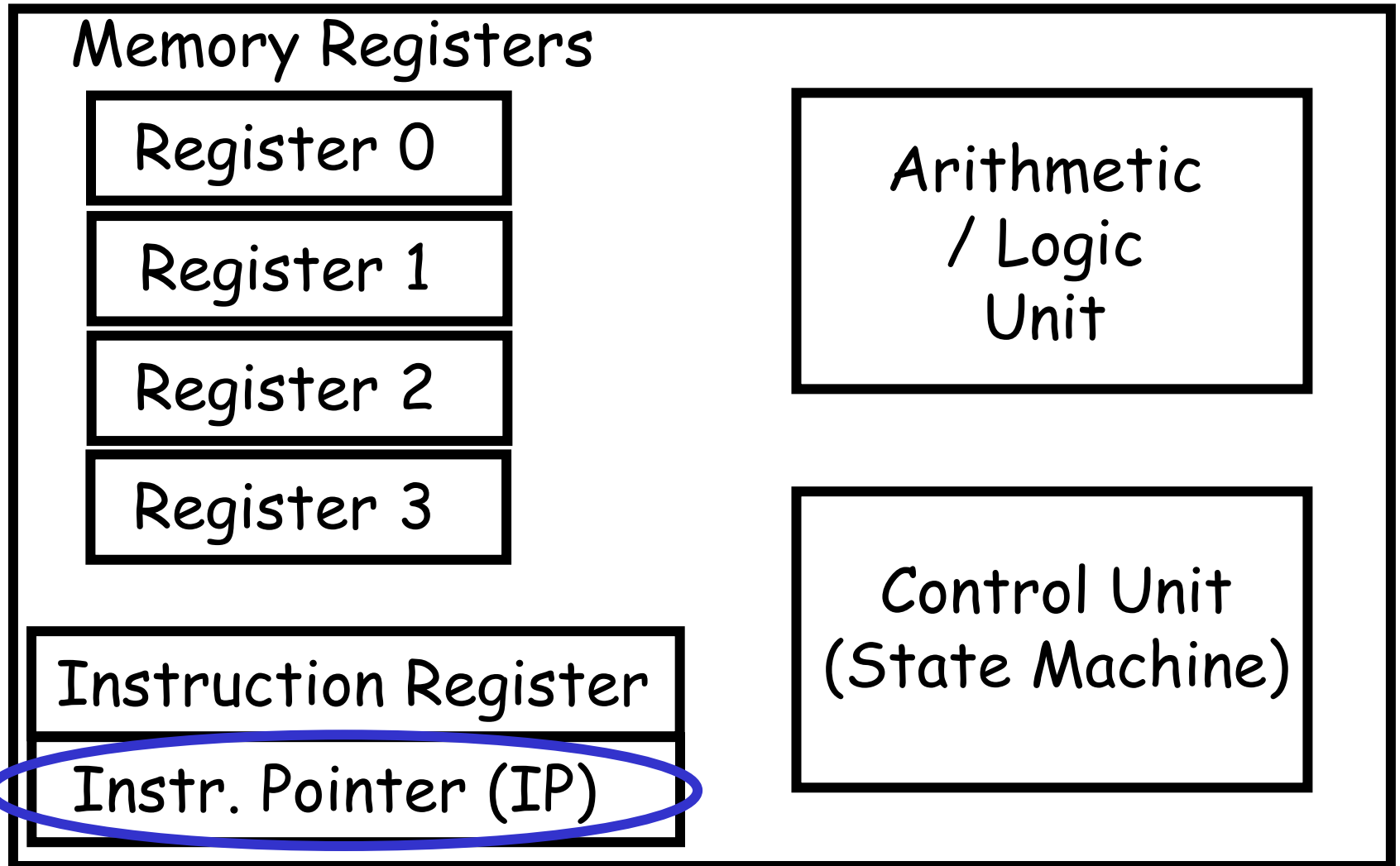
Putting it all together

- This cycle is orchestrated by the Control Unit in the CPU.



