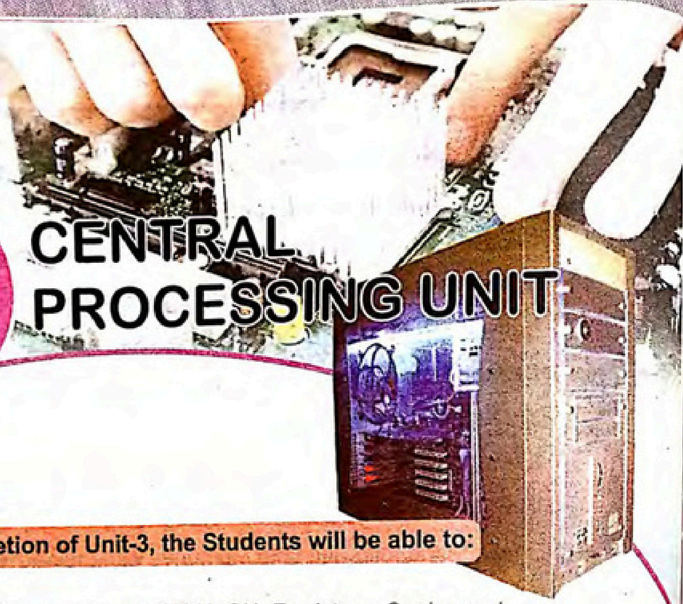
UNIT 3

CENTRAL PROCESSING UNIT



After the completion of Unit-3, the Students will be able to:

- *define CPU and its components (ALU, CU, Registers, Cache and Internal Buses).*
- *describe the functions of general purpose and special purpose registers.*
- *explain system bus and its types.*
- *define instruction and its types.*
- *explain instruction format.*
- *describe instruction cycle (Fetch, Decode and Execute).*
- *describe CISC and RISC architecture.*
- *differentiate between Intel and AMD processors.*

3.1 CPU (CENTRAL PROCESSING UNIT)

Central Processing Unit (CPU) is the integral part of any computer system. It is the brain of computer system. Just like human brain which controls all the activities of human body, the CPU controls all the operations of the computer. CPU is connected to all parts of the Computer. CPU not only execute instructions but also controls the storage of data, input output activities and functions of different devices attached. CPU is also called microprocessor or processor.

3.1.1 Basic Components of CPU

CPU consists of the following basic components.

a. Arithmetic and Logic Unit (ALU)
b. Control Unit (CU)
c. Registers
d. Cache
e. Internal Buses

a. Arithmetic and Logic Unit (ALU)

Arithmetic Logic Unit is the main processing unit of CPU. It performs arithmetic and logic operations on data. Arithmetic means addition, subtraction, multiplication, division and logical operation is the comparison between two data items. ALU processes the data and then gives back the results. The results of an operation are stored in registers (temporary storage locations). Now a days CPUs have more than one ALUs that can do the calculation simultaneously in order to improve the efficiency of computer system.

b. Control Unit (CU)

Control Unit manages the functions performed by different parts of the computer. It coordinates and controls the overall computer system, just like the brain controls the human body. It executes the program instructions, controls and directs the input, informs ALU for processing, arranges the storage and directs the data to the output device.

Control unit is responsible for directing the flow of instructions and data within the CPU. It directs the operation of the other units by providing timing and control signals. The control unit contains the necessary logic to interpret instructions and to generate the signals necessary for the execution of those instructions. The descriptive words "fetch" and "execute" are used to describe the actions of the control unit. It fetches an instruction by sending an address and a read command to the memory unit. The instruction at that memory address is transferred to the control unit for decoding. It then generates the necessary signals to execute the instruction.

c. Registers

Registers are small memory devices available in the CPU. These are used to store data temporarily. CPU registers are at the top of the memory hierarchy, and provide the fastest way for a CPU to access data. Each register is designed for a special purpose and the size of each varies. Registers are measured by the number of bits they can hold, like 8-bits, 16 bits or a 32-bits register. Processor contains different kinds of registers and is classified according to their content or instructions. CPU registers are divided into two main types.

