Unit 2:
The Computer System Hardware

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Syllabus

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Introduction

- **Computer architecture** refers to the structure and behavior of the computer. It includes the specifications of the components, for example, instruction format, instruction set and techniques for addressing memory, and how they connect to the other components.

- **Computer Organization** focuses on the organizational structure. It deals with how the hardware components operate and the way they are connected to form the computer.

- **Computer Design** focuses on the hardware to be used and the interconnection of parts.

Components of Computer

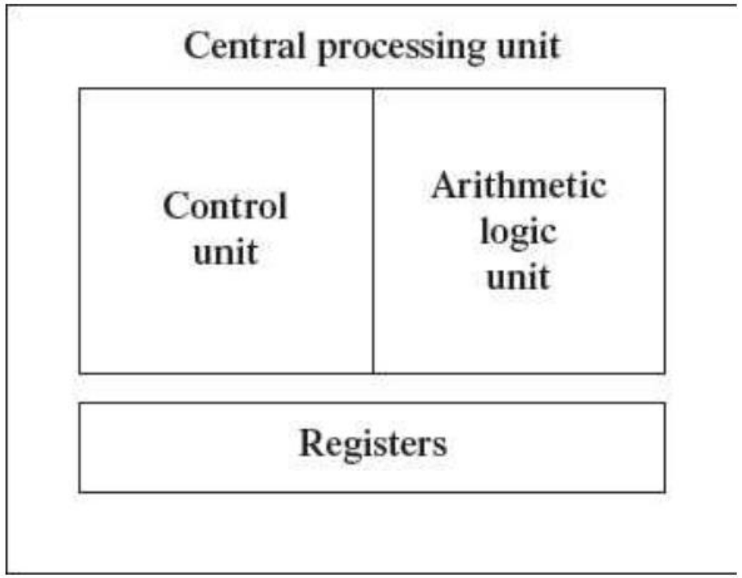
- (1) **Input/output (I/O) Unit** → provide data and instructions as input to the computer
- (2) **Central Processing Unit (CPU)**→ CPU controls the operations of

the computer and processes the received input to generate the relevant output

- (3) **Memory Unit** → stores the instructions and the data during the input activity, to make instructions readily

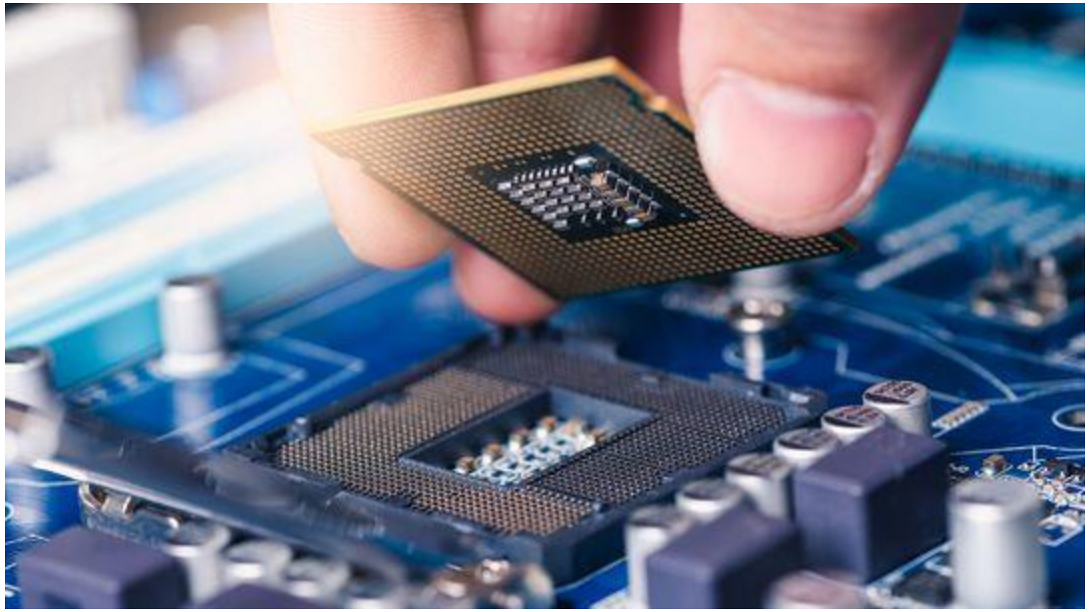
CENTRAL PROCESSING UNIT (CPU)

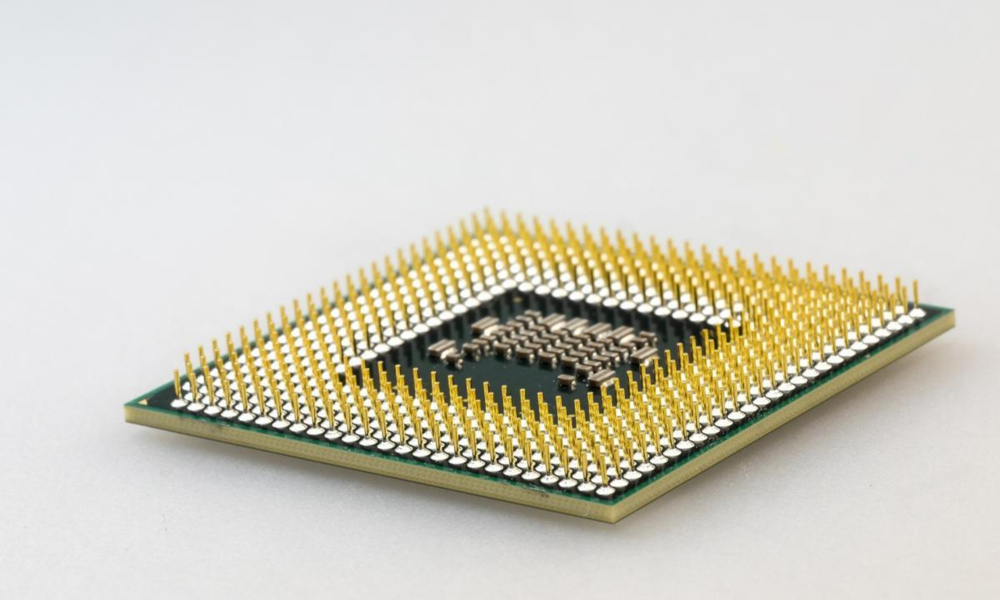
- often called the brain of computer.
- Consists of Arithmetic Logic Unit (ALU) and Control Unit (CU).
- also has a set of registers which are temporary storage areas for holding data, and instructions.
- ALU performs the arithmetic and logic operations on the data that is made available to it.
- CU is responsible for organizing the processing of data and instructions. CU controls and coordinates the activity of the other units of computer.
- CPU uses the registers to store the data, instructions during processing.

