CHAPTER 3

CENTRAL PROCESSING UNIT

After completing this lesson, you will be able to:

- Define CPU and its components (ALU, CU, Register, Cache and Internal Buses).
- Describe the functions of general purpose and special purpose registers.
- Define bus and explain data bus, address bus and control bus.
- Define instructions and its types.
- Explain instruction formats.
- Describe instruction cycle (Fetch, Decode and Execute).
- Describe CISC and RISC architecture.
- Differentiate between Intel Pentium IV and AMD Athlon processors.

UNIT INTRODUCTION

Central Processing Unit (CPU) is the main part of any computer system. This unit explains central processing unit and the components inside it. It describes instruction formats and their execution by the control unit. It describes how control unit cycles through fetch, decode and execute operations to carry out program instructions stored in main memory. It also discusses the role of registers and buses in programs execution.

3.1 INSIDE CPU

Q.1 State the capabilities of computers.

Answer

Computers have the capabilities to store and process a large amount of information at extremely high speed and produce accurate results. Computers can work for many hours uninterruptedly and can do the same jobs repeatedly that would be impossible without them.

Q.2 Write a note on CPU.

Answer

Central Processing Unit (CPU)

The Central Processing Unit (CPU) is the main part of the computer, which performs all its activities. It is also called the processor or microprocessor and is truly the "brain" of the computer system. It combines the circuitry that generates all the control signals needed to execute instructions. A latest CPU or microprocessor is shown in Fig.3.1.

Fig.3.1 Intel Core I7 Microprocessor

DO YOU KNOW?

Intel Corporation released the Intel 4004, a 4-bit central processing unit (CPU) in 1971. It was the first microprocessor.

3.1.1 COMPONENTS OF CPU

Q.3 What are the main Components of CPU?

Answer

Main Components of CPU

The following are main components of CPU:

- ALU
- CU
- Registers
- Cache
- Internal Buses

Q.4 What is arithmetic logic unit? Which operations are performed by it? Explain the working of arithmetic logic unit?

Answer

Arithmetic Logic Unit (ALU)

Arithmetic Logic Unit (ALU) is the part of the CPU where the actual processing takes place. ALU is capable of performing arithmetic, logical and data manipulation operations on data

Operations performed by ALU

The ALU consists of logic circuitry that performs operations such as addition, subtraction, multiplication, division, exponentials, data manipulations (for example, shifting), comparisons and logical operations such as AND, OR, NOT, etc on the data contained in the registers. An ALU is shown in Fig 3.2 with its associated registers.