- General Purpose Registers
- Special Purpose Registers

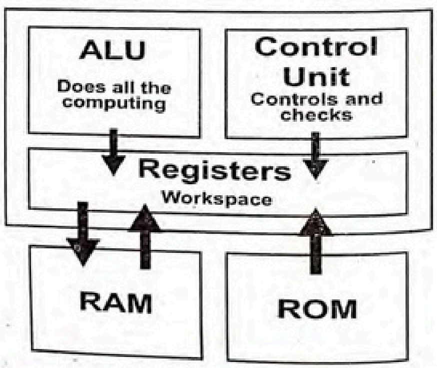


Figure 3.1 CPU Registers

d. Cache Memory

It is the small amount of memory located between main memory and processor. Cache memory is also known as high speed buffer or on chip memory. The microprocessor stores a copy of most frequently used data and instructions in the cache memory. The microprocessor when desires the data, it first looks in to the cache memory, if not found there then it will ask for the same from the main memory. This will result in the better efficiency of the microprocessor speed and its usage.

There are different levels of cache memory.

Level 1 (L1) Cache memory resides inside the microprocessor and is very fast from the other memories. Microprocessor first checks the Level 1 Cache memory.

Level 2 (L2) Cache memory lies just outside the microprocessor, it is slow as compared to Level 1 cache but fast from rest of the memories. If data or instruction not found in Level 1 cache memory then microprocessor will look in to Level 2 cache memory.

Now days modern microprocessor has **Level 3 cache** on the motherboard.

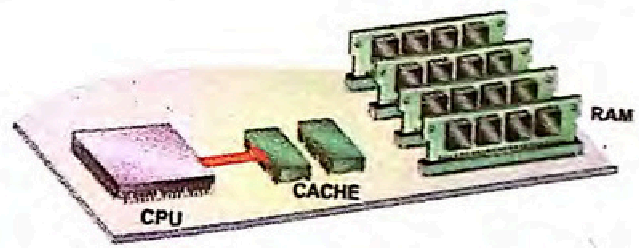


Figure 3.2 Cache memory

e. Internal Buses

Bus is a subsystem that transfers data between computer components inside a computer. Internal bus connects all the components of computer to the motherboard. An internal bus enables communication between internal components such as a computer video card and memory.

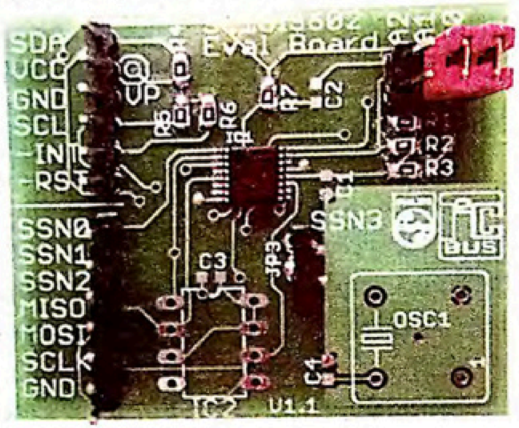


Figure 3.3 internal buses

Modern computer buses can use both parallel and serial-bit connections. Parallel buses are those which carry data in parallel on multiple wires (Conventional PCI, Extended ISA, PCI-104) and serial buses are those that carry data in serial-bit form (PCI Express, SATA). The buses size in computers are from 8-bits to 128 bits.

3.1.2 Types of Registers

Registers are categorized into two types according to their purpose and function.

- General Purpose Registers
- Special Purpose Registers

a. General Purpose Registers

General purpose registers are used to store data as well as addresses. They are combined data and address registers. These registers are used for

arithmetic and data movement. Typically these registers are 8-32 bit registers. Following are the commonly used general purpose registers.

i. Accumulator (AX)
ii. Data Register (DX)
iii. Base Register (BX)
iv. Counter Register (CX)

i. Accumulator (AX)

Accumulator is a general purpose register and is used by CPU for performing arithmetic and logic operations and to hold the result of those operations. The accumulator is initially set to zero, and then each number in turn is added to the value in the accumulator. It consists of two 8-bit registers (AH and AL) which can be combined together and used as a one 16-bit register.

Bits 15...0

16-bit AX register	
8-bit AH register	8-bit AL register

ii. Base Register (BX)

The Base Register can perform arithmetic and data movement and it has some special addressing abilities. BX register can hold a memory address that points to another variable. It usually contains a data pointer. It consists of two 8-bit registers (BH and BL) which can be combined together and used as a one 16-bit register.

Bits 15...0

16-bit BX register	
8-bit BH register	8-bit BL register

iii. Counter Register (CX)

The Counter Register acts as a counter for repeating or looping instructions. The instructions given are automatically repeated and will decrement the value of CX and quits when it is equal to 0. It consists of two 8-bit registers (CH and CL) which can be combined and used as a 16-bit register CX.