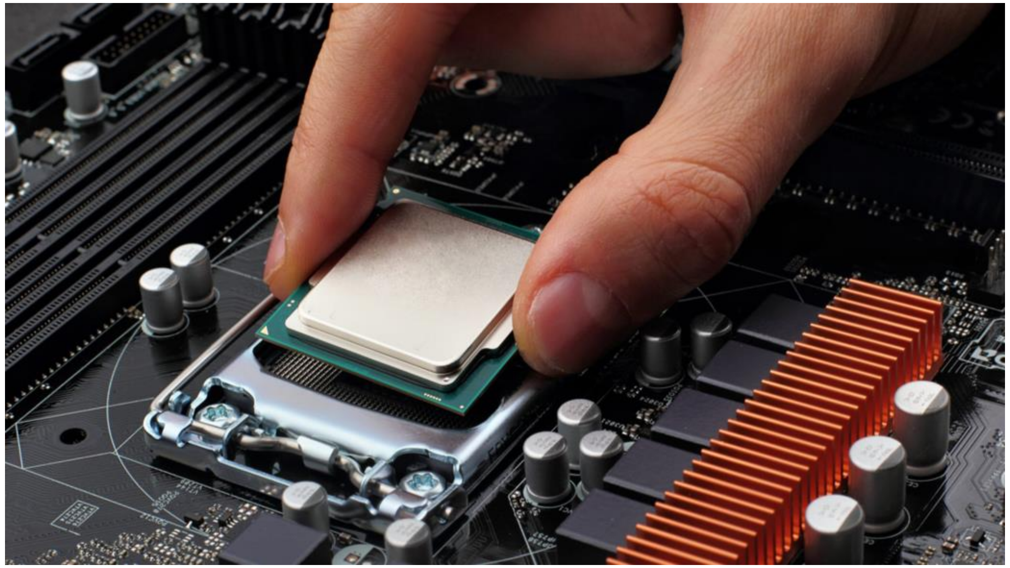


- CPU executes the stored program instructions, i.e. instructions and data are stored in memory before execution.
- For processing, CPU gets data and instructions from the memory.
- It interprets the program instructions and performs the arithmetic and logic operations required for the processing of data.
- Then, it sends the processed data or result to the memory.
- CPU also acts as an administrator and is responsible for supervising operations of other parts of the computer.

- The CPU is fabricated as a single Integrated Circuit (IC) chip, and is also known as the microprocessor.
- The microprocessor is plugged into the motherboard of the computer (Motherboard is a circuit board that has electronic circuit etched on it and connects the microprocessor with the other hardware components).





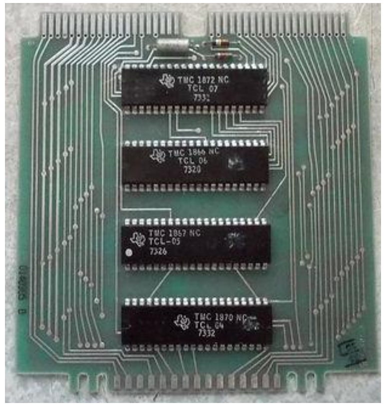


Arithmetic Logic Unit (ALU)

- ALU consists of two units—arithmetic unit and logic unit.
- The arithmetic unit performs arithmetic operations on the data that is made available to it. Eg. addition, subtraction, multiplication and division.
- The logic unit of ALU is responsible for performing logic operations. Logic unit performs comparisons of numbers, letters and special characters. Logic operations include testing for greater than, less than or equal to condition.
- ALU performs arithmetic and logic operations, and uses registers to hold the data that is being processed.

Registers

- Registers are high-speed storage areas within the CPU, but have the least storage capacity.
- Registers are not referenced by their address, but are directly accessed and manipulated by the CPU during instruction execution.
- Registers store data, instructions, addresses and intermediate results of processing. Registers are often referred to as the CPU's working memory.
- The data and instructions that require processing must be brought in the registers of CPU before they can be processed.
- For example, if two numbers are to be added, both numbers are brought in the registers, added and the result is also placed in a register



Types of Register

- Registers are used for different purposes, with each register serving a specific purpose:
- **Accumulator (ACC)** stores the result of arithmetic and logic operations.
- **Instruction Register (IR)** contains the current instruction most recently fetched.
- **Program Counter (PC)** contains the address of next instruction to be processed.
- **Memory Address Register (MAR)** contains the address of next location in the memory to be accessed.
- **Memory Buffer Register (MBR)** temporarily stores data from memory or the data to be sent to memory.
- **Data Register (DR)** stores the operands and any other data.

More about register

- The number of registers and the size of each (number of bits) register in a CPU helps to determine the power and the speed of a CPU.
- The overall number of registers can vary from about ten to many hundreds, depending on the type and complexity of the processor.
- The size of register, also called word size, indicates the amount of data with which the computer can work at any given time.
- The bigger the size, the more quickly it can process data.
- The size of a register may be 8, 16, 32 or 64 bits. For example, a 32–bit CPU is one in which each register is 32 bits wide and its CPU can manipulate 32 bits of data at a time. Nowadays, PCs have 32–bit or 64–bit registers.

- 32-bit processor and 64-bit processor are the terms used to refer to the size of the registers.
- Other factors remaining the same, a 64-bit processor can process the data twice as fast as one with 32-bit processor.

Control Unit

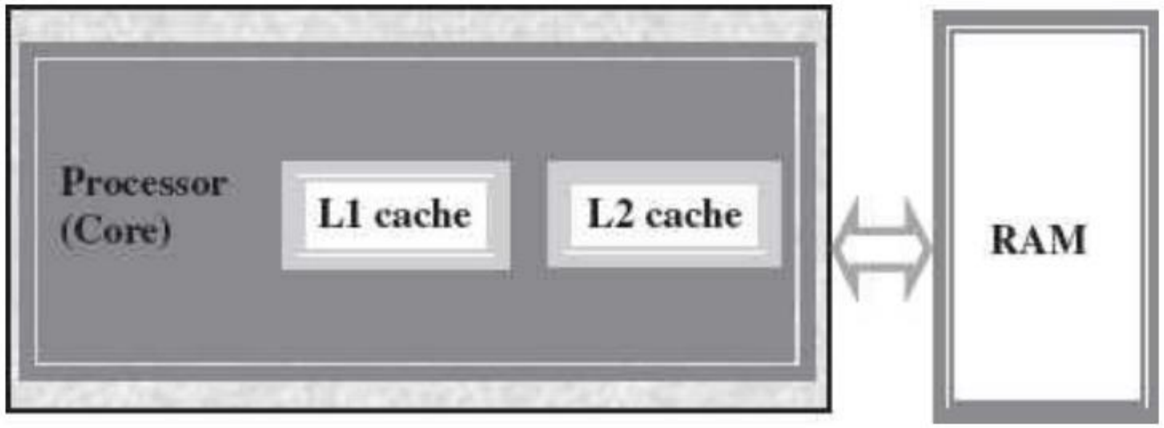
- The control unit of a computer does not do any actual processing of data. It organizes the processing of data and instructions. It acts as a supervisor and, controls and coordinates the activity of the other units of computer.
- CU coordinates the input and output devices of a computer. It directs the computer to carry out stored program instructions by communicating with the ALU and the registers. CU uses the instructions in the Instruction Register (IR) to decide which circuit needs to be activated. It also instructs the ALU to perform the arithmetic or logic operations. When a program is run, the Program Counter (PC) register keeps track of the program instruction to be executed next.
- CU tells when to fetch the data and instructions, what to do, where to store the results, the sequencing of events during processing etc.
- CU also holds the CPU’s Instruction Set, which is a list of all operations that the CPU can perform.

