Lecture 03

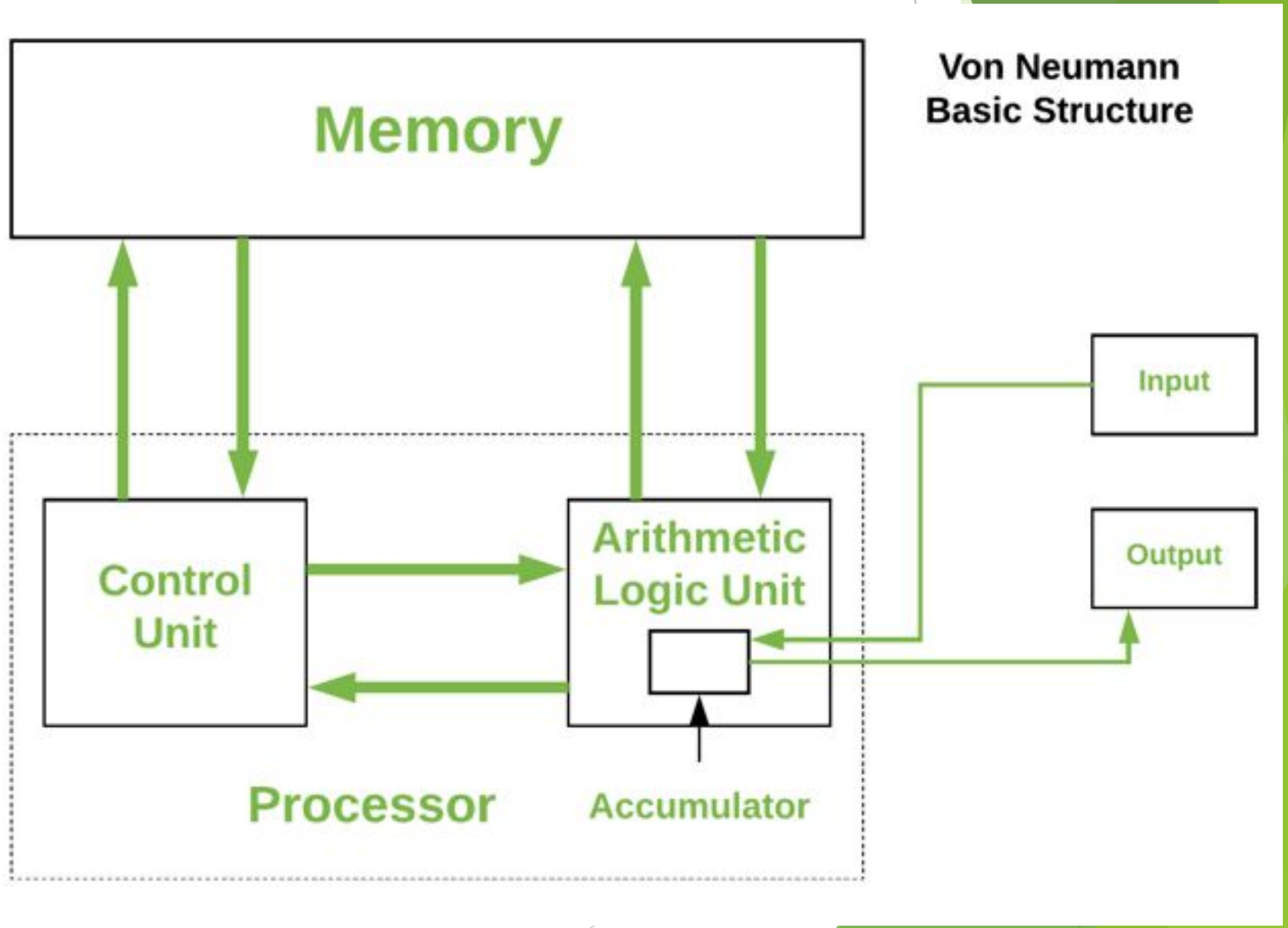
Computer Organization

Computer Organization

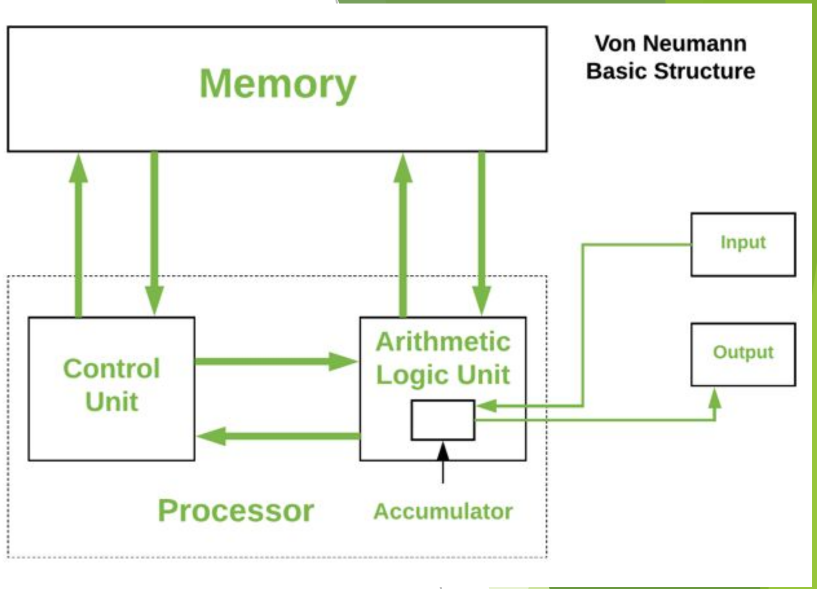
- It deals with the hardware components of a computer system such as the input/output devices, CPU and memory devices

Von Neumann Basic Structure

1. The Central Processing Unit (CPU)
2. The Main Memory Unit (RAM)
3. The Input / Output Device



Von Neumann Basic Structure



- Let’s consider them in details.
- **Arithmetic and Logic Unit (ALU)**
  - The arithmetic logic unit is that part of the CPU that handles all the calculations the CPU may need, e.g. Addition, Subtraction, Comparisons.
  - It performs Logical Operations, Bit Shifting Operations, and Arithmetic Operation.
- **Control Unit**
  - A control unit (CU) handles all processor control signals. It directs all input and output flow, fetches code for instructions and controlling how data moves around the system.

Instruction and CPU Registers

- Instruction:
  - In computer, instruction is a single operation that can be performed/execute by a computer.
  - A computer program/software is a collection of instructions

- CPU Register
  - Small amount of fast storage, quickly accessible to CPU.