Bits 15..0

16-bit CX register	
8-bit CH register	8-bit CL register

iv. Data Register (DX)

Data Register has a special role in multiply and divide operations. It works like a buffer and holds anything that is copied from the memory ready for the processor to use it. It also consists of two 8-bit registers (DH and DL) and can be combined to work as a 16-bit register. In Input/Output (I/O) operations DX register can be used as a port number.

Bits 15..0

16-bit DX register	
8-bit DH register	8-bit DL register

b. 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 the programs. Following are the special purpose registers.

i. Instruction Register (IR)

Instruction register is a part of control unit, which stores the instructions currently being executed. Each instruction to be executed is loaded into the instruction register. It is also known as current instruction register (CIR) because it holds the current instruction being executed.

ii. Memory Address Register (MAR)

Memory Address Register holds the memory address, the memory address from which data will be provided to the CPU or will have the address to which data will be sent and then stored. It basically holds the memory location of data that needs to be accessed. When reading from memory, the data addressed by MAR is fed into the MDR (Memory Data Register) and then is used by the CPU. When writing to memory, the CPU writes data from Data Register to the memory location whose address is stored in MAR. So, in both reading and writing, it is holding the address of the memory location where the data is to be read or stored.

iii. Memory Buffer Register (MBR)

The Memory Buffer Register actually holds the contents of the memory which are to be moved from memory to other components or from components to the memory. In order to store a word it must be transferred to the MBR and then from here it will go to the specific memory location. It works as a buffer allowing the processor and memory units to act independently.

iv. Program Counter (PC)

Program Counter is also known as Instruction Pointer. It is a register in a computer processor that contains the address (location) of the instruction being executed at the current time. As each instruction gets fetched, the program counter increases its stored value by 1. After each instruction is fetched, the program counter points to the next instruction in the sequence.

3.1.3 System Bus

A bus is a data communication path over which information is transferred a byte or word at a time. System bus connects the central processing unit to main memory on the motherboard. The majority of system buses are made up of 50 to 100 distinct lines for communication. The system bus consists of three types of buses.

a. Data Bus
b. Address Bus
c. Control Bus

a. Data Bus

Data bus is the bidirectional bus. It can communicate in two ways, but in one direction at a time. It handles the transfer of data and instructions. The data bus is used to transfer instructions from memory to the CPU for execution. It carries data (operands) to and from the CPU and memory as required. It is also used to transfer data between memory and I/O devices during input output operations. A typical data bus is 32-bits wide. This means that up to 32-bits of data can travel through a data bus every second. New computers have 64-bit data buses and even more.

b. Address Bus

Address bus carries addresses not data. An address is defined as a label, symbol, or other set of characters used to designate a location or register where information is stored. Before data or instructions can be written into or read from memory by the CPU or I/O sections, an address must be transmitted to memory over the address bus. The number of lines on the bus determines the number of addressable memory elements. For example an 8-bit bus can represent 2^8 i.e. 256 unique addresses. A 16-bit bus can address 65536 unique addresses.

c. Control Bus

The control bus is used by the CPU to direct and monitor the actions of the other functional areas of the computer. It is used to transmit a variety of individual signals (read, write, interrupt, acknowledge) necessary to control and coordinate the operations of the computer. The size of control bus is from 8 to 16 bits.

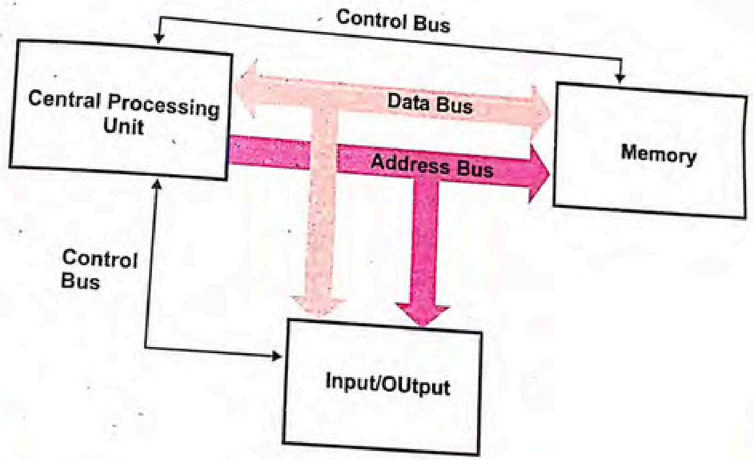


Figure 3.4 System Buses

3.2 CPU OPERATIONS

A central processing unit (CPU) is the hardware within a computer system which carries out the instructions of a computer program by performing the basic arithmetical, logical, and input/output operations of the system. The fundamental operation of most CPUs, regardless of the physical form they have, 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. There are four steps that CPUs use in their operation, these are fetch, decode, execute and store.