Memory Unit

- The memory unit consists of cache memory and primary memory.
- Primary memory or main memory of the computer is used to store the data and instructions during execution of the instructions.
- Random Access Memory (RAM) and Read Only Memory (ROM) are the primary memory.
- In addition to the main memory, there is another kind of storage device known as the secondary memory.
- Secondary memory is non-volatile and is used for permanent storage of data and programs.
- A program or data that has to be executed is brought into the RAM from the secondary memory.

Cache Memory

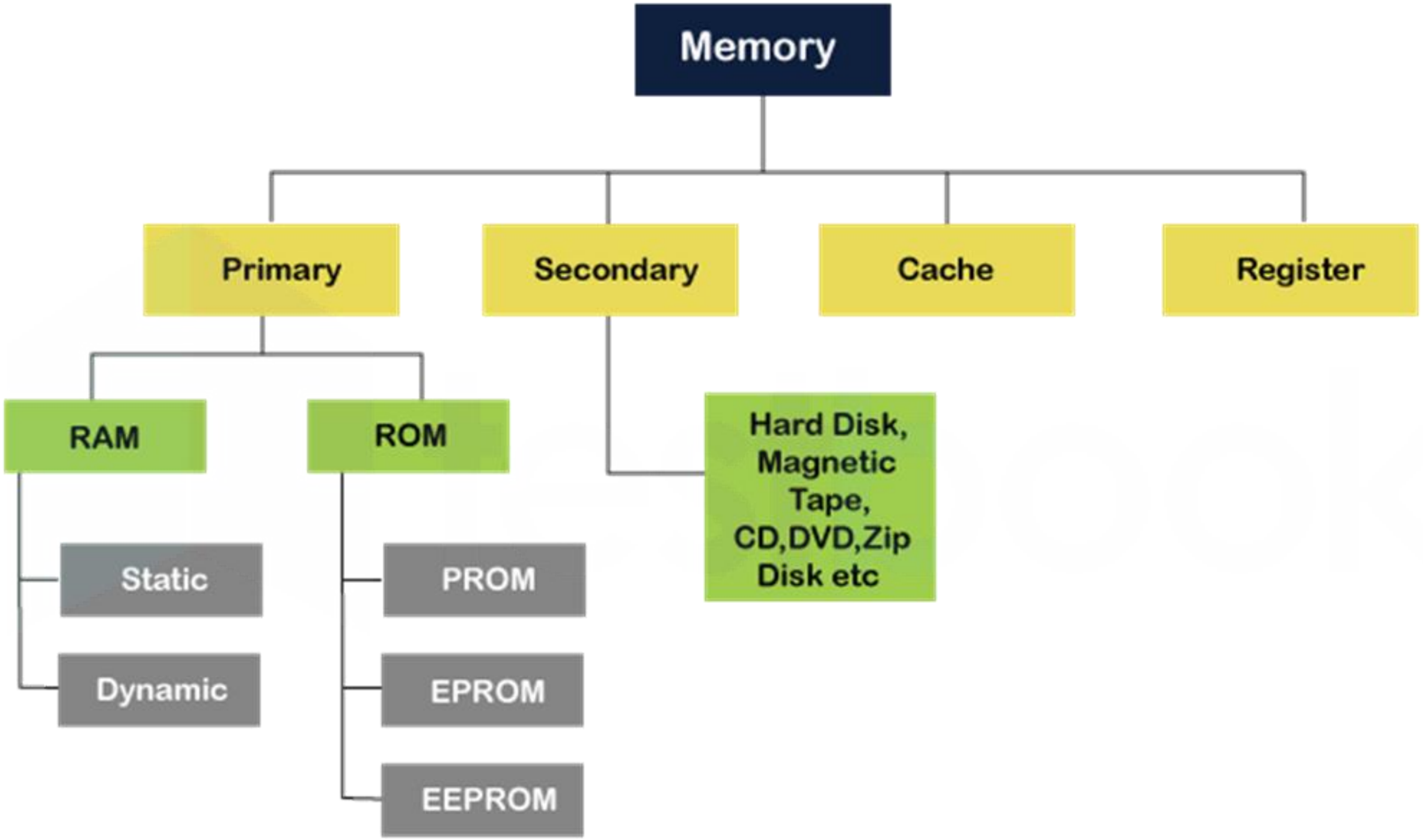
- Cache memory is a very high speed memory placed in between RAM and CPU. Cache memory increases the speed of processing.