Byte-Size Memory Location

- Common visualization of computer memory
- Discrete locations are shown as boxes holding 1-byte each

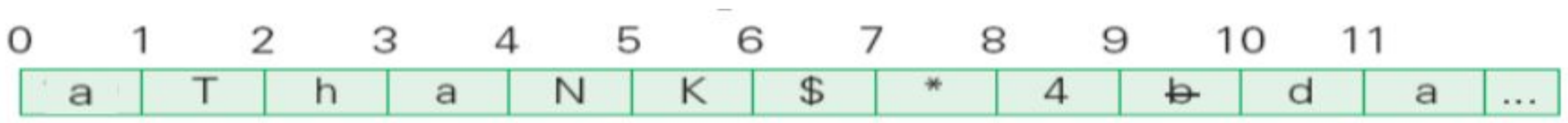
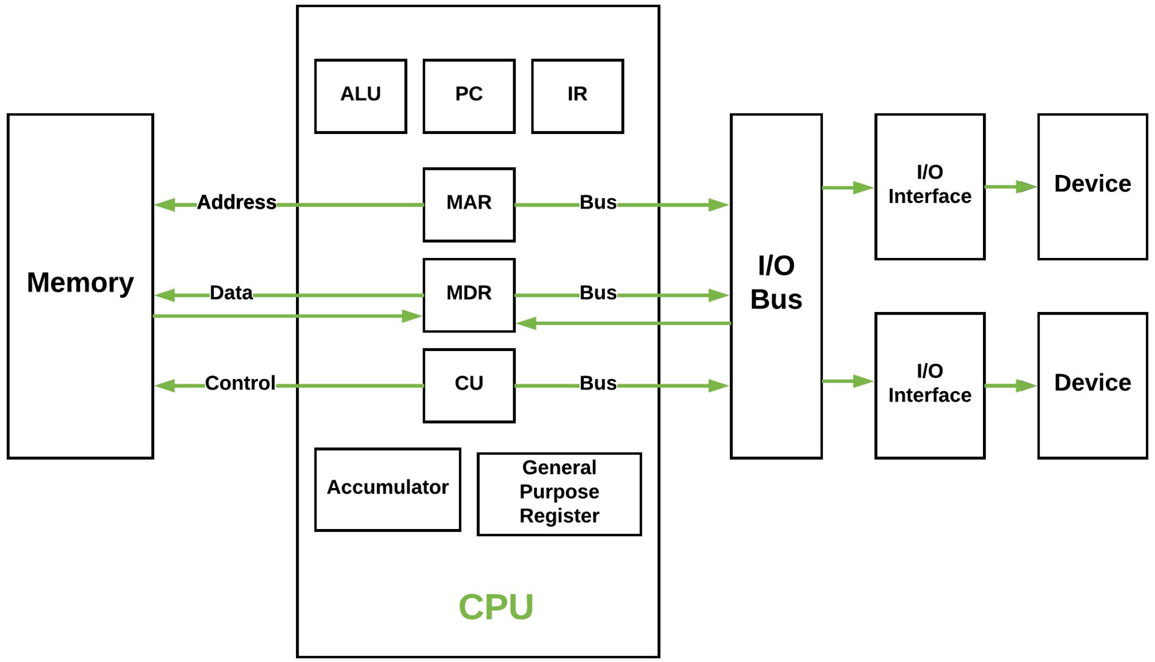


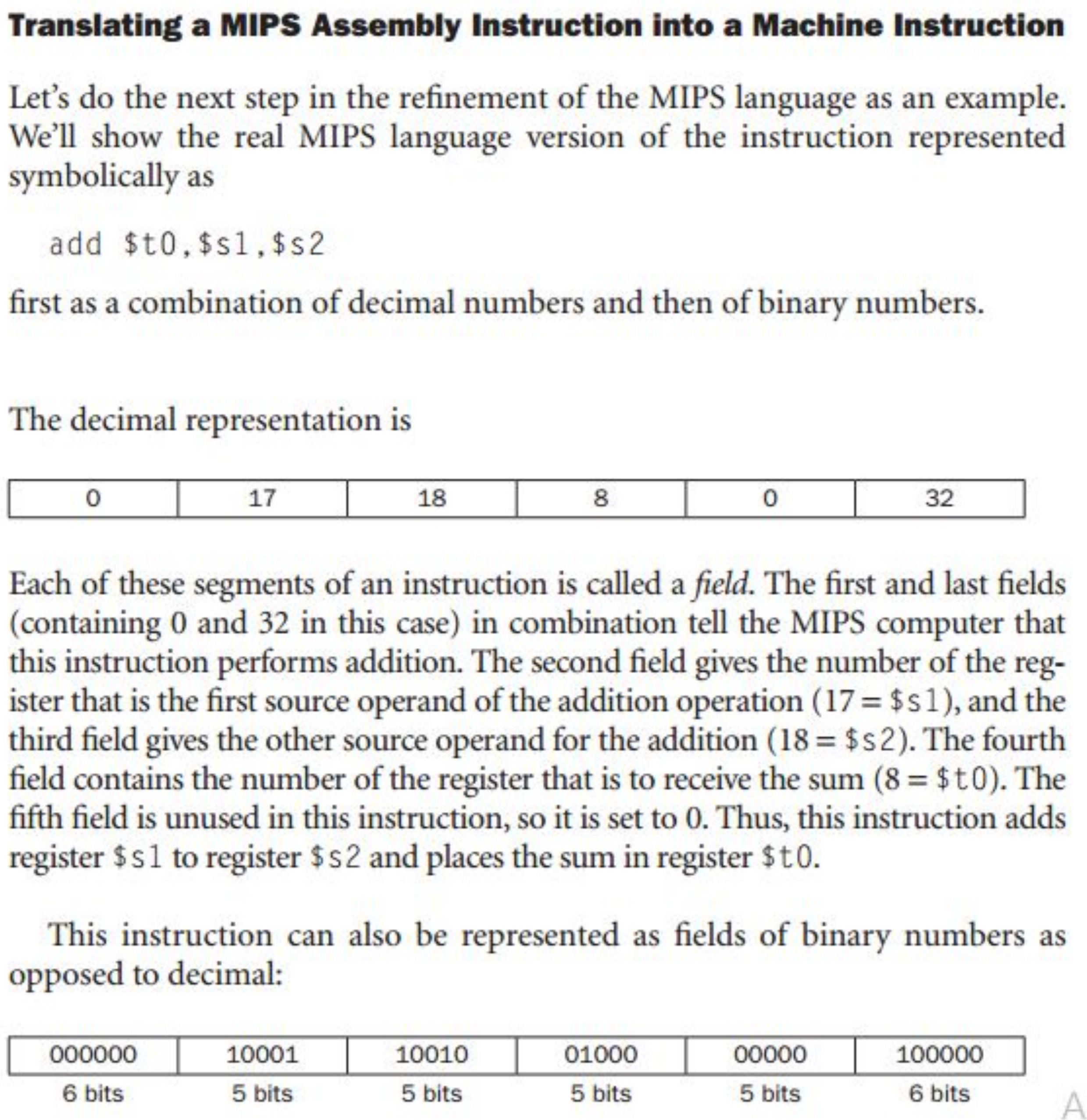
Figure 9.3 Diagram of computer memory illustrating its key properties.

- Address of location is displayed above the box and the contents of location is shown in the box

CPU Registers

- **Accumulator:** Stores the results of calculations made by ALU.
- **Program Counter (PC):** Keeps track of the memory location of the next instructions to be dealt with. The PC then passes this next address to Memory Address Register (MAR).
- **Memory Address Register (MAR):** Holds the address of the location in memory, which contains data, that is required by the current instruction being executed. simply MAR points to the memory location that contains data required.
- **Memory Data Register (MDR):** It stores instructions fetched from memory or any data that is to be transferred to, and stored in, memory.
- **Current Instruction Register (CIR):** Holds the **instruction** currently being executed or decoded.
- **Instruction Buffer Register (IBR):** The instruction that is not to be executed immediately is placed in the instruction buffer register IBR.





Translating a MIPS Assembly Instruction into a Machine Instruction

Let's do the next step in the refinement of the MIPS language as an example. We'll show the real MIPS language version of the instruction represented symbolically as

```
add $t0,$s1,$s2
```

first as a combination of decimal numbers and then of binary numbers.