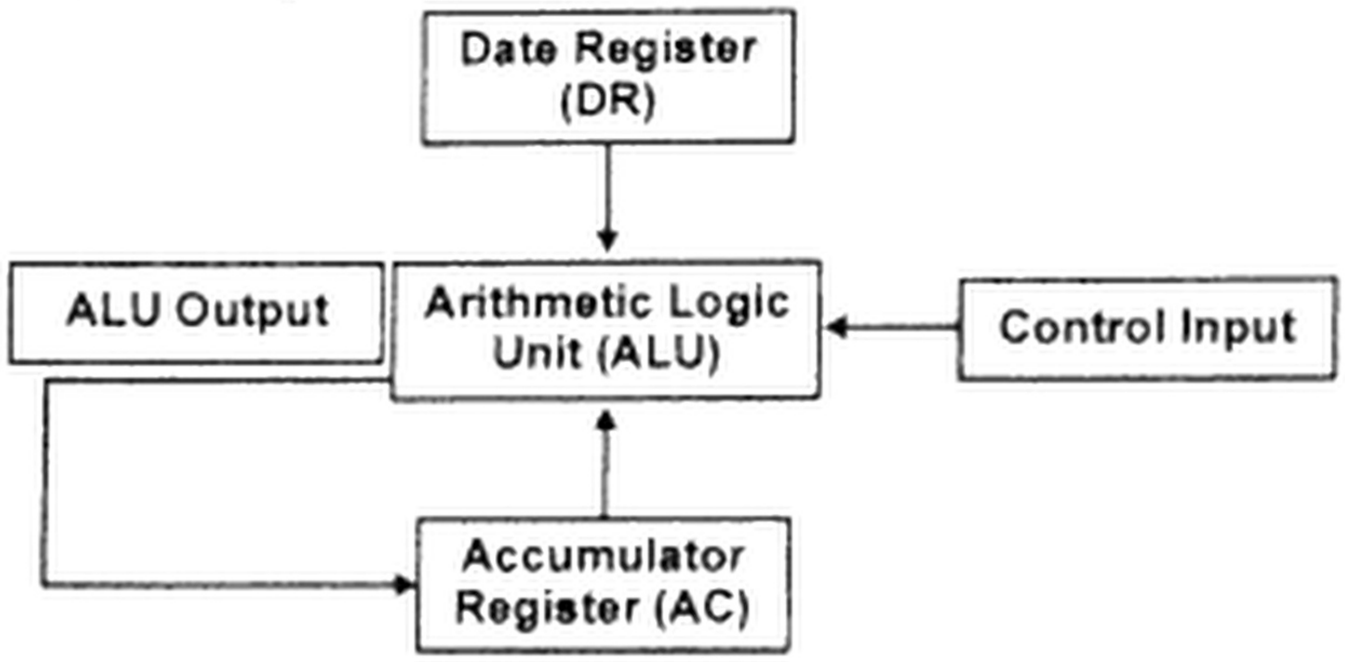


Fig 3.2 Arithmetic Logic Unit

Working of ALU

Suppose we want to add two numbers 30 and 45. The ALU will perform the following steps to do this addition:

1. The first number, 30 will be stored in the Accumulator Register (AC).
2. The second number, 45 will be stored in the Data Register (DR).
3. Control unit (CU) will send the command to add the numbers through the control input.
4. Two numbers, 30 and 45 will be added by the circuitry in the ALU.
5. The result 75 will appear at the ALU output and will be transferred to AC.
6. Finally, the result 75 will be sent to the main memory from AC.

Q.5 What is control unit? Explain its parts.

Answer

Control Unit (CU)

Control unit directs and coordinates the activities of the entire computer system. It controls the working of all the input/output devices, all the primary and secondary storage devices and the calculations performed by the ALU. Control unit controls the operations of computer system based on the instructions in the program by executing them in a proper order.

Parts of Control Unit

Control Unit consists of three main components:

- Instruction Register
- Instruction Decoder
- Timing and Control Logic

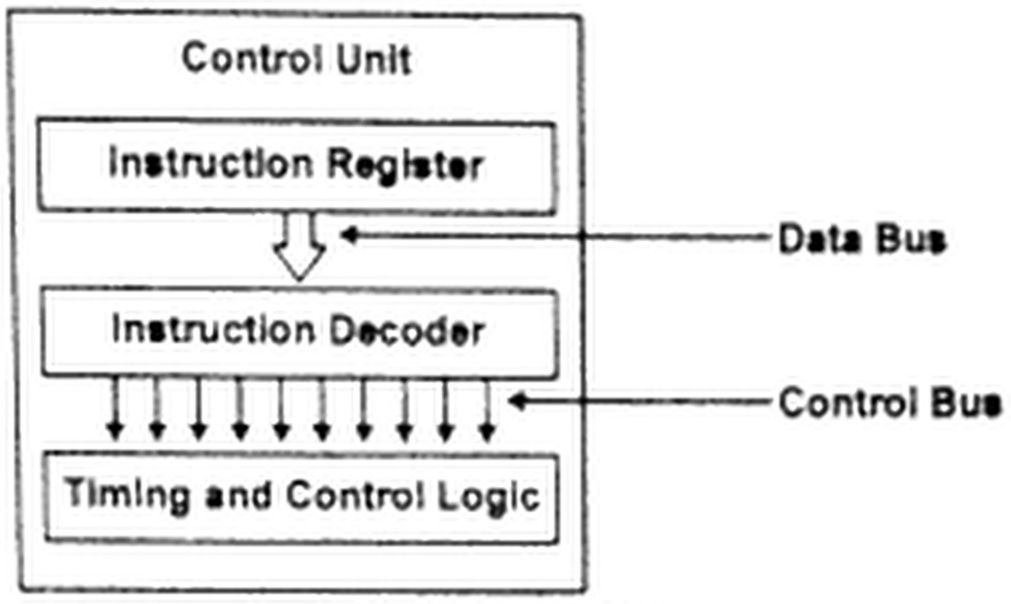


Fig.3.3 Control Unit

1. **Instruction Register**
   Instruction register stores the instruction while it is being executed.
2. **Instruction Decoder**
   Instruction decoder decodes (translates) it and timing and control logic generates the signals to execute it.
3. **Timing and Control Logic**
   All sequential circuits in the Basic Computer CPU are driven by a master clock, with the exception of the INPR register.