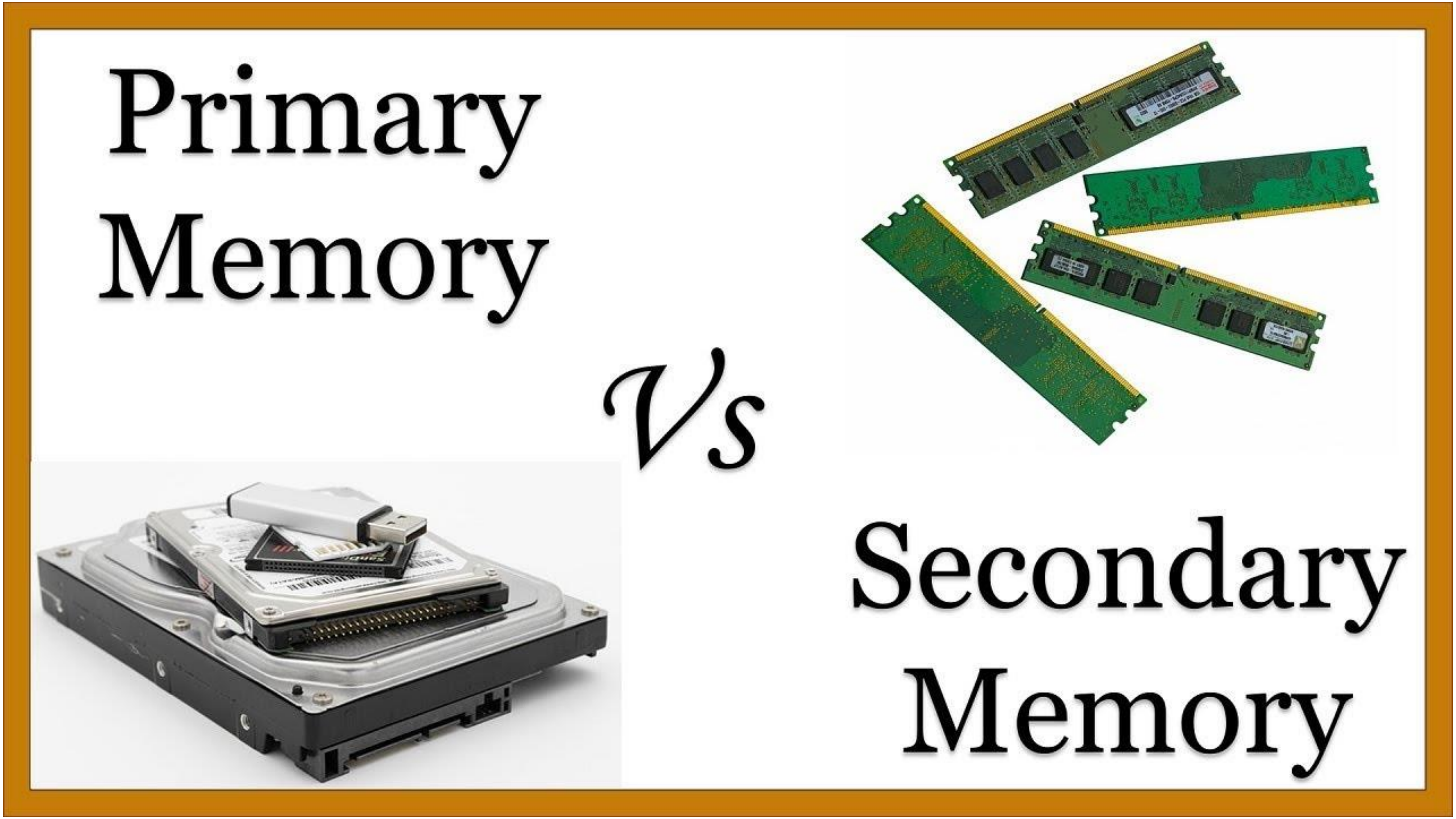


Cache Performance

- When the processor needs to read or write a location in main memory, it first checks for a corresponding entry in the cache.
  - If the processor finds that the memory location is in the cache, a cache hit has occurred and data is read from the cache.
  - If the processor does not find the memory location in the cache, a cache miss has occurred. For a cache miss, the cache allocates a new entry and copies in data from main memory, then the request is fulfilled from the contents of the cache.
- The performance of cache memory is frequently measured in terms of a quantity called Hit ratio.
- Hit ratio = hit / (hit + miss) = no. of hits/total accesses