The decimal representation is

0	17	18	8	0	32

Each of these segments of an instruction is called a *field*. The first and last fields (containing 0 and 32 in this case) in combination tell the MIPS computer that this instruction performs addition. The second field gives the number of the register that is the first source operand of the addition operation (17 = `$s1`), and the third field gives the other source operand for the addition (18 = `$s2`). The fourth field contains the number of the register that is to receive the sum (8 = `$t0`). The fifth field is unused in this instruction, so it is set to 0. Thus, this instruction adds register `$s1` to register `$s2` and places the sum in register `$t0`.

This instruction can also be represented as fields of binary numbers as opposed to decimal:

000000	10001	10010	01000	00000	100000
6 bits	5 bits	5 bits	5 bits	5 bits	6 bits

I/O Devices

- **Input / Output Devices**
  - Program or data is read into main memory from the *input device* or secondary storage under the control of CPU input instruction.
  - *Output devices* are used to output the information from a computer. If some results are evaluated by computer and it is stored in the computer, then with the help of output devices, we can present it to the user.

Buses

- **Buses**
  - Data is transmitted from one part of a computer to another, connecting all major internal components to the CPU and memory, by the means of Buses.
- Types:
  - **Data Bus:** It carries data among the memory unit, the I/O devices, and the processor.
  - **Address Bus:** It carries the address of data (not the actual data) between memory and processor.
  - **Control Bus:** It carries control commands from the CPU (and status signals from other devices) in order to control and coordinate all the activities within the computer.

Instruction Set

- The complete set of all the instructions in machine code that can be recognized and executed by a central processing unit.

What Computers Can and Cannot Do

- **What computers can do**
  - Deterministically perform or execute instructions to process information
    - Deterministically…the computer determines which instruction to do next…it does only what it is “told” to do
  - They have no imagination, are not creative or purposeful. No sense of irony, subtlety, etc.
  - Computers only execute instructions

The Fetch/Execute Cycle

- **"Instruction Execution Engine"…a machine that cycles through a series of operations**
- **Series is called: Fetch/Execute Cycle**
  - Get the next instruction
  - Figure out what to do
  - Gathering the data needed to do it
  - Do it
  - Save the result, and
  - Repeat (billions of times/second)!

A Five-Step Cycle

- **These operations are repeated in a never-ending sequence**
- **The step names suggest the operations described in the previous paragraph**

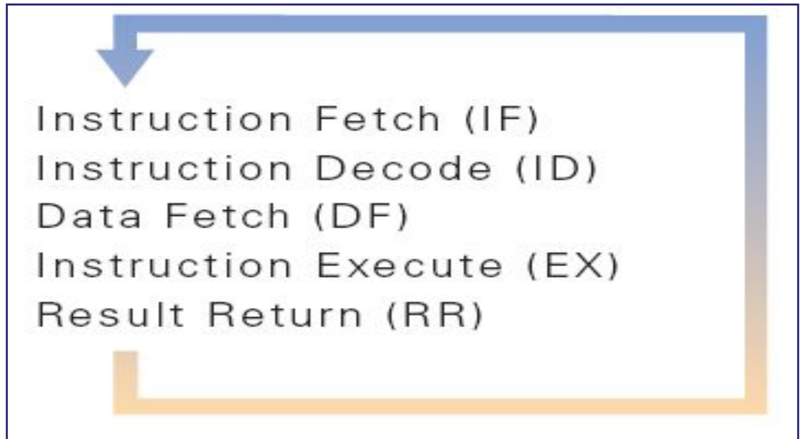


Figure 9.1 The Fetch/Execute Cycle.

Anatomy of a Computer

- **All computers, regardless of their implementing technology, have five basic parts or subsystems:**
  1. Memory,
  2. Control unit,
  3. Arithmetic/logic unit (ALU),
  4. Input unit, and
  5. Output unit

Principal Subsystems of a Computer

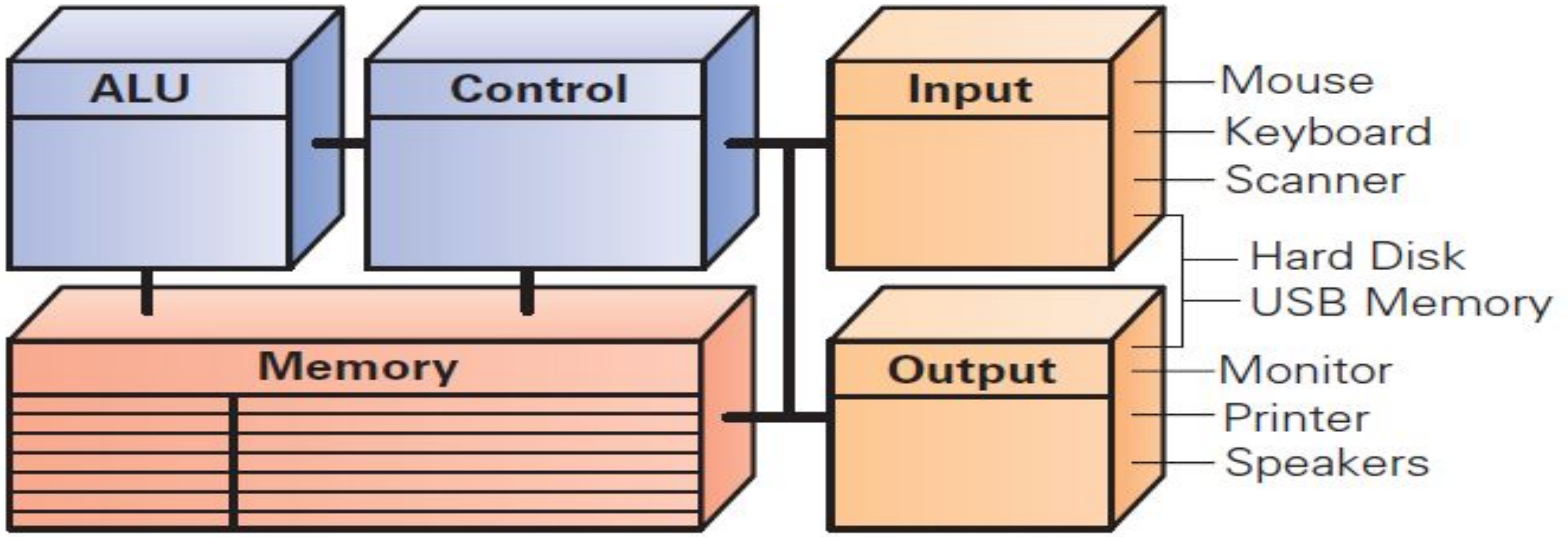


Figure 9.2 The principal subsystems of a computer.

1. Memory

- **Memory stores both the program while it is running and the data on which the program operates**
- **Properties of memory:**
  - **Discrete locations**
    - –Memory is organized as a sequence of discrete locations
    - –In modern memory, each location is composed of 1 byte (8 bits)

1. Memory

- **Addresses**
  - Every memory location has an address, whole numbers starting at 0
- **Values**
  - Memory locations record or store values
- **Finite capacity**
  - Memory locations have a finite capacity (limited size),
  - Data may not “fit” in the memory location

Byte-Size Memory Location

- Common visualization of computer memory
- Discrete locations are shown as boxes holding 1-byte each

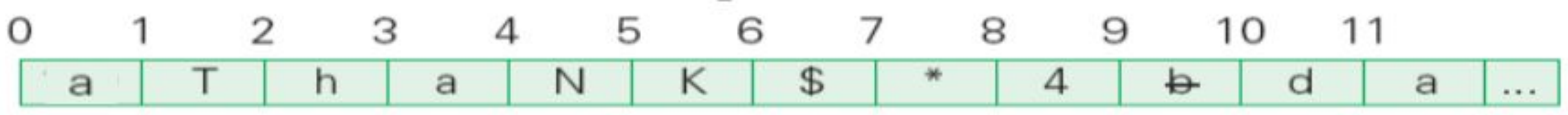


Figure 9.3 Diagram of computer memory illustrating its key properties.