At each clock pulse, the control unit sends control signals to control inputs of the bus, the registers, and the ALU.

Q.6 Define Registers. Name some commonly found registers inside CPU.

Answer

Registers

Registers are small memory devices whose function is to temporarily store data information and pass it on to the other parts of the processor or main memory during the processing. CPU contains several registers that are used to store various kinds of information needed by the microprocessor as it performs its functions.

Commonly Found Registers

Some commonly found registers inside the CPU are:

- Instruction Register
- Accumulator Register
- Data Register
- Program Counter
- Memory Address Register

Q.7 Write a short note on cache memory.

Answer

Cache Memory

Cache memory is a very small amount of memory inside the microprocessor as shown in Fig.3.4.

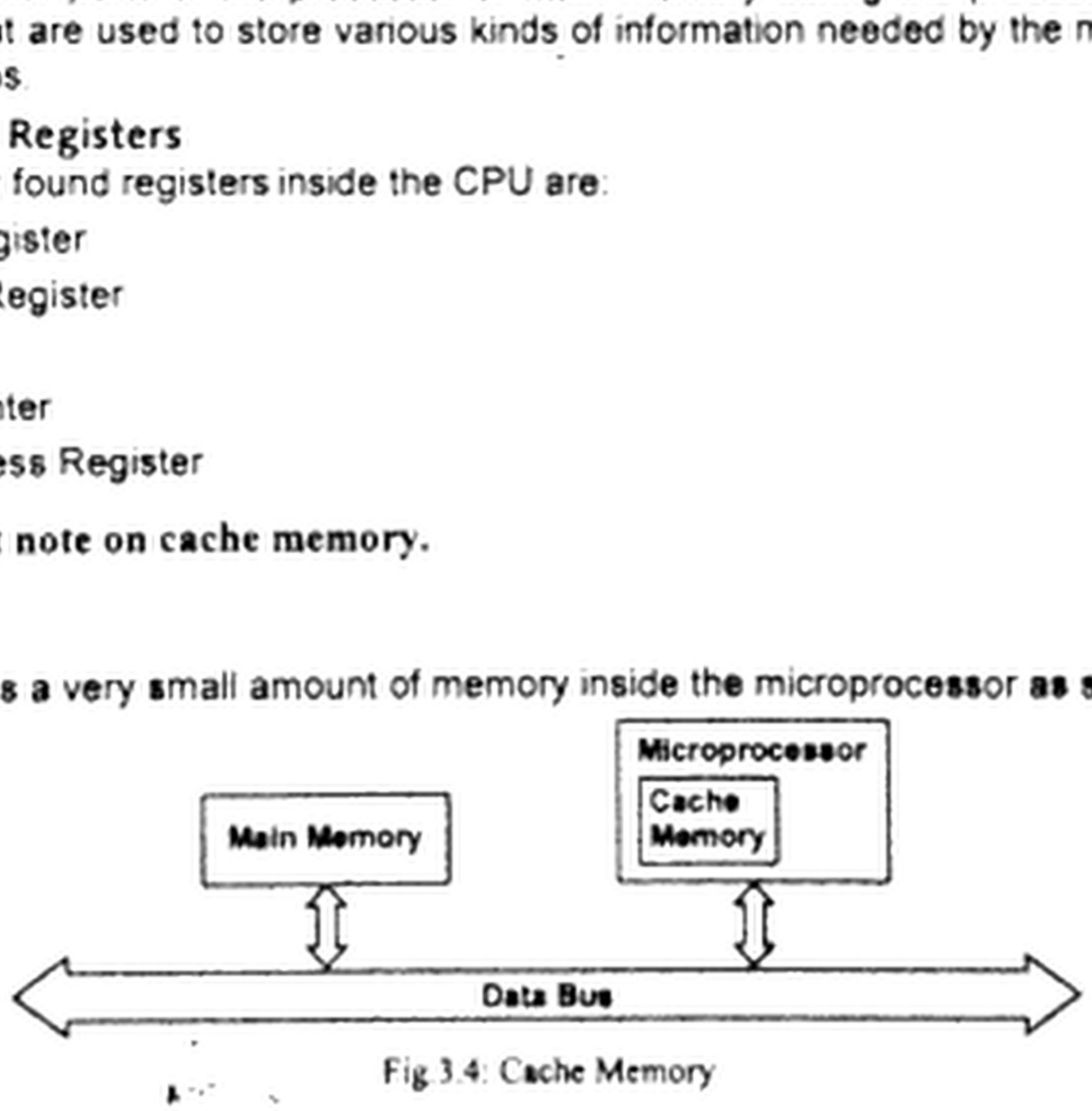


Fig.3.4: Cache Memory

It is faster than main memory but it is very expensive. It stores some active portion main memory, which is frequently required by the CPU.