3.2.1 Instructions and their types

An instruction (or instruction code) is a group of bits that tells the computer to perform a specific operation. Instruction is an elementary operation that the processor can accomplish. Instructions are stored in the main memory, waiting to be processed by the processor. An instruction has two fields:

- **Operation code**, which represents the action that the processor execute.
- **Operand code,** which defines the parameters of the action. The operand code depends on the operation. It can be data or a memory address.

Operation code	Operand code

There are different types of instructions.

a. Data Transfer Instructions
b. Data Processing Instructions
c. Program Control Instructions
d. Miscellaneous Instructions

a. Data Transfer Instructions

Most of the operations of the CPU are data transferring. These instructions are used when the data needs to be moved from memory location to register. These 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 some common data transfer instructions are MOV, LOAD and STORE.

- **MOVE (MOV)** instruction transfers data from a memory location to a register, register to memory and register to register. This is also used to obtain the data to perform a computation on it later, or to store the result of a computation.

  Example: MOV A, B (Move the contents of register A to B)
- **LOAD (LD)** instruction loads particular register contents from memory.

  Example: LD A (Load the data to register A from memory)
- **STORE (STO)** instruction stores information from register to memory location.

b. 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. Data manipulation instructions can be divided into three basic types, i.e. arithmetic, logical and shift instructions.

i. Arithmetic Instructions

The four basic operations are ADD, SUB, MUL and DIV. An arithmetic instruction may operate on fixed-point data, binary or decimal data. The other possible operations include a variety of single-operand instructions, for example ABSOLUTE, NEGATE, INCREMENT, DECREMENT.

The execution of arithmetic instructions requires bringing the operands in the operational registers so that the data can be processed by ALU. Such functionality is implemented generally within instruction execution steps.

ii. Logical Instructions

AND, OR, NOT, XOR operate on binary data stored in registers.

iii. Shift Instructions

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

c. Program Control Instructions

These instructions specify conditions for altering the sequence of program execution or in other words the content of PC (program counter) register. 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 like JMP (Jump) and LOOP.

- The **JMP** instruction jumps to begin the execution at another location.
- The **LOOP** instruction is used when number of statements are to be repeated.

3.2.2 Instruction Format

An instruction format defines the layout of the bits of an instruction. An instruction format must include an Op-code (Operation-Code) and zero or more Operands. The Op-code will always be present.

- Op-Code
- Operand

Op-Code field of an instruction 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.

Operand address field can be data, or can refer to data – i.e. address of data, or can be labels, which may be the address of an instruction to be executed next.

Different instruction formats are used. A few of them are explained below.

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

a. Zero Address Instruction

The Zero Address instruction format requires only op-code, having no operand to work with. Example of the Zero Address instruction format is HALT, STOP, which do not have any address.

0......................7 bits

Op-Code

Example: STOP

b. One Address Instruction

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

0 ....7, 8..........................20 bits

Op-Code	Operand

Example: JMP AX

c. Two Address Instruction

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

0....................7, 8..................19, 20.....................31 bits

Op-Code	Operand	Operand

Example: ADD A, B

3.2.3 Instruction Cycle

Instruction cycle (sometimes called fetch-and-execute cycle, fetch-decode-execute cycle) is the basic operation cycle of a computer. It is the process by which a computer retrieves a program instruction from its memory, determines what actions the instruction requires, and carries out those actions. This cycle is repeated continuously by the central processing unit (CPU), from booting of computer till it is shut down.

There are typically four stages of an instruction cycle that the CPU carries out:

a. **Fetch** the instruction from memory
b. **Decode** the instruction
c. **Execute** the instruction
d. **Store** the result

a. Fetch the instruction

The instruction is fetched from the memory address that is currently in the Program Counter (PC), and store it in the Instruction Register (IR).

b. Decode the instruction

The instruction decoder interprets the instruction. If the instruction has an indirect address, the effective address is read from main memory, and any

required data is fetched from main memory to be processed and then placed into data registers. During this phase the instruction inside the IR (instruction register) gets decoded.

c. Execute the instruction

The CU passes the decoded information as a sequence of control signals to the relevant function units of the CPU to perform the actions required by the instruction such as reading values from registers, passing them to the ALU to perform mathematical or logic functions on them, and writing the result back to a register.

d. Store results

The result generated by the operation is stored in the main memory, or sent to an output device. But this condition is not always required.