- Address of location is displayed above the box and the contents of location is shown in the box

Byte-Size Memory Location

- **That 1-byte memory location can store one ASCII character or a number less than 256**
- **Blocks of four bytes are used as a unit so often that they are called memory words**

Random Access Memory

- **Computer memory is called random access memory (RAM)**
  - “Random access” is out-of-date and simply means that the computer can refer to the memory locations in any order
- **RAM is measured in megabytes (MB) or gigabytes (GB)**
- **Lots of memory is need to handle the space required of programs and data**

2. Control Unit

- **The control unit of a computer is where the Fetch/Execute Cycle occurs**
- **Its circuitry *fetches* an instruction from memory and performs the other operations of the Fetch/Execute Cycle on it**
- **A typical machine instruction has the form ADD 4000, 2000, 2080**

2. Control Unit

- **ADD 4000, 2000, 2080**
  - Looks like those three numbers should be added together
  - What it really means is that whatever numbers are stored in memory locations 2000 and 2080 be added together, and the result be stored in location 4000

Illustration of a single instruction

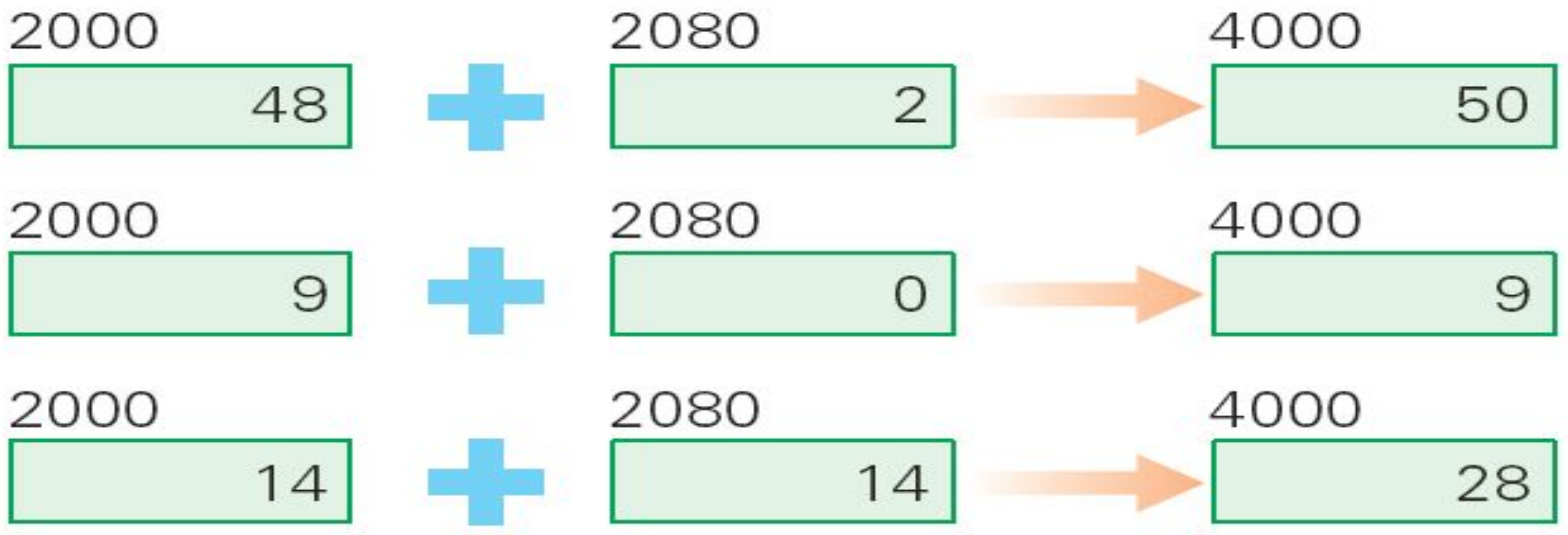


Figure 9.4 Illustration of a single ADD instruction producing different results depending on the contents of the memory locations referenced in the instruction.

3. Arithmetic/Logic Unit (ALU)

- **“Does the math”**
- **A circuit in the ALU can add two numbers**
- **The circuit uses logic gates or simpler circuits that implement operations like AND and OR**
- **There are also circuits for multiplying, for comparing two numbers, etc.**
- **The ALU carries out each machine instruction with a separate circuit**

4. And 5. Input and Output Units

- **These two components are the wires and circuits through which information moves into and out of a computer**
- **A computer without input or output is useless**

The Peripherals

- **Peripherals connect to the computer input/output (I/O) ports**
- **They provide input or receiving its output**
- **They are not considered part of the computer:**
  - They are only specialized gadgets that encode or decode information between the computer and the physical world

The Peripherals

- **The keyboard encodes our keystrokes into binary form for the computer**
- **The monitor decodes information from the computer's memory and displays it on a screen**
- **The peripherals handle the physical part of the operation**

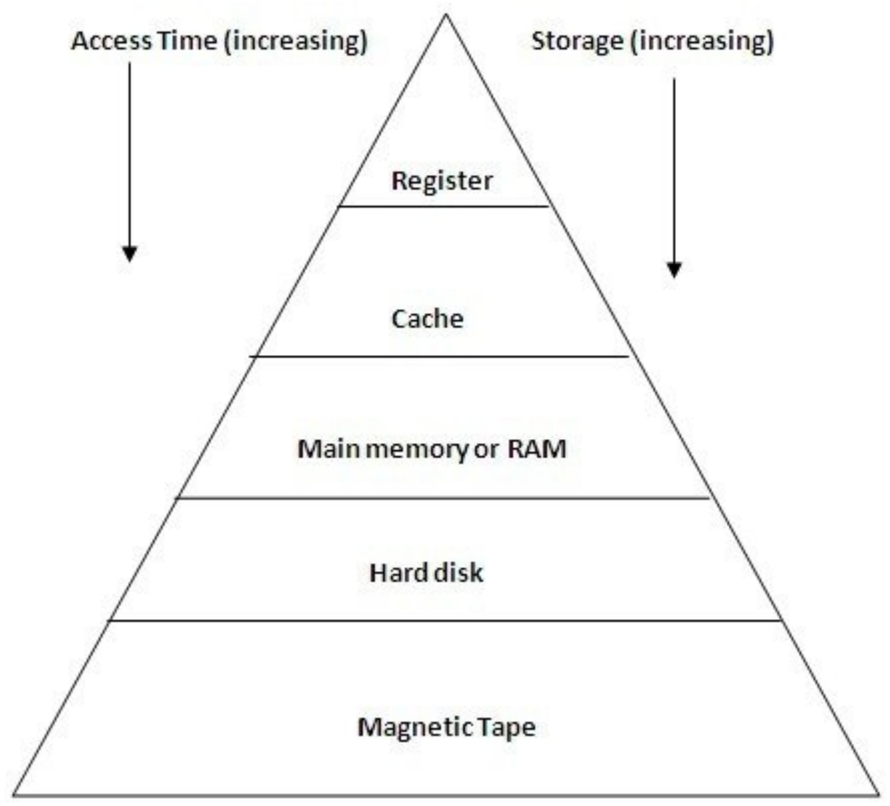
Portable Memory & Hard Drives

- **Some peripherals are used by computers for both input and output:**
  - USB memory
  - Hard disks/drives
- **They are storage devices**