Q.8 Define bus and internal bus. How many types of buses are inside microprocessor?

Answer

Bus

A bus is a group of parallel wires used for transmitting data/information from one part of the computer to another. In other words, it provides a pathway for transmitting data/information among various components of computer.

Internal Buses

The buses that are found inside the CPU are known as internal buses.

Types of Buses

There are three types of buses inside microprocessor, which are:

- Address Bus
- Data Bus
- Control Bus

Types of buses are shown in Fig.3 5.

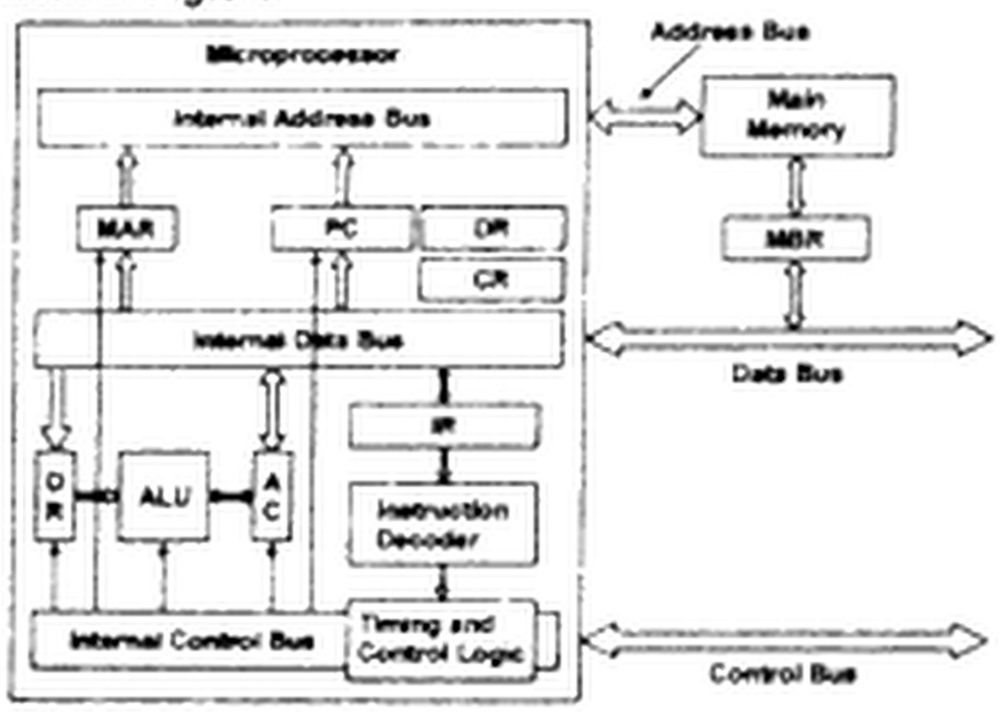


Fig.3.5 Microprocessor bus architecture with associated registers

3.1.2 REGISTERS

Q.9 State the purpose of registers. Explain the types of registers used in the computer.

Answer

Registers

Registers are used to quickly accept, store, and transfer data and instructions that are being used immediately by the CPU.

Types of Registers

Registers used in the computer are divided into two types:

- General Purpose Registers
- Special Purpose Registers

1. General Purpose Registers

General-purpose registers are used to store data as well as addresses. These registers are used for arithmetic data movement. Typically, these are 8 to 32 bit registers.