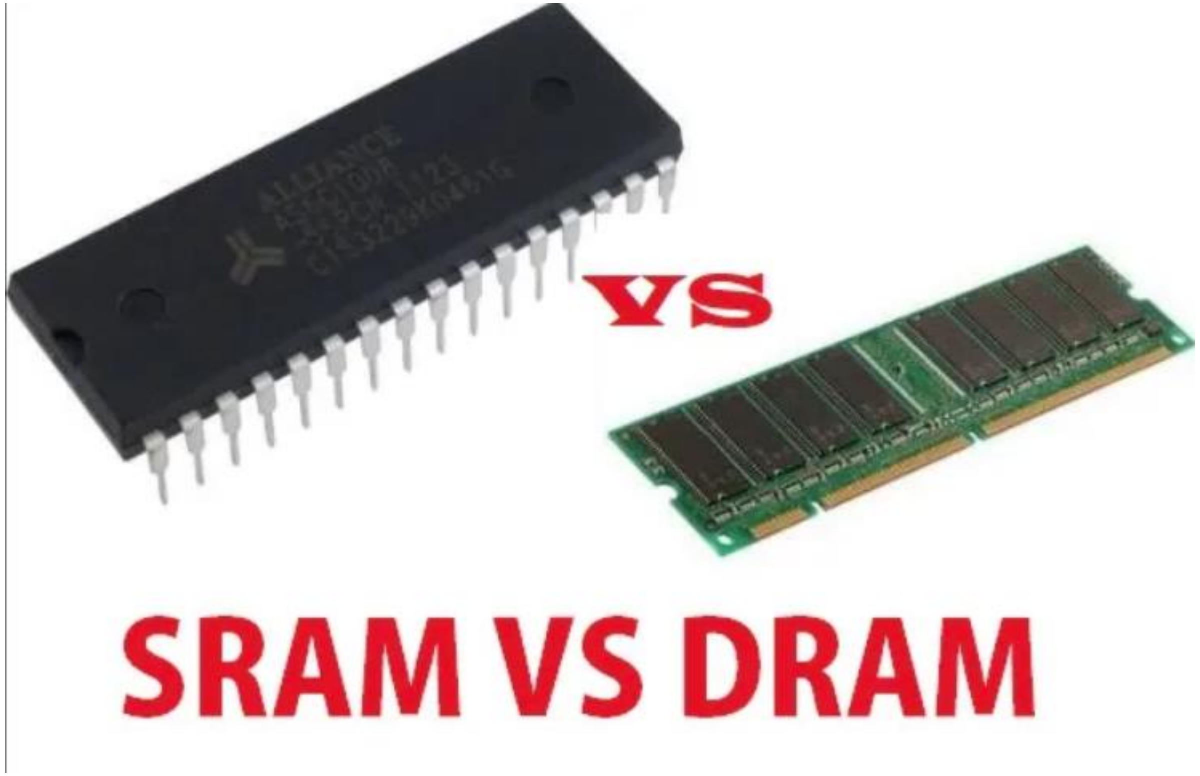
Primary and Secondary Memory




Primary
Memory
Vs
Secondary
Memory

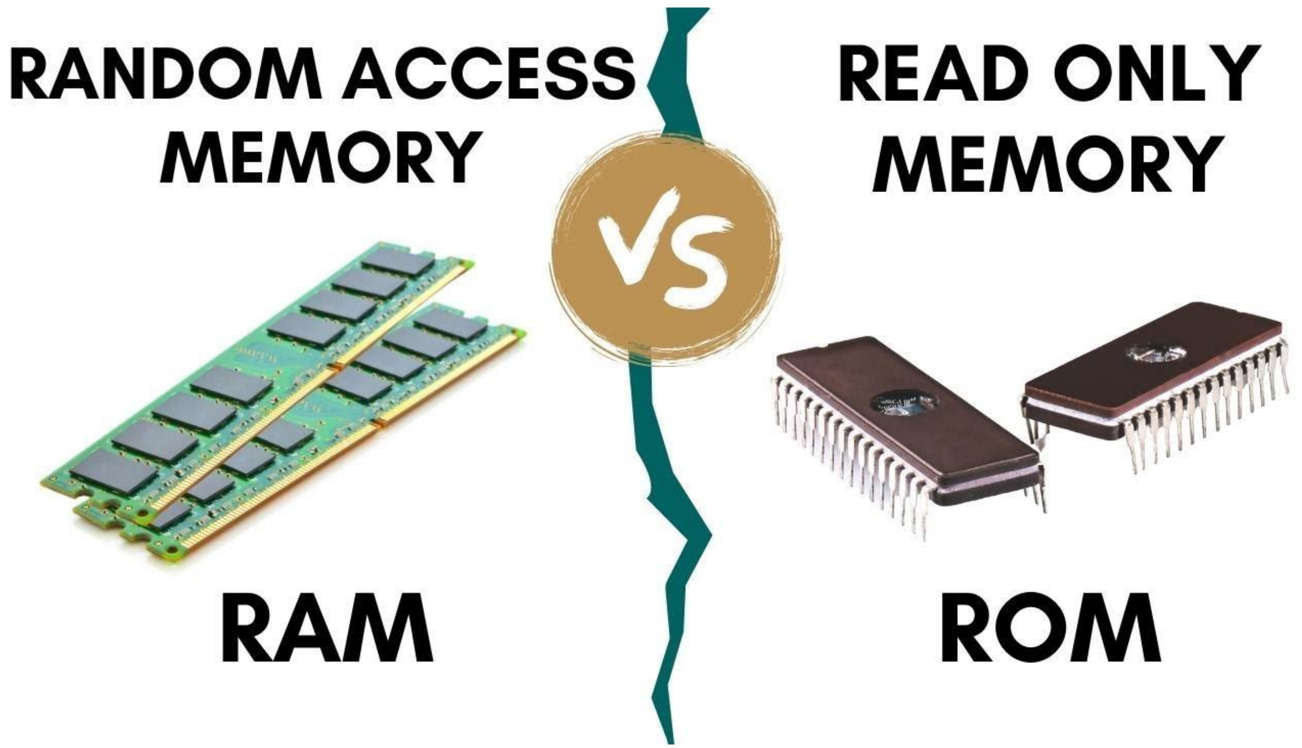
S.N	Primary memory	Secondary Memory
1	Primary Memory is known as Main memory or Internal Memory.	Secondary Memory is known as External Memory / Backup Memory or Auxiliary Memory.
2	Primary Memory data is directly accessed by the Processor.	Secondary Memory data cannot be accessed directly by the Processor.
3	Primary Memory is Both Volatile and Non-volatile Because RAM is volatile & Rom is Non-volatile.	Secondary memory is always a non-volatile Memory.
4	Primary Memory is faster than Secondary Memory.	Secondary Memory is slower than Primary Memory.
5	Primary Memory Stores Data Temporarily and it can be erased when power cut off.	Secondary Memory store data permanently unless one deletes it intentionally.
6	Semiconductor Chips are used to store information in Primary Memory.	Magnetic Disk, Optical disk are used to store information in Secondary Memory.
7	Primary Memory has limited storage Capacity.	Secondary memory can store bulk amounts of data in a single unit.
8	Primary Memory Devices are more expensive than secondary Memory.	Secondary Memory Devices are less expensive than primary Memory.
9	Data operated and stored in Uniform Manner.	Data stored is not Uniform in secondary Memory.
10	Ex:- RAM, ROM, Cache Memory, Registers etc.	Ex:- Hard Disk, Magnetic Tapes, Optical Disc, Floppy Disks, Flash memory [USB drives], Paper Tape, Punched cards etc.

Static RAM Vs. Dynamic RAM



SRAM	**DRAM**
1. SRAM has lower access time, so it is faster compared to DRAM.	1. DRAM has higher access time, so it is slower than SRAM.
2. SRAM is costlier than DRAM.	2. DRAM costs less compared to SRAM.
3. SRAM requires constant power supply, which means this type of memory consumes more power.	3. DRAM offers reduced power consumption, due to the fact that the information is stored in the capacitor.
4. Due to complex internal circuitry, less storage capacity is available compared to the same physical size of DRAM memory chip.	4. Due to the small internal circuitry in the one-bit memory cell of DRAM, the large storage capacity is available.
5. SRAM has low packaging density.	5. DRAM has high packaging density.

RAM vs. ROM



RAM	ROM
1. Temporary Storage.	1. Permanent storage.
2. Store data in MBs.	2. Store data in GBs.
3. Volatile.	3. Non-volatile.
4.Used in normal operations.	4. Used for startup process of computer.
5. Writing data is faster.	5. Writing data is slower.

Difference between RAM and ROM

Types of ROM

- Content loading (programming) done many ways depending on device type
  - ROM: mask programmed, loaded at the factory
    - hardwired - can't be changed
    - embedded mass-produced systems
  - PROM: OTP (One Time Programmable), programmed by user, using an external programming device
  - EPROM: reusable, erased by UV light, programmed by user, using an external programming device
  - EEPROM: electrically erasable, clears entire blocks with single operation, programmed in-place (no need to remove from circuit board)

INSTRUCTION FORMAT

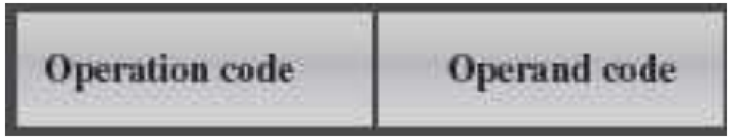


Figure 2.5 Instruction format

Figure 2.6 Instruction format for ADD command

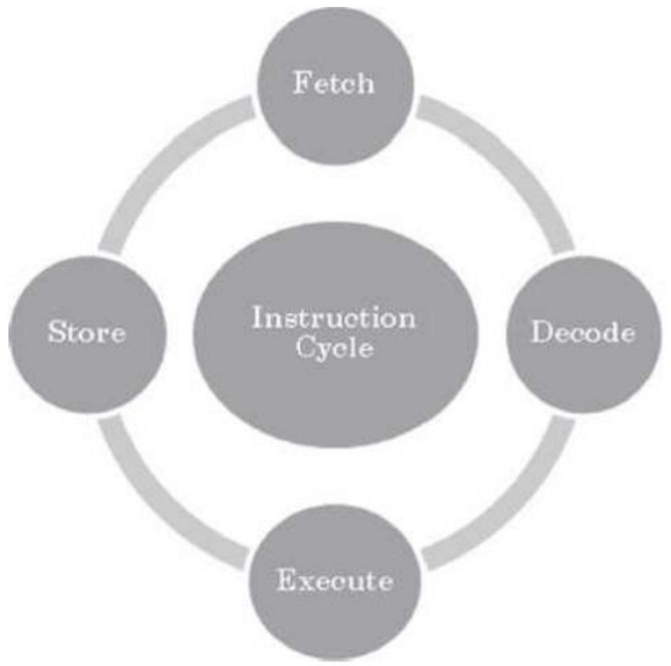
INSTRUCTION SET

- A processor has a set of instructions that it understands, called as instruction set.
- An instruction set or an instruction set architecture is a part of the computer architecture.
- It relates to programming, instructions, registers, addressing modes, memory architecture, etc. An Instruction Set is the set of all the basic operations that a processor can accomplish.

```
LOAD R1, A
ADD R1, B
STORE R1, X
```