Hard Disk

- **Hard disk is essential**
- **Programs and their data *must* reside in the computer’s memory when programs run**
- **The hard disk can be seen as an extension of the computer’s memory**
- **Typically it is a hundred times larger and several thousand times slower**

Memory Hierarchy



The Program Counter (PC)

- **How does the computer determine which instruction it should execute next?**
- **Address of the Next Instruction**
  - The instruction is stored in memory and the computer has its address
  - Computers use the address (known as the *program counter* or *PC)* to keep track of the next instruction

The Program Counter

- The computer gets ready to process the next instruction
- It assumes that the next instruction is the next instruction in sequence
- Because instructions use 4 bytes of memory, the next instruction must be at the memory address PC + 4 or 4 bytes further along the sequence

Instruction Interpretation

- The process of executing a program is also called instruction interpretation.
- The term derives from the idea that the computer interprets our commands, but in its own language.

The Fetch/Execute Cycle

- **A five-step cycle:**

1. Instruction Fetch (IF)
2. Instruction Decode (ID)
3. Data Fetch (DF) / Operand Fetch (OF)
4. Instruction Execution (EX)
5. Result Return (RR) / Store (ST)

ADD 800, 428, 884

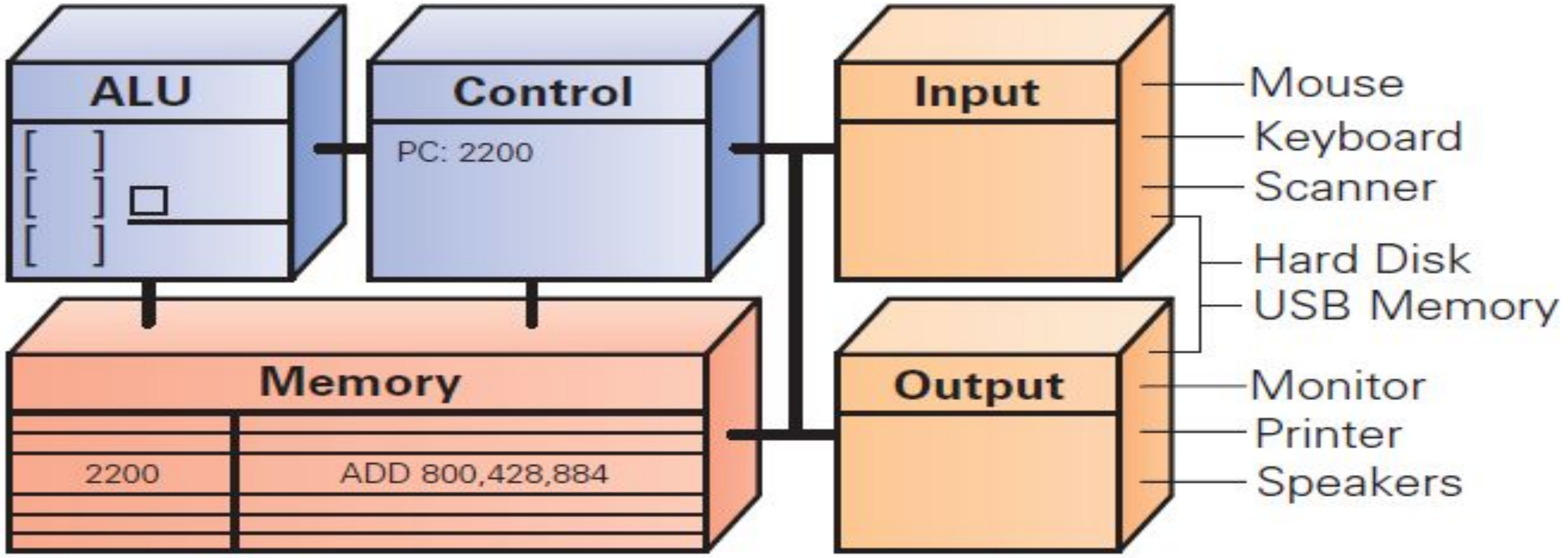


Figure 9.5 Computer before executing an ADD instruction.

ADD the values found in memory locations 428 and 884 and store the result in location 800

Instruction Fetch (IF)

- Execution begins by moving the instruction at the address given by the PC (*PC 2200*) from memory to the control unit
- Once instruction is fetched, the PC can be readied for fetching the next instruction

IF

- **Accumulator:** Stores the results of calculations made by ALU.
- **Program Counter (PC):** Keeps track of the memory location of the next instructions to be dealt with. The PC then passes this next address to Memory Address Register (MAR).
- **Memory Address Register (MAR):** Holds the address of the location in memory, which contains data, that is required by the current instruction being executed. simply MAR points to the memory location that contains data required.
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- **Instruction Buffer Register (IBR):** The instruction that is not to be executed immediately is placed in the instruction buffer register IBR.

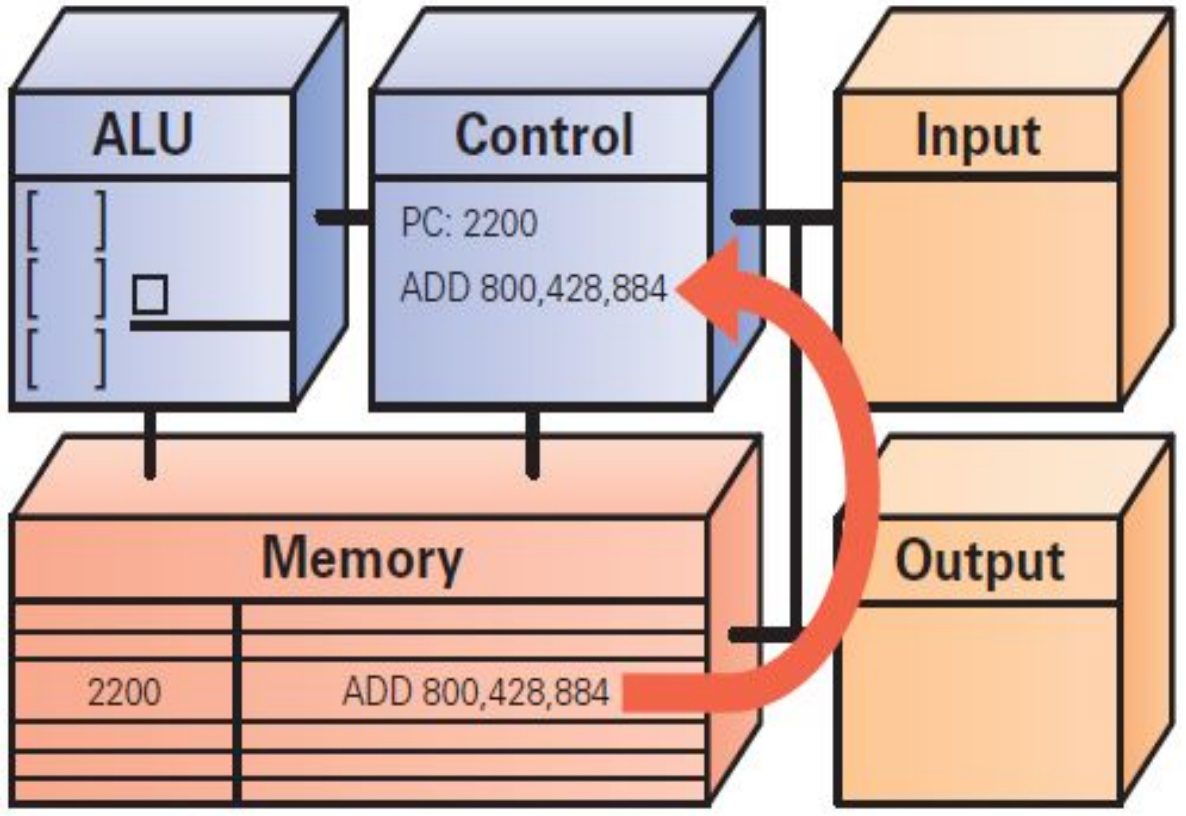


Figure 9.6 Instruction Fetch: Move instruction from memory to the control unit.