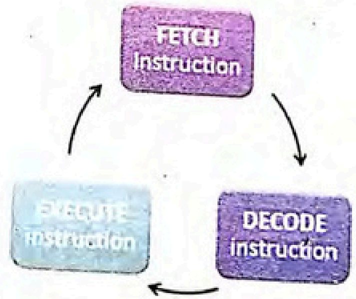


Figure 3.5 Instruction Cycle

3.2.4 CISC and RISC architecture

There are two major types of CPUs, which are classified according to the instruction set philosophy adopted by their designers. They are:

a. CISC (complex instruction set computer)
b. RISC (Reduced instruction set computer)

a. CISC (Complex Instruction Set Computer)

Complex Instruction Set Computer (CISC) is processor architecture. The instructions which the processor could execute were built into the chip. In common CISC chips are relatively slow per instruction. CISC have a large amount of different and complex instructions. CISC architecture was a bit complex because of the instructions used at the hardware level. The more complex the instruction set, the greater the overhead of decoding an instruction. CISC emphasizes on hardware. Examples of CISC processors are the Motorola 680x0 families and Intel 486 and Pentium series.

b. RISC (Reduced Instruction Set Computer)

Reduced Instruction Set Computer (RISC) is a microprocessor architecture that is designed to perform a smaller number of instructions. RISC architecture was developed around mid 1980 as a reaction to the CISC chips. It is designed to perform smaller number of instructions in order to operate on a higher speed. RISC has limited and simple instruction set. The simplicity of RISC allows more freedom to choose how to use the space on a microprocessor.

Larger set of instructions make the microprocessor more complicated and slower in operation. Operating System and application programmers will find it easier to work with smaller instruction set. One of the drawbacks of the RISC is that it puts a lot of burden on software due to its smaller size of instruction set. RISC emphasizes on software. Examples of RISC processor are IBM PowerPC, Sun SPARC and some mobiles.

3.2.5 Intel and AMD Processors

A processor controls every function in a computer. **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. Intel makes the **Core**, **Pentium** and **Celeron** families of processors, matched by the **Phenom**, **Athlon** and **Sempron** processors from AMD.

Difference between Intel P4 and AMD Athlon Processors

Pentium 4: The Pentium 4 brand refers to Intel's line of central processing units (CPUs) introduced in November 20, 2000. With Pentium 4, Intel introduced a new processor architecture known as NetBurst which featured a very deep instruction pipeline that helped these processors to achieve very high clock speeds (up to 3.8 GHz). The Pentium 4 line of processors contains both 32 bit and 64 bit processors. The typical speed of these processors ranges from 400 MHz to 1066 MHz.

AMD Athlon: Athlon is the brand name applied to a series of x86-compatible microprocessors designed and manufactured by Advanced Micro Devices (AMD). The original Athlon (now called Athlon Classic) was the first seventh generation x86 processor. Typical speed for these processors ranges from 1333 MHz to 2.33 GHz and their bus speed lies in between 100 and 200 MHz. The original Athlon processors were 32 bit and the later Athlon64 and 64 bit processors.

	Pentium 4	Athlon
Clock Speeds (MHz)	1300 – 3800	1333 – 2333
Front Side Bus Speeds (MHz)	400 – 1066	100 – 200
Cache Size (KB)	256 – 2048	64 – 512
Bus Width (bits)	32, 64	32, 64

SUMMARY

- Central processing unit (CPU) is the integral part of any computer system. It is the brain of computer system.
- Arithmetic logic unit is the main processing unit of CPU. It performs the arithmetic and logic operations on data.
- Control unit manages the functions performed by different parts of the computer. It coordinates and controls the computer system, just like the brain controls the human body.
- Registers are small memory devices available in the CPU. These are used to store data temporarily.
- Cache memory is the small amount of memory located between main memory and Processor. Cache memory is also known as high speed buffer or on chip memory.
- Bus is a subsystem that transfers data between computer components inside a computer.
- General purpose registers are used to store data as well as addresses.
- Accumulator is a general purpose register and is used by CPU for performing arithmetic and logic operations and to hold the result of those operations.
- The base register can perform arithmetic and data movement and it has some special addressing abilities.