INSTRUCTION CYCLE

- The primary responsibility of a computer processor is to execute a sequential set of instructions that constitute a program.
- CPU executes each instruction in a series of steps, called instruction cycle



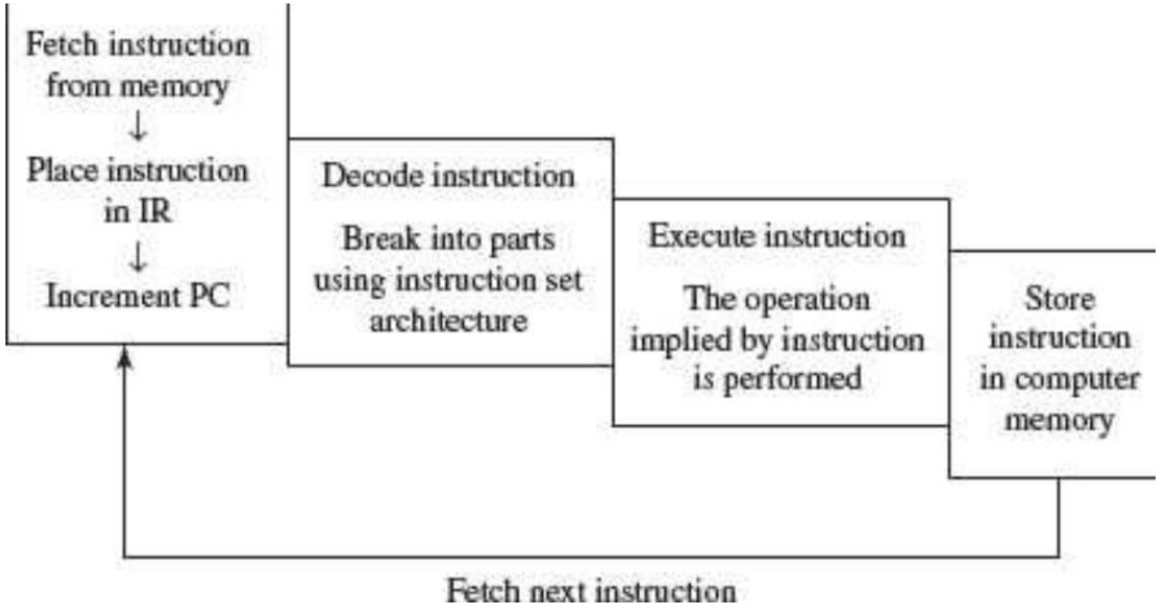
Steps in Instruction Cycle

o Fetching The processor fetches the instruction from the memory. The fetched instruction is placed in the Instruction Register. Program Counter holds the address of next instruction to be fetched and is incremented after each fetch.

o Decoding The instruction that is fetched is broken down into parts or decoded. The instruction is translated into commands so that they correspond to those in the CPU's instruction set. The instruction set architecture of the CPU defines the way in which an instruction is decoded.

o Executing The decoded instruction or the command is executed. CPU performs the operation implied by the program instruction. For example, if it is an ADD instruction, addition is performed.

o Storing CPU writes back the results of execution, to the computer's memory.



Instruction Categories

- Memory access or transfer of data between registers.
- Arithmetic operations like addition and subtraction.
- Logic operations such as AND, OR and NOT.
- Control the sequence, conditional connections, etc.

A CPU performance is measured by the number of instructions it executes in a second, i.e., MIPS (million instructions per second), or BIPS (billion instructions per second).

MICROPROCESSOR

- A processor's instruction set is a determining factor in its architecture. On the basis of the instruction set, microprocessors are classified as
  - Reduced Instruction Set Computer (RISC)
  - Complex Instruction Set Computer (CISC)

- The x86 instruction set of the original Intel 8086 processor is of the CISC type. The PCs are based on the x86 instruction set.

CISC

- CISC architecture hardwires the processor with complex instructions, which are difficult to create otherwise using basic instructions.
- CISC combines the different instructions into one single CPU.

- CISC has a large instruction set that includes simple and fast instructions for performing basic tasks, as well as complex instructions that correspond to statements in the high level language.
- An increased number of instructions (200 to 300) results in a much more complex processor, requiring millions of transistors.
- Instructions are of variable lengths, using 8, 16 or 32 bits for storage. This results in the processor's time being spent in calculating where each instruction begins and ends.
- With large number of application software programs being written for the processor, a new processor has to be backwards compatible to the older version of processors.
- AMD and Cyrix are based on CISC.

RISC

- RISC has simple, single-cycle instructions, which performs only basic instructions.
- RISC architecture does not have hardwired advanced functions.
- All high-level language support is done in the software.

- RISC has fewer instructions and requires fewer transistors, which results in the reduced manufacturing cost of processor.
- The instruction size is fixed (32 bits).
- The processor need not spend time in finding out where each instruction begins and ends.
- RISC architecture has a reduced production cost compared to CISC processors.
- The instructions, simple in nature, are executed in just one clock cycle, which speeds up the program execution when compared to CISC processors.
- RISC processors can handle multiple instructions simultaneously by processing them in parallel.
- Apple Mac G3 and PowerPC are based on RISC