Instruction Decode (ID)

- **ALU is set up for the operation**
- **Decoder finds the memory address of the instruction's data (*source operands*)**
  - Most instructions operate on two data values stored in memory (like ADD), so most instructions have addresses for two source operands
  - These addresses are passed to the circuit that fetches them from memory during the next step

Instruction Decode (ID)

- Decoder finds the *destination address* for the Result Return step and places the address in the RR circuit
- Decoder determines what operation the ALU will perform (ADD), and sets up the ALU

ID

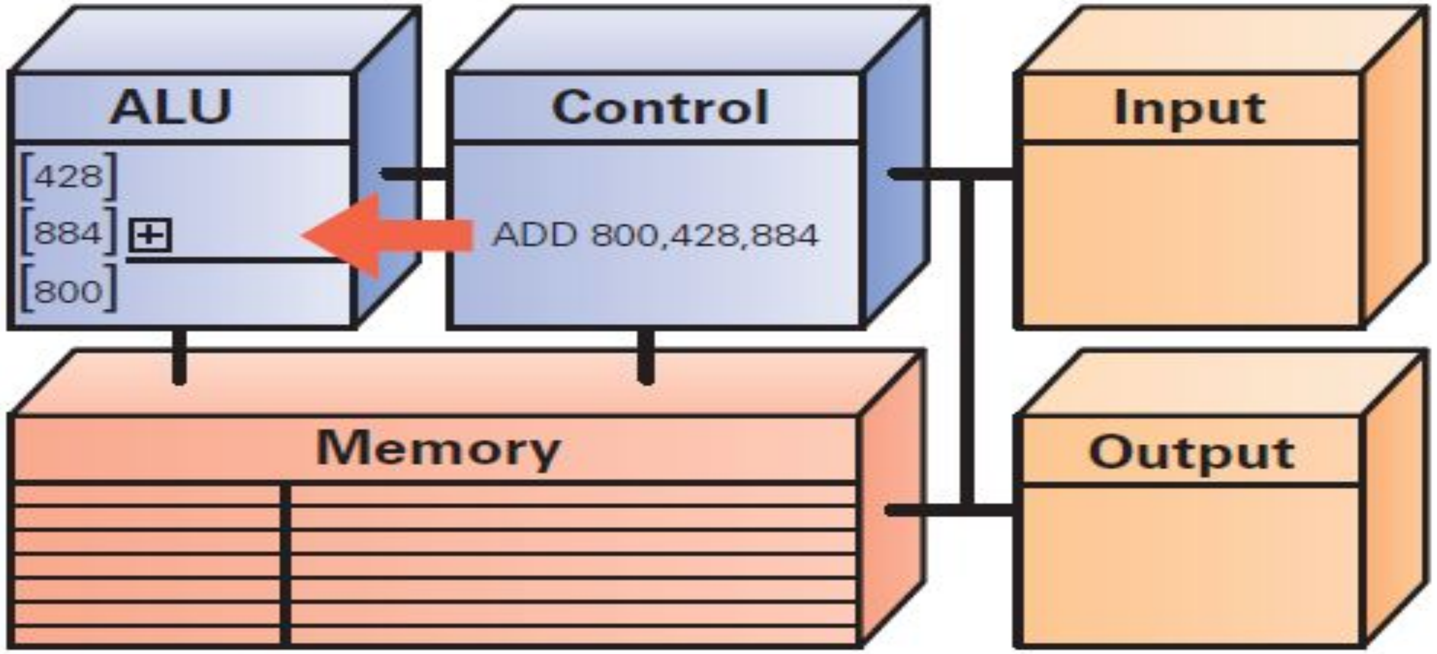


Figure 9.7 Instruction Decode: Pull apart the instruction, set up the operation in the ALU, and compute the source and destination operand addresses.

Data Fetch (DF)

- The data values to be operated on are retrieved from memory
- Bits at specified memory locations are copied into locations in the ALU circuitry
- Data values remain in memory (they are not destroyed)