Commonly Used General Purpose Registers

Following are the commonly used general purpose registers:

i) Accumulator Register (AC) and Data Register (DR)

These two registers hold the operands (values) that the ALU operates on during the execution of an

instruction. Operands are values on which operations such as addition or multiplication is to be performed. Operands are loaded into these registers from memory. After performing the operation, the results of ALU are transferred to the accumulator (AC). Both the accumulator and the data registers can receive data from memory over the data bus but only the accumulator can send data/information back to the memory.

ii) Base Register (BR)

It is used to hold a number that can be added to (or, in some cases, subtracted from) the address portion of a computer instruction to form an effective address. It is also known as Index register

iii) Counter Register (CR)

It contains the address (location) of the instruction being executed at the current time. As each instruction gets fetched, the Counter register increases its stored value by 1. After each instruction is fetched, it points to the next instruction in the sequence. When the computer restarts or is reset, it normally reverts to 0

2. Special Purpose Registers

These registers hold the state of a program. They include program counter, instruction register, memory address register and memory buffer registers. These are used by Control Unit to control the operations of CPU and by the Operating System programs to control the execution of me programs.

Types of Special Purpose Registers

Following are the types of special purpose registers:

i) Instruction Register (IR)

Instruction register holds program instructions that are fetched from the memory for execution. It holds the instruction while the instruction decoder circuit decodes it. After decoding, the timing and control logic generates the proper sequence of control signals to complete the execution of the instruction.

ii) Memory Address Register (MAR)

Memory address register hold the address of memory location from where a memory word is to be fetched or where data is to be stored.

iii) Memory Buffer Register (MBR)

A memory word that is to be stored in or to be fetched from memory must first be transferred into memory buffer register. MBR acts as a buffer (a small temporary memory) allowing to microprocessor and memory unit to act independently without being affected by minor differences in operation.

iv) Program Counter (PC)

It controls the sequence in which instructions are fetched from memory. At any given instant, the contents of PC indicate the address in memory from which the next instruction is be fetched. Contents of PC are loaded into MAR to fetch an instruction from memory. After fetching an instruction from memory, the PC is incremented by one to point to the next instruction to be fetched.

3.1.3 BUSES

Q.10 What is meant by bus? Explain its types.

Answer

Bus

A bus is an electrical pathway inside the computer system over which data/information is transferred from one part to the other. It connects the CPU to the main memory on to motherboard.

Types of Buses

Following are the three types of buses:

- Address Bus
- Data Bus
- Control Bus

1. Address Bus

The address bus is used by the CPU to select a memory word for a read or operation. It is

unidirectional bus because information flows in only one direction. Address width is from 16 to 32 bits. A system with a 32-bit address bus can address 2^{32} (4,294,967,296) memory locations.

2. Data Bus

The data bus is a bidirectional bus over which data can be sent from the microprocessor to memory (Write operation) or from the memory to the microprocessor (Read operation). Although, it is called data bus, the information carried on this will not always be data, it will often be instruction codes fetched by the microprocessor. Data bus width is from 32 to 64 bits.

3. Control Bus

The control bus is a group of wires that sends timing and control signals to all the parts of computer needed to carry out the instructions. Some of the control lines are outputs from the microprocessor and others are inputs to the microprocessor from I/O devices. Control bus width is in the range of 8 to 16 bits.