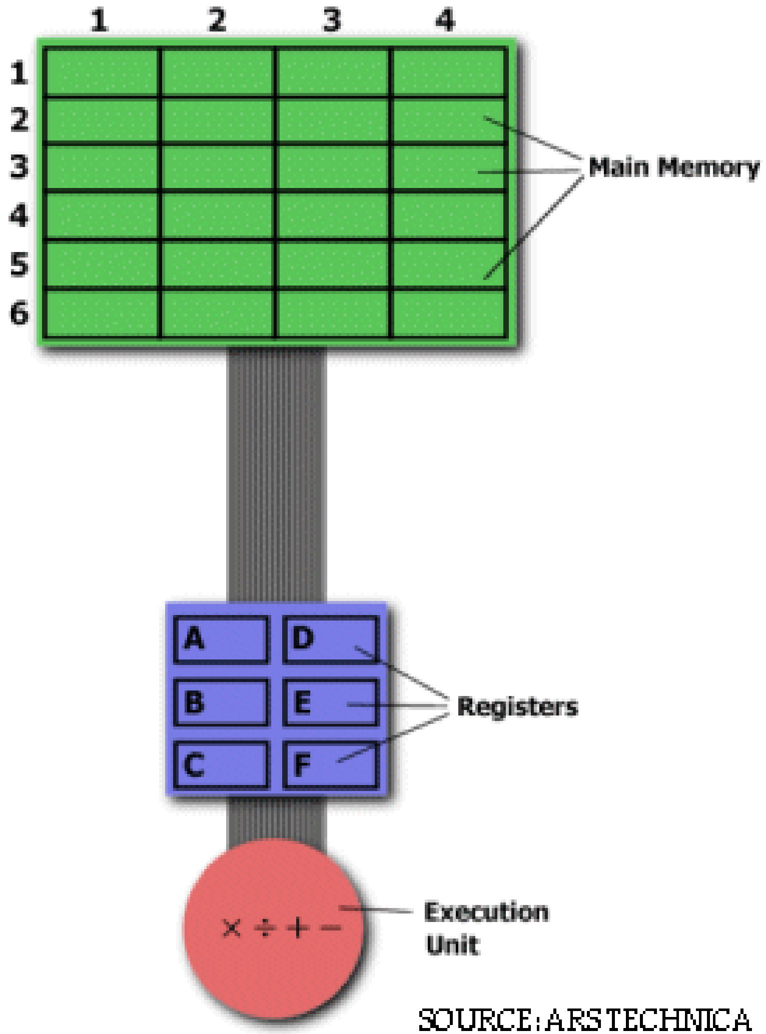
Multiplying Two Numbers in Memory

- **The CISC Approach**

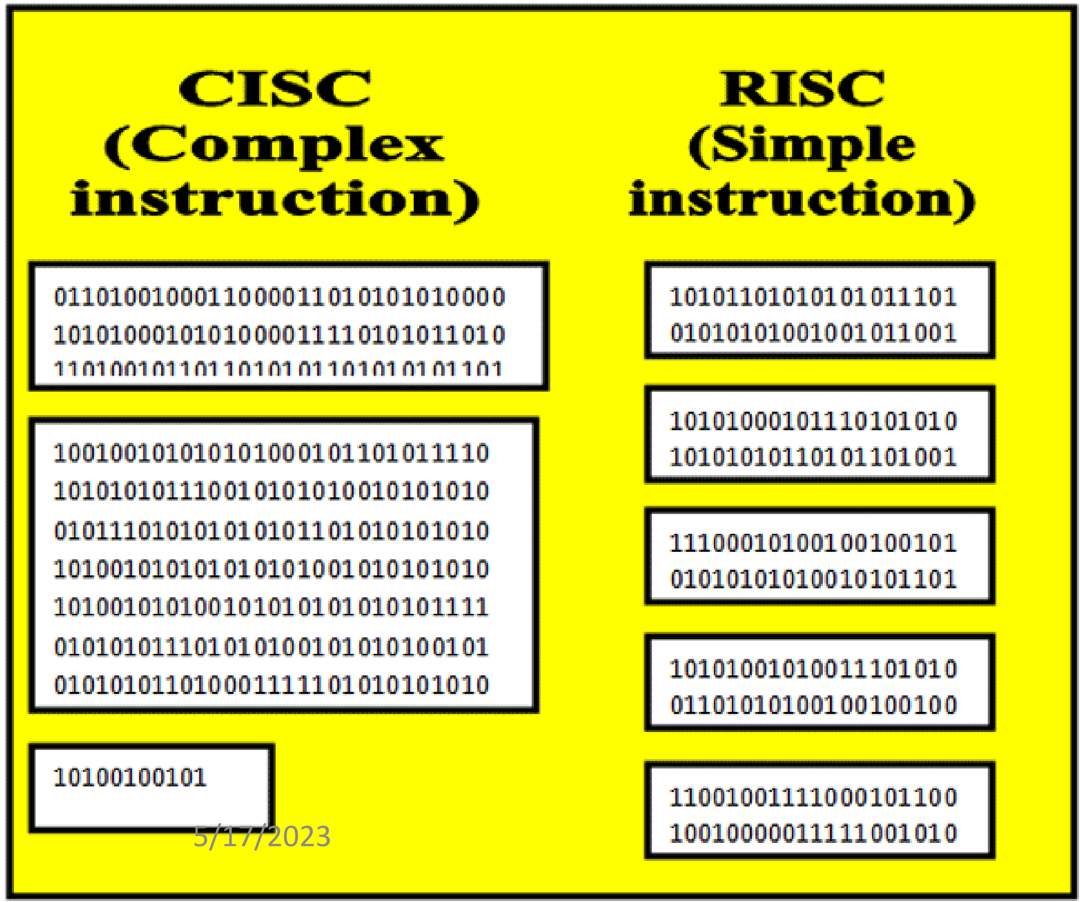
MULT 2:3, 5:2

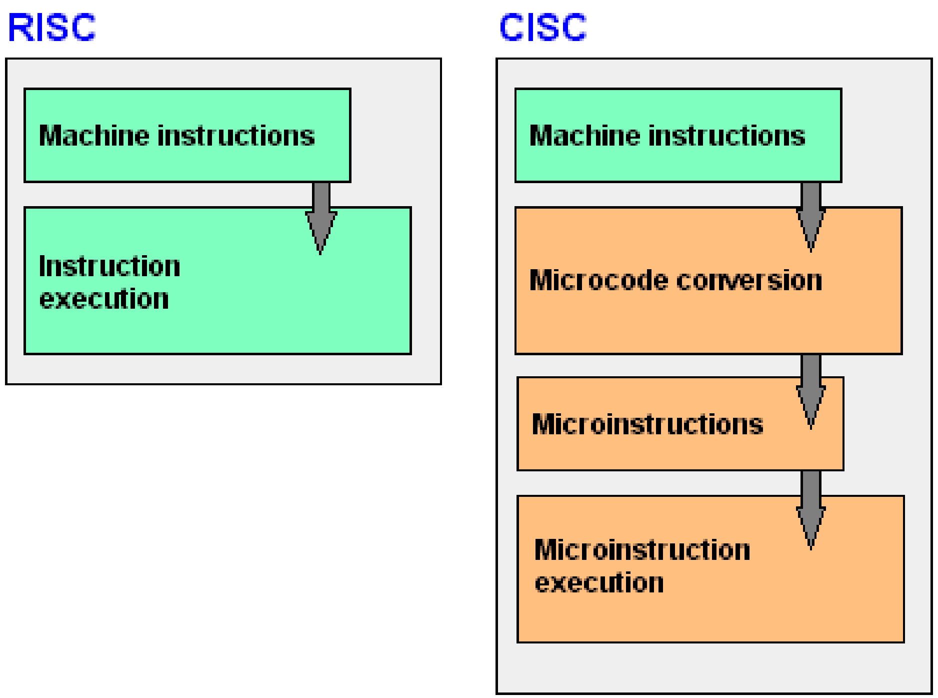
- **The RISC Approach**

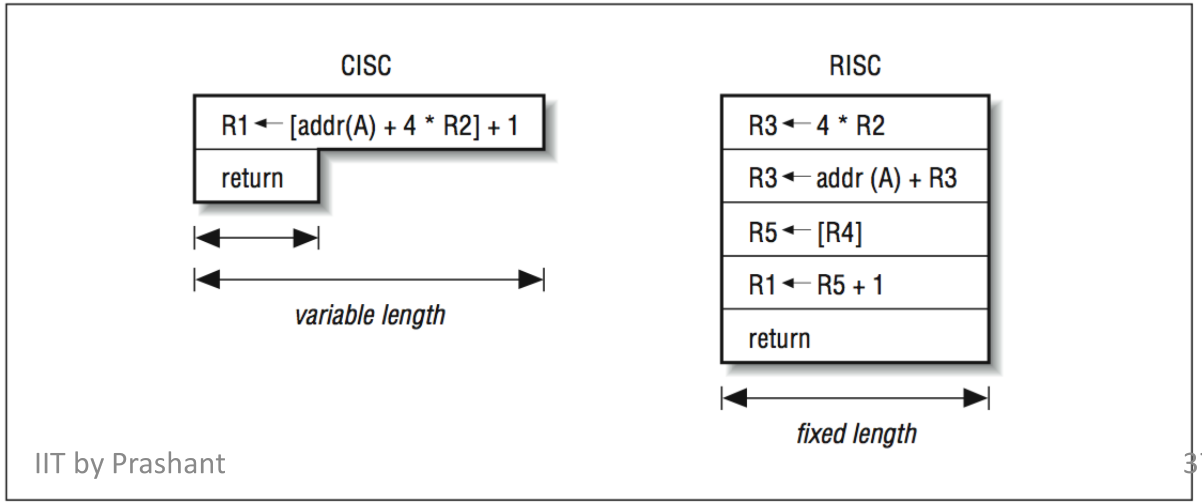
LOAD A, 2:3
LOAD B, 5:2
PROD A, B
STORE 2:3, A



SOURCE:ARSTECHNICA


CISC
(Complex
instruction)
RISC
(Simple
instruction)


RISC
Machine instructions
Instruction execution
CISC
Machine instructions
Microcode conversion
Microinstructions
Microinstruction execution


CISC
R1 ← [addr(A) + 4 * R2] + 1
return
variable length
RISC
R3 ← 4 * R2
R3 ← addr (A) + R3
R5 ← [R4]
R1 ← R5 + 1
return
fixed length

Computer Memory

- The computer memory stores different kinds of data like input data, output data, intermediate results, etc., and the instructions.
- Binary digit or bit is the basic unit of memory.
- A bit is a single binary digit, i.e., 0 or 1.
- A bit is the smallest unit of representation of data in a computer.