DF

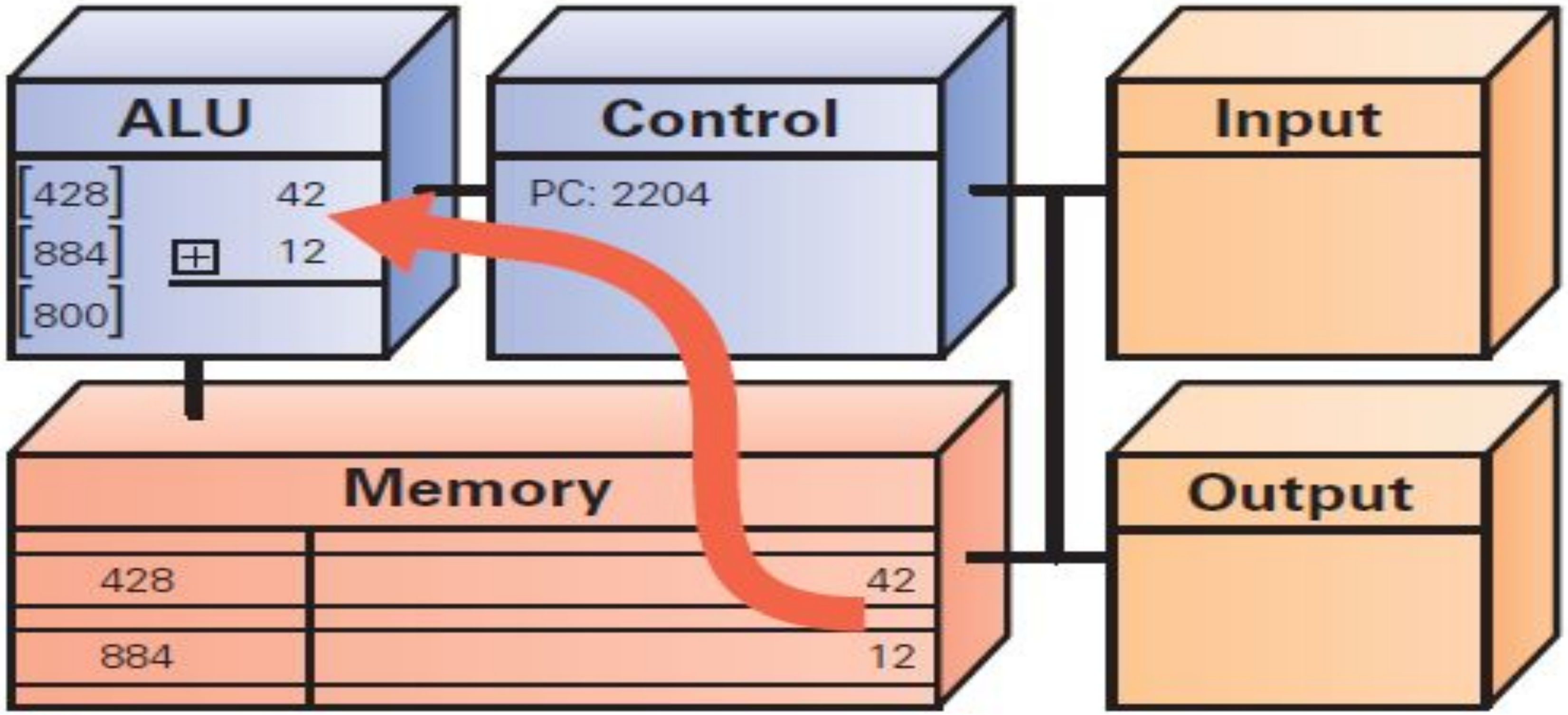


Figure 9.8 Data Fetch: Move the operands from memory to the ALU.

Instruction Execution (EX)

- For this ADD instruction, the addition circuit adds the two source operands together to produce their sum
- Sum is held in the ALU circuitry
- This is the actual computation

EX

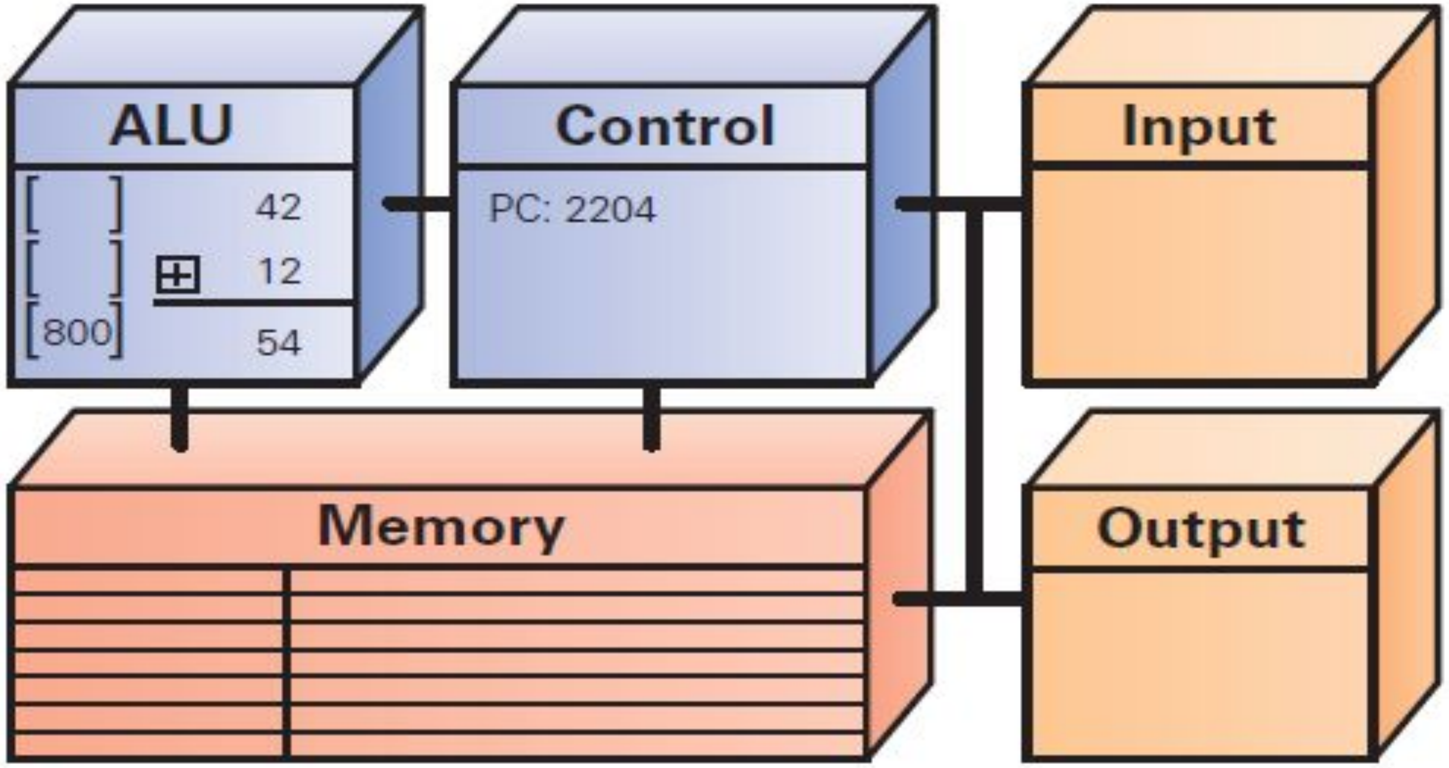


Figure 9.9 Instruction Execute: Compute the result of the operation in the ALU.

Return Result (RR)

- RR returns the result of EX to the memory location specified by the destination address.
- Once the result is stored, the cycle begins again