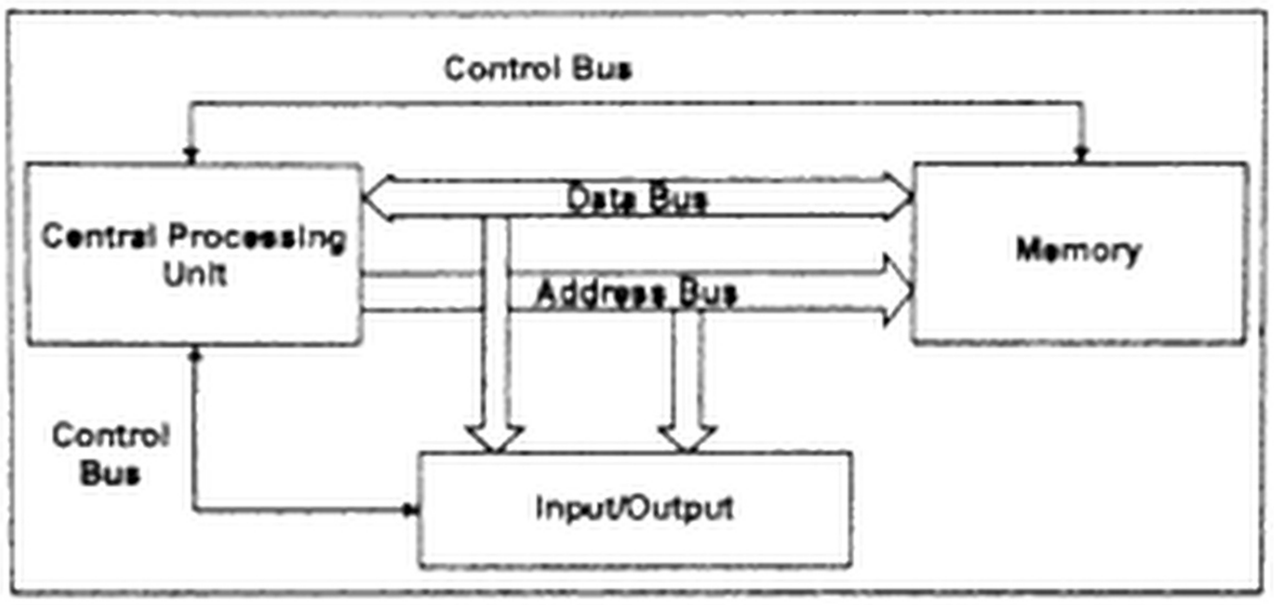


Fig.3 5b System Buses

3.2 CPU OPERATIONS

Q.11 What are CPU operations? State the fundamental operations of most CPUs. Also state the steps that CPUs use in their operations.

Answer

CPU Operations

CPU is the main component of a computer system, which carries out the instructions by performing the basic arithmetical, logical, and input/output operations of the system.

Fundamental Operation of most CPUs

The fundamental operation of most CPUs is to execute a sequence of stored instructions called a program. The program is represented by a series of instructions that are kept in some kind of computer memory.

Steps performed in operations

There are four steps that CPUs use in their operations, these are:

- Fetch
- Decode
- Execute
- Store

3.2.1 INSTRUCTIONS

Q.12 What is meant by instruction? What are its fields?

Answer

Instruction / Instruction Code

An instruction (or instruction code) is a group of bits that tells the computer to perform a specific operation. Instructions are stored in the main memory, waiting to be processed by the processor.

Fields of Instruction

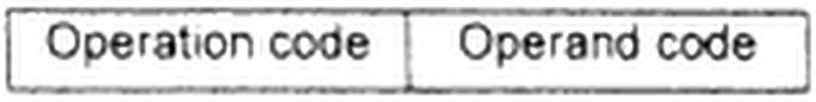
An instruction has two fields.

1. **Operation code**

Operation code, which represents the action that the processor execute.

2. **Operand code**

Operand code, which defines the parameters of the action. The operand code depends on the operation. It can be data or a memory address.



Q.13 Explain the types of instructions.

Answer

Types of Instructions

Modern computers support many types of instructions. The following are some general types of instructions used in computers:

- Data Transfer Instructions
- Data Processing Instructions
- Program Control Instructions

1. Data Transfer Instructions

Data Transfer instructions transfer data from one location in the computer to another location without changing the data content. The most common transfers are between:

- Registers and memory
- Registers and I/O
- Registers to registers

Examples of data transfer instructions

Examples of some common data transfer instructions are as follows:

- MOV
- LOAD
- STORE

i) MOV (MOVE) instruction

MOV (MOVE) instruction transfers data from a memory location to a register, register to memory and register to register. This instruction is also used to store the result of a computation.

Example:

MOV A, B (Move the contents of register A to B)

ii) LD (LOAD) instruction

LD (LOAD) instruction loads particular register contents from memory.

Example:

LD A (Load the data to register A from memory)

iii) STO (STORE) instruction

STO (STORE) instruction stores information from register to memory location.

2. Data Processing Instructions

These instructions are related to the arithmetic and logic operations. The arithmetic or logic operations are performed on the values of two registers and the result is also placed in a register.

Types of Data manipulation instructions

Data manipulation instructions can be divided into three basic types:

- Arithmetic Instructions
- Logical Instructions
- Shift Instructions

i) Arithmetic Instructions

These instructions are used to perform arithmetic operations. The four basic arithmetic instructions are ADD (Addition), SUB (Subtraction), MUL (Multiplication) and DIV (Division).

ii) Logical Instructions

These instructions are used to perform logical operations like AND, OR, NOT, etc. on binary data stored in registers.

iii) Shift Instructions

Shift instruction is used for transfer of bits either to the left or to the right of an operand.

3. Program Control Instructions

Program control or transfer of control is a way of altering the order in which statements are executed There are a number of instructions used for this purpose like JMP (Jump) and LOOP.

i) JMP instruction

The JMP instruction jumps to begin the execution at another location.

ii) LOOP instruction

The LOOP instruction is used when number of statements is to be repeated.