- The counter register acts as a counter for repeating or looping instructions.
- Data register has a special role in multiply and divide operations. It works like a buffer and holds anything that is copied from the memory ready for the processor to use it.
- Special purpose registers are used to hold the state of a program. They include program counter, instruction register, memory address register and memory buffer registers.
- Instruction register is a part of control unit, which stores the instructions currently being executed.
- Memory address register holds the memory address, the memory address from which data will be provided to the CPU or will have the address to which data will be sent and then stored.
- Memory buffer register holds the contents of the memory which are to be moved from memory to other components or from components to the memory.
- Program counter is also known as instruction pointer, it is a processor register that holds either the address of the instruction being executed or the address of the next instruction to be executed.
- Data bus is the bidirectional bus. It can communicate in two ways, but in one direction at a time.
- Address bus carries addresses not data.

- The control bus is used by the CPU to direct and monitor the actions of the other functional areas of the computer.
- An instruction (or instruction code) is a group of bits that tells the computer to perform a specific operation.
- An instruction format defines the layout of the bits of an instruction. An instruction format must include an op-code (operation-code) and zero or more operands.
- Instruction cycle (sometimes called fetch-and-execute cycle, fetch-decode-execute cycle, or FDX) is the basic operation cycle of a computer.
- Complex Instruction Set Computer (CISC) is processor architecture.
- Reduced Instruction Set Computer (RISC) is a microprocessor that is designed to perform a smaller number of types of computer instructions.

EXERCISE

Q1. Select the best choice for the following MCQs.

i. Which of the following performs the arithmetic and logic operations on data?

A. ALU B. Control unit
C. Bus D. Memory unit

ii. ______________ coordinates and controls the computer system, just like the brain controls the human body.

A. Bus B. Control unit
C. Output unit D. Register

iii. Where are the logical operations performed in the CPU?

A. CU B. Register
C. ALU D. Memory

iv. ______________ is a small memory device available in the CPU to store data temporarily.

A. CU B. Register
C. ALU D. Memory

v. ______________is the small amount of memory located between main memory and Processor.

A. RAM B. ROM
C. Cache D. PROM

vi. Which of the following cache memories resides inside the microprocessor and is very fast from the other memories?

A. L1 cache B. L2 cache
C. L3 cache D. L4 cache

vii. ____________ Register can perform arithmetic and data movement and it has some special addressing abilities.

A. Base register B. Memory buffer register
C. Data register D. Counter register

viii. Which of the following register has a special role in multiply and divide operations?

A. Base register B. Memory buffer register
C. Data register D. Counter register

ix. ____________ register holds either the address of the instruction being executed or the address of the next instruction to be executed.

A. Program counter B. Memory buffer register
C. Data register D. Counter register

x. System bus connects the Central Processing Unit to ____________ on the motherboard.

A. Register B. Main memory
C. ALU D. Input unit

xi. Which of the following steps, in instruction cycle, interprets the instruction?

A. Fetch B. Decode
C. Execute D. Write-back

xii. __________ instruction is used when number of statements is to be repeated.

A. LD B. LOOP
C. JMP D. MOV

xiii. ____________ is a microprocessor architecture that is designed to perform a smaller number of types of computer instructions.

A. RISC B. CISC
C. DISK D. LIST

xiv. How many op-codes do a Zero-Address instruction has?

A. 1 B. 2
C. 3 D. 0

xv. Which of the following is not an arithmetic instruction?

A. DIV B. MUL
C. SUB D. JMP

Q2. Give short answers to the following questions.

i. What is the function of ALU in the computer?
ii. What is the function of control unit in the computer?
iii. What is a microprocessor?
iv. Define system bus.
v. Write short note on Memory Buffer Register (MBR).
vi. What is CPU operation?
vii. What is meant by an instruction?
viii. Differentiate between op-code and operand?
ix. Show computer instruction format with the help of a diagram and label its parts.
x. Differentiate between CISC and RISC processor architecture.

Q3. Give detailed answers to the following questions.

i. What is CPU? Describe basic components of CPU in detail.
ii. What is a register? Explain different types of registers.
iii. What is a system bus? Explain different types of buses used in computers.
iv. Explain different types of CPU instructions. Also give examples.
v. What is Instruction cycle? Explain different phases of CPU instruction cycle.