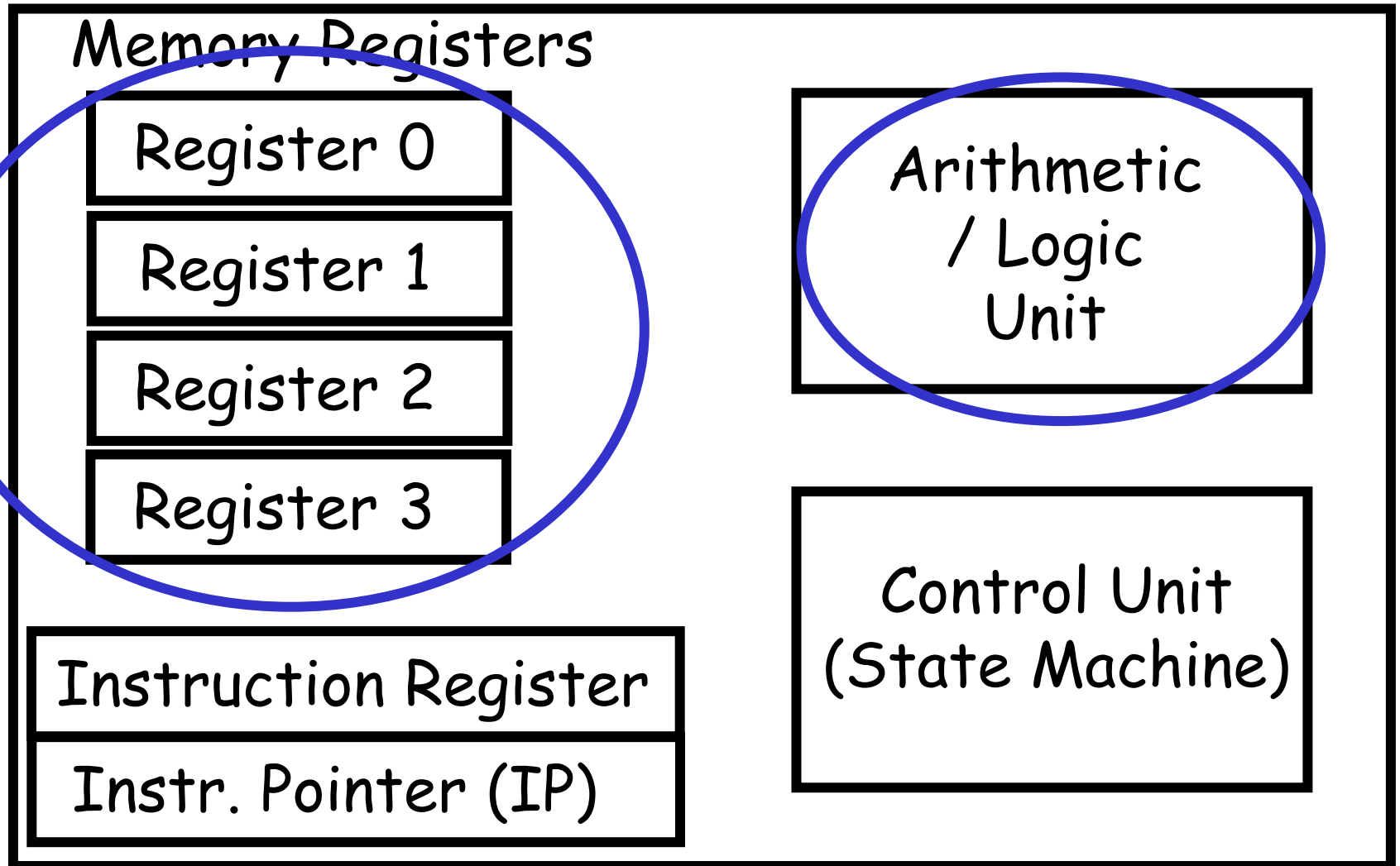
Back to the Control Unit

- It simply looks at where IP is pointing, reads the instruction there from RAM, and executes it.



Putting it all together

- To execute an instruction, the Control Unit uses the ALU plus Memory and/or the Registers.



Programming

Where we are

- Examined the hardware for a computer
  - Truth tables
  - Logic gates
  - States and transitions in a state machine
  - The workings of a CPU and Memory

- Now, want to program the hardware

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

Specifying a Program and its Instructions

- High-level programs: each statement translates to many instructions
  - E.g. $c \leftarrow a + b$ to:

Load a into r1
Load b into r3
r2 ← r1 + r3
Store r2 into c

- Assembly language: specify each machine instruction, using mnemonic form
  - E.g. Load r1, A
- Machine language: specify each machine instruction, using bit patterns
  - E.g. 11011010000011110011

Machine/Assembly Language

- We have a machine that can execute instructions
- Basic Questions:
  - What instructions?
  - How are these instructions represented to the computer hardware?

Complex vs Simple Instructions

- Computers used to have very complicated instruction sets – this was known as:
  - CISC = Complex Instruction Set Computer
  - Almost all computers 20 years ago were CISC.

- 80s introduced RISC:
  - RISC = Reduced Instruction Set Computer

Complex vs Simple Instructions

- RISC = Reduced Instruction Set Computer
  - Fewer, Less powerful basic instructions
  - But Simpler, Faster, Easier to design CPU's
  - Can make "powerful" instructions by combining several wimpy ones

- Shown to deliver better performance than Complex Instruction Set Computer (CISC) for several types of applications.

Complex vs Simple Instructions

- Nevertheless, Pentium is actually CISC !
- Why?

Complex vs Simple Instructions

- Nevertheless, Pentium is actually CISC !
- Why: Compatibility with older software

- Newer application types (media processing etc) perform better with specialized instructions

- The world has become too complex to talk about RISC versus CISC

Typical Assembly Instructions

- Some common assembly instructions include:
  - 1) "Load" – Load a value from RAM into one of the registers
  - 2) "Load Direct" – Put a fixed value in one of the registers (as specified)
  - 3) "Store" - Store the value in a specified register to the RAM
  - 4) "Add" - Add the contents of two registers and put the result in a third register

Typical Assembly Instructions

- Some common instructions include:
  - 5) "Compare" - If the value in a specified register is larger than the value in a second register, put a "0" in Register r0
  - 6) "Jump" - If the value in Register r0 is "0", change Instruction Pointer to the value in a given register
  - 7) "Branch" - If the value in a specified register is larger than that in another register, change IP to a specified value

Machine Languages

- Different types of CPU's understand different instructions
  - Pentium family / Celeron / Xeon / AMD K6 / Cyrix … (Intel x86 family)
  - PowerPC (Mac)
  - DragonBall (Palm Pilot)
  - StrongARM/MIPS (WinCE)
  - Many Others (specialized or general-purpose)
- They represent instructions differently in their assembly/machine languages (even common ones)