RR

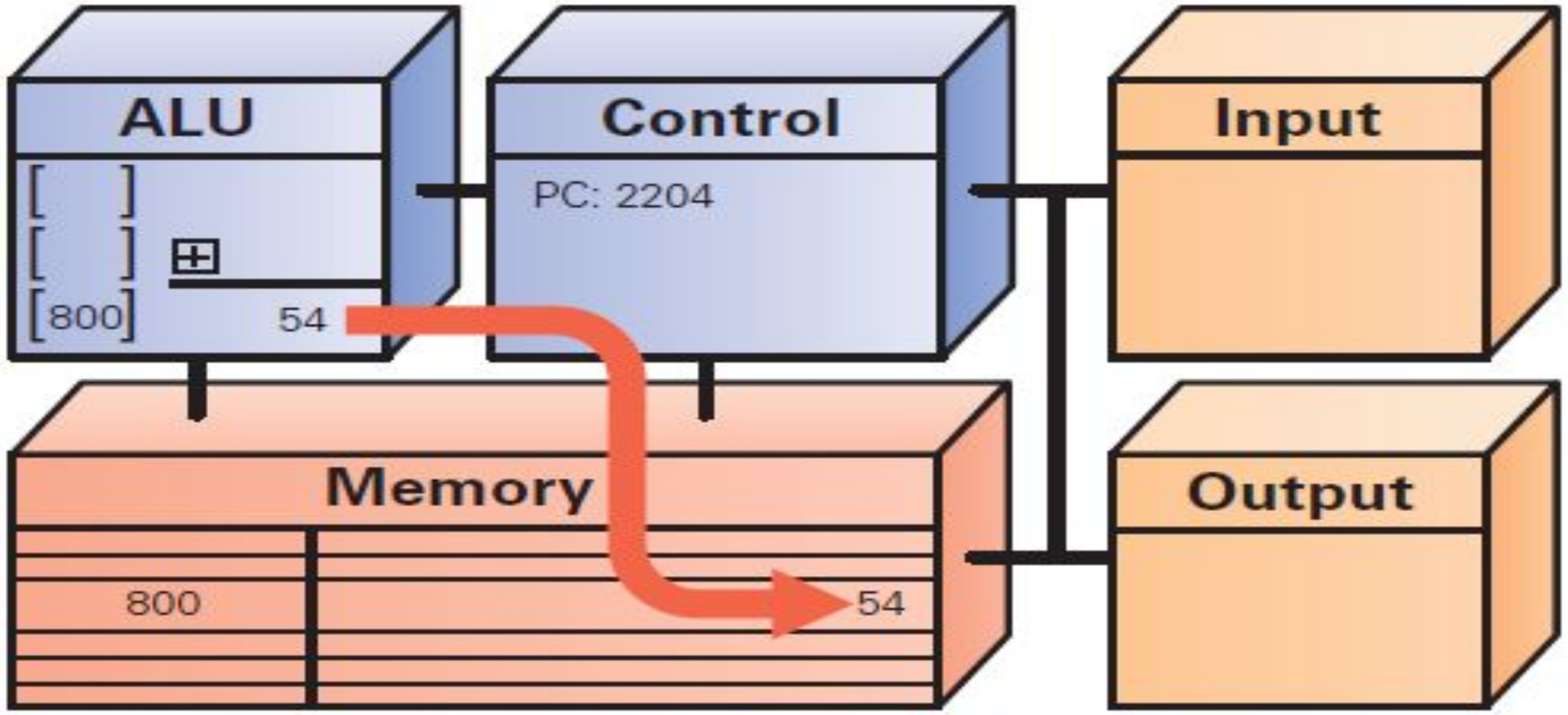


Figure 9.10 Result Return: Store the result from the ALU into the memory at the destination address.

Many, Many Simple Operations

- Computers “know” very few instructions
- The decoder hardware in the controller recognizes, and the ALU performs, only about 100 different instructions (with a lot of duplication)
- There are only about 20 different kinds of operations.
- Everything that computers do must be reduced to some combination of these primitive, hardwired instructions

Cycling the Fetch/Execute Cycle

- ADD is representative of the complexity of computer instructions…some are slightly simpler, some slightly more complex
- Computers achieve success at what they can do with speed.
- They show their impressive capabilities by executing many simple instructions per second

The Computer Clock

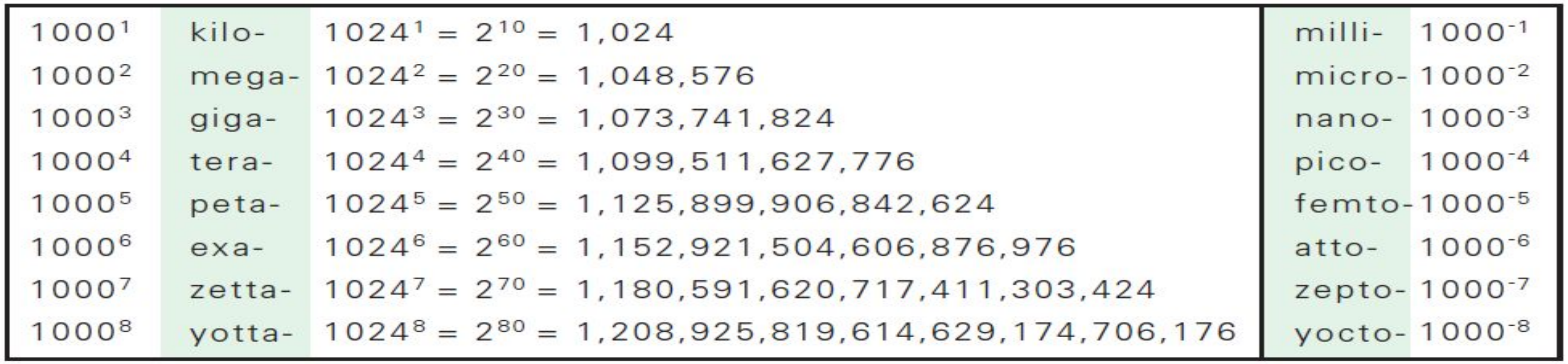
- Computers are instruction execution engines.

- Since the computer does one instruction per cycle in principle, the speed of a computer depends on the number of Fetch/Execute Cycles it completes per second.

The Computer Clock

- The rate of the Fetch/Execute Cycle is determined by the computer’s clock, and it is measured in megahertz, or millions (mega) of cycles per second (hertz).
- A 1,000 MHz clock ticks a billion (in American English) times per second, which is one gigahertz (1 GHz)

Standard Prefixes



1000^1	kilo-	$1024^1 = 2^{10} = 1{,}024$	milli-	1000^{-1}
1000^2	mega-	$1024^2 = 2^{20} = 1{,}048{,}576$	micro-	1000^{-2}
1000^3	giga-	$1024^3 = 2^{30} = 1{,}073{,}741{,}824$	nano-	1000^{-3}
1000^4	tera-	$1024^4 = 2^{40} = 1{,}099{,}511{,}627{,}776$	pico-	1000^{-4}
1000^5	peta-	$1024^5 = 2^{50} = 1{,}125{,}899{,}906{,}842{,}624$	femto-	1000^{-5}
1000^6	exa-	$1024^6 = 2^{60} = 1{,}152{,}921{,}504{,}606{,}876{,}976$	atto-	1000^{-6}
1000^7	zetta-	$1024^7 = 2^{70} = 1{,}180{,}591{,}620{,}717{,}411{,}303{,}424$	zepto-	1000^{-7}
1000^8	yotta-	$1024^8 = 2^{80} = 1{,}208{,}925{,}819{,}614{,}629{,}174{,}706{,}176$	yocto-	1000^{-8}

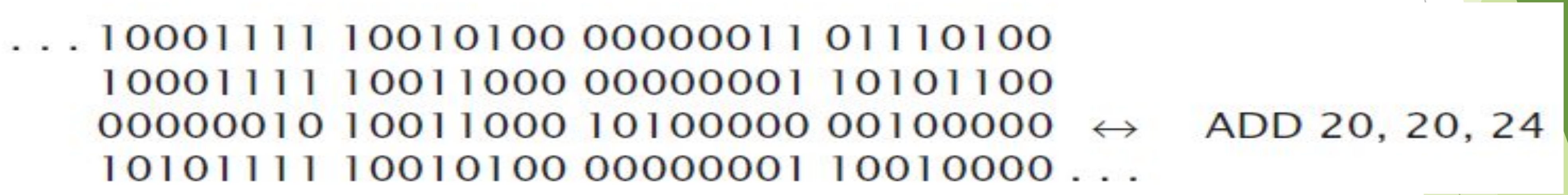
Figure 9.11 Standard prefixes from the Système International (SI) convention on scientific measurements. Generally a prefix refers to a power of 1000, except when the quantity (for example, memory) is counted in binary; for binary quantities the prefix refers to a power of 1024, which is 2^{10}.

One Cycle per Clock Tick

- A computer with a 1 GHz clock has one billionth of a second—one nanosecond—between clock ticks to run the Fetch/Execute Cycle.
- In that amount of time, light travels about one foot (~30 cm).
- Modern computers *try* to start an instruction on each clock tick.

Computer’s View of Software

- **A program “sees” software as a long sequence of 4-byte groups of bits (0's and 1's)**



```
. . . 10001111 10010100 00000011 01110100
      10001111 10011000 00000001 10101100
      00000010 10011000 10100000 00100000  ↔   ADD 20, 20, 24
      10101111 10010100 00000001 10010000 . . .
```

- This binary object file can be hundreds of thousands to millions of words long

Computer's View of Software

- **Once installed, the computer runs the software by:**
  - copying the binary instructions into the RAM
  - interpreting them using the Fetch/Execute Cycle.
- **It does whatever the instructions tell it to do**