- However, the data is handled by the computer as a combination of bits.
- A group of 8 bits form a byte.
- One byte is the smallest unit of data that is handled by the computer.
- One byte can store 28 , i.e., 256 different combinations of bits, and thus can be used to represent 256 different symbols.
- In a byte, the different combinations of bits fall in the range 00000000 to 11111111. A group of bytes can be further combined to form a word.
- A word can be a group of 2, 4 or 8 bytes.

1 bit = 0 or 1

1 Byte (B) = 8 bits

1 Kilobyte (KB) = 2^{10} = 1024 bytes

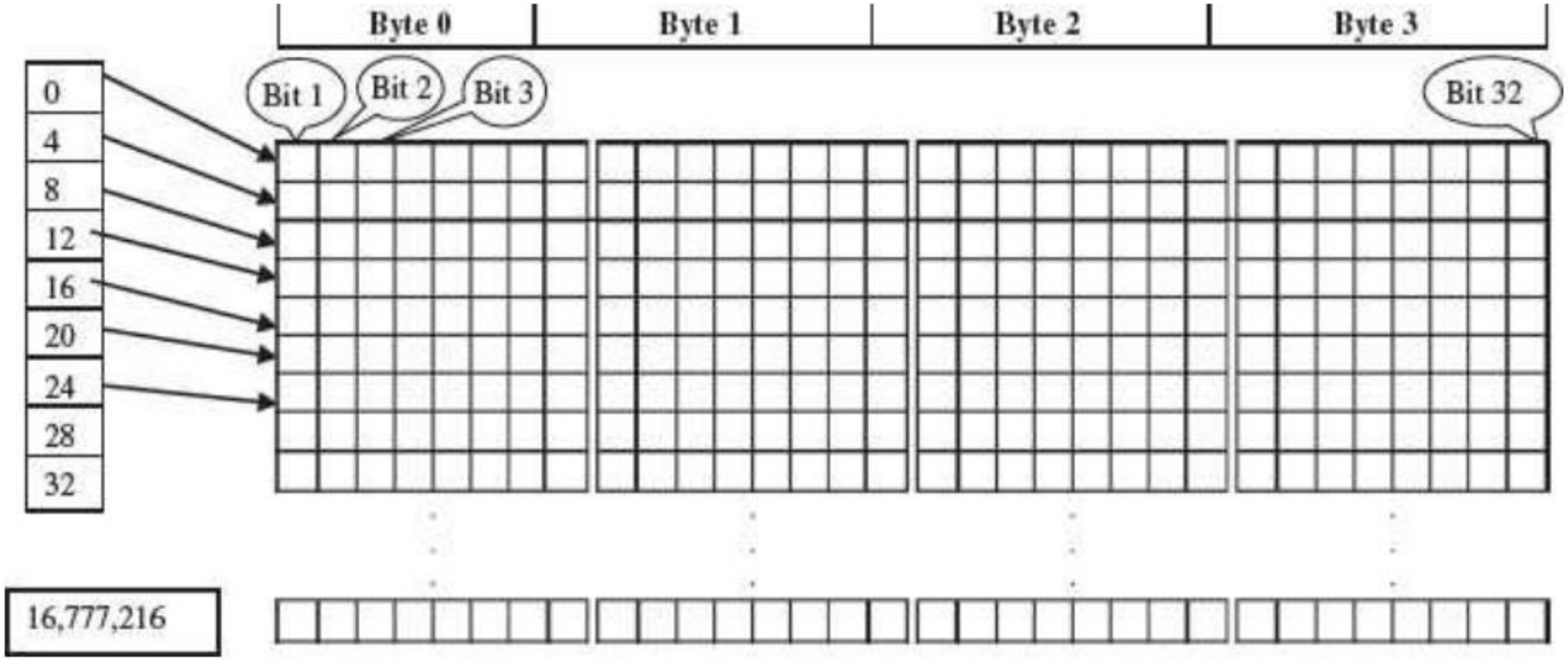
1 Megabyte (MB) = 2^{20} = 1024KB

1 Gigabyte (GB) = 2^{30} = 1024 MB = 1024 *1024 KB

1 Terabyte (TB) = 2^{40}= 1024 GB = 1024 * 1024 *1024 KB

- Memory is logically organized as a linear array of locations.
- For a processor, the range of the memory addresses is 0 to the maximum size of memory.
- Figure shows the organization of a 16 MB block of memory for a processor with a 32-bit word length.

Memory Organization



Memory Hierarchy