3.2.2 INSTRUCTION FORMATS

Q.14 Define instruction format and its parts.

Answer

Instruction Format

An instruction format defines the layout of the instruction.

Parts of Instruction Format

Instruction Format consists of two parts:

- Op-Code
- Operand

1. Op-Code

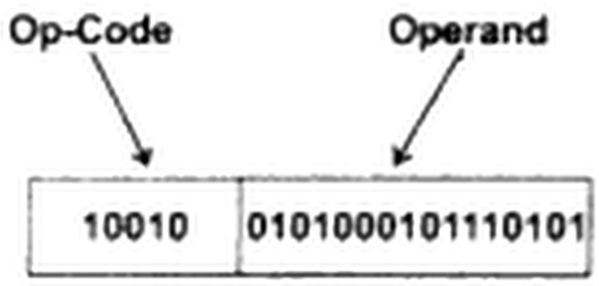
Op-Code is a group of bits that define various processor operations such as LOAD, STORE, ADD and SHIFT to be performed on some data stored in registers or memory.

2. Operand

Operand can be data, or can refer to data - i.e. address of data.

Example

The Op-code (10010) specifies the code for ADD operation to be performed on the operand at the address specified in Operand part.



Q.15 Explain some common instruction formats.

Answer

Common Instruction Formats

Some common instruction formats are discussed as follows:

- Zero-Address Instruction
- One-Address Instruction
- Two-Address Instruction

1. Zero Address Instruction

The Zero Address instruction format requires only op-code, having no operand to work with.

Example

Examples of the Zero Address instruction format are HALT and STOP, which do not have any address.

Example: STOP

2. One Address Instruction

One Address instruction format requires one op-code and one Operand.

Example

Example of the one address instruction format is LDA (Load Accumulator), JMP (Jump) etc. These instructions require one address to do the operation. Like JMP requires one address in order to jump to that specific address location.

Op-Code	Operand

Example: JMPAX

3. Two Address Instruction

Two Address instruction format requires one op-code and two operands.

Example

Example of such instruction format is the MOV (Move), which moves data from the memory location to the register and from register to the memory location.

Op-Code	Operand	Operand

Example: ADD A, B

3.2.3 INSTRUCTION CYCLE

Q.16 Define instruction cycle.

Answer

Instruction cycle

Instruction cycle is the basic operation cycle of a computer to execute various instructions. A computer retrieves an instruction from its memory, determines what actions the instruction requires, and carries out those actions by the process.

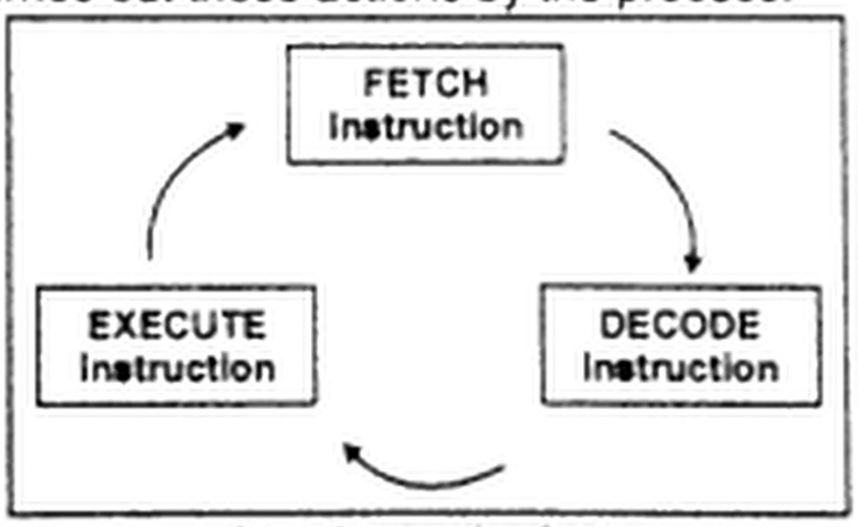


Fig.3.7 Instruction Cycle

Q.17 Describe the steps of instruction cycle.

Answer

Steps of Instruction Cycle

The following are the three instruction cycle steps:

- Fetch operations
- Decode operation
- Execute operation

1. Fetch Operation

In this operation, the control unit fetches an instruction from main memory by sending an address through the address bus and a read command through the control bus. The fetch operation places the instruction into the instruction register (IR) inside the microprocessor.

2. **Decode operation**

In this step, the instruction decoder decodes the instruction to determine what the instruction is intended to do.

3. **Execute Operation**

Once the instruction has been decoded, it can be executed. In this operation, the timing and control logic circuitry in the control unit generates signals needed to execute the instruction. The instruction may perform arithmetic, make a decision, simply move data from one memo location to another, etc..

3.2.4 CISC AND RISC ARCHITECTURE

Q.18 Explain CISC and RISC architecture.

Answer

CISC and RISC are two different competing philosophies in designing modern computer architecture.

CISC Architecture

CISC stands for Complex Instruction Set Computer. CISC architecture is the traditional architecture of CPU that supports a large variety of instructions. These instructions may have different length, and use all addressing modes and require complex circuitry to decode them. CISC architecture is complex because of the instructions used at the hardware level.

Examples

Examples of CISC processors are the Intel 486 series and Pentium series.

RISC Architecture

RISC stands for Reduced Instruction Set Computer. It is considered new architecture of CPUs. RISC architecture of CPU supports same size of instructions and it does not use indirect addressing mode. The instructions of a CPU that uses RISC architecture are very simple and are executed very fast. RISC CPUs require fewer transistors, which makes them cheaper to design and easy to manufacture.

Examples

Examples of RISC processor are:

- IBM PowerPC
- Sun SPARC
- Mobile phones
- Tablet PCs

Q.19 Differentiate between CISC and RISC architecture.

Answer

Differences between CISC and RISC architectures

The following are few differences between CISC and RISC architectures:

1. CISC instructions utilize more cycles than RISC.
2. CISC has way more complex instructions than RISC.
3. CISC typically has fewer instructions than RISC.
4. CISC implementations tend to be slower than RISC implementations.
5. Computers typically use CISC while tablets, smart phones and other devices use RISC.

3.2.5 INTEL AND AMD PROCESSOR

Q.20 Explain Intel and AMD processor.

Answer

Intel and AMD (Advanced Micro Devices) are the primary manufacturers of processors. They make processors for desktop computers, laptops, notebooks and mobile devices. Different types of processors perform different functions at different speeds, depending on what kind of system they run.

Each type of processor has different functionality, but similarities do exist among various types. Both Intel and AMD make processors for a variety of systems. Core, Pentium and Celeron families of processors belong to Intel while Phenom, Athlon and Sempron processors belong to AMD.

Intel Pentium IV Processor

Intel Pentium IV processors have 20 steps execution process. They have high clock speed and perform fewer operations per clock. Pentium processors generally use 478 pin sockets and use Mega Hertz (MHz) to specify processor speed.

AMD Processor

AMD processors have 10 steps execution process. These processors generally use 462 pin sockets. AMD processors do not use Mega Hertz (MHz) to specify processor speed. This is due to the instruction set handling that AMD uses.

Q.21 Compare Pentium IV and AMD processors.

Answer

Comparison between Pentium IV and AMD Athlon processors

The following is the comparison between Pentium IV and AMD Athlon processors:

	Intel Pentium IV Processor	AMD Athlon Processor
Clock Speed	1.7 to 3.0 GHz.	1.4 to 2.33 GHz.
Bus width	32/64 bits	32/64 bits
Cache	256 KB to 1 MB	256/512 KB
Architecture	CISC/RISC	RISC

KEY POINTS

- Central Processing Unit (CPU) is a single unit that consists of ALU and Control Unit. It is the "brain" of a computer
- Arithmetic Logic Unit (ALU) is the part of the computer where actual processing takes place.
- Control Unit directs and coordinates the activities of the entire computer system. It controls the working of all the input/output devices, storage devices and the calculations performed by the ALU.
- A bus is a group of parallel wires used for transmitting binary information from one part computer to another. There are three types of buses, address bus, data bus and control bus.
- The general types of instructions used in computers are data movement, operation, shift comparison, branch and input/output instructions.
- Instruction code is a group of bits that tells the computer to perform a specific operation.
- Control Unit repeatedly cycles through the FETCH, DECODE and EXECUTE steps till the last instruction of the program is executed
- CISC stands for Complex Instruction Set Computer that supports a large variety of instructions, which may be as many as three hundred.
- RISC stands for Reduced Instruction Set Computer that supports very simple limited number of instruction.