Hardware: Input, Processing, and Output Devices

Computer Systems

Hardware Components
Execution of an Instruction
Processing Characteristics and Functions
Physical Characteristics of CPU
Memory Characteristics and Functions
Computer Processing
Storage and Accessing Data from the Storage Devices
Computer Systems

As we have discussed before, a computer-based information system is a combination of hardware, software, database(s), telecommunications, people, and procedures – all organized to input, process, and output data and information.

Computer Hardware

Any machinery (most of which uses digital circuits) that assists in the input, processing, storage, and output activities of an information system.

Hardware Components

Computer system hardware components include devices that perform the functions of input, processing, data storage, and output.

The input device might be a keyboard, the output device might be a monitor, a communication device might be a modem, a secondary storage device might be disk drive, and the processing devices include central processing unit (CPU) and main memory.
The Central Processor

The central processor and its components handle all processing operations of the computer. It consists of two parts: the Central processing unit (CPU), and primary memory.

Central Processing Unit (CPU)

A hardware device that performs computing and manipulating functions, and controlling of other hardware devices. It utilizes three associated elements: the Arithmetic/Logic Unit (ALU), Control Unit, and Registers.

- **Arithmetic/Logic Unit (ALU):** Performs mathematical calculations (addition, subtraction, etc.) and makes logical (true/false) comparisons.

- **Control Unit:** Sequentially accesses program instructions, decodes them, and coordinates flow of data in/out of ALU, registers, primary and secondary storage, and various output devices.

- **Registers:** High-speed storage areas used to temporarily hold small units of program instructions and data that are being transferred from the primary storage to the CPU for processing.

Primary Storage (Main Memory)

It serves as a temporary storage area for data and program instruction for processing. Information must be transferred into the primary memory from the secondary storage devices.

During the program execution, data and instructions are transferred between the primary memory and register.
Execution of an Instruction

The execution of any machine-level instruction involves two phases: the instruction phase and the execution phase.

Instruction Phase

• Step 1: Fetch instruction: The instruction to be executed is accessed from the memory by the control unit.

• Step 2: Decode instruction: The instruction is decoded so the central processor can understand what is to be done, relevant data is moved from memory to the register area, and the location of the next instruction is identified.

Execution Phase

• Step3: Execute the Instruction: The ALU performs mathematical calculation or logical comparisons, if there are any.

• Step4: Store Results: The results are stored in registers or memory.

Instruction Time (I-time)

• Time it takes to perform the instruction phase is called instruction time.

Execution time (E-time)

• Time it takes to perform the execution phase of the instruction is called execution time.

Machine Cycle

• The instruction phase followed by the execution cycle is termed as machine cycle.
Processing Characteristics and Functions

The processing characteristics of a computer depends on factors such as machine cycle time, clock speed, and others.

**Machine Cycle Time**

- Time it takes to execute an instruction. It is the sum of the instruction time and the execution time. Machine cycle times are a very small fraction of a second.

- *Slow Computers*: Machine cycle times are in the microseconds (one-millionth of a second)

- *Fast Computers*: Machine cycle times are in the nanoseconds (one-billionth of a second) to picoseconds (one-trillionth of a second)

- *MIPS*: Machine cycle times can also be measured in terms of how many instructions are executed in a second. This is termed as MIPS (Millions of instructions per second).
Clock Speed

- Each CPU produces a series of electronic pulses at a predetermined rate, called the clock speed. It affects machine cycle time.

- Clock speed is often measured in Megahertz (MHz).

  Hertz (Hz): One clock cycle or pulse per second.
  Megahertz (MHz): Millions of clock cycles per second.

- The clock speed for personal computers can range from 200 MHz to 600 MHz or more.

- A machine cycle may take one or more clock cycles, depending on the type of instruction. Thus, there is no direct relationship between the clock speed and the processing speed.
Bit

- Data is moved within a computer system not in a continuous stream, but in groups of bits.

- A bit is a binary digit - 0 or 1, which means that a signal is either off or on.

Byte

- All numbers, characters, and special symbols are represented by an eight-bit binary string, and termed as a byte.
  Example: 1 = 00000001, 3=00000011, A=01000001, Z=01011010.


- All characters (1, 2, a, A, b, B, $, >, etc.) used in the computer are assigned a standard code understandable by most computer systems. It was developed by the American National Standard Institute (ANSI) and is used by a wide variety of computers.

Word (Wordlength)

- Number of bits the CPU can process at any one time is called a word. A CPU with a wordlength of 32 (called a 32-bit CPU) will process 32 bits of data in one machine cycle.
Bus lines

- Data is transferred from CPU to other system components via buslines, the physical wiring that connects the computer system components.

- Three kinds of buslines link the CPU, primary storage, and the other devices:
  1. The data bus moves data to and from primary storage.
  2. The address bus transmits signals for locating a given address in primary storage.
  3. The control bus transmits signals specifying whether to read or write data to or from a given primary storage address, input device, or output device.

- The number of bits a bus line can transfer at one time is known as bus line width. A bus line with a width of 32 will transfer a 32 bits of data at a time. Common wordlength and bus line widths are 32 and 64. Bus line width should be matched with CPU wordlength for optimal performance.
iCOMP index

- Machine cycle time, clock speed, wordlength, and bus line width – all affect the processor speed of the CPU. Thus comparing the speed of two different processors can be confusing.

- Intel, the world leader in chip manufacturer, introduced the Intel Comparative Microprocessor Performance Index (iCOMP).

- Thus a processor’s MHz rating may not be a direct measurement of its performance.

<table>
<thead>
<tr>
<th>Processor</th>
<th>iCOMP Index 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pentium 150 MHz</td>
<td>114</td>
</tr>
<tr>
<td>Pentium 166 MHz</td>
<td>127</td>
</tr>
<tr>
<td>Pentium 200 MHz</td>
<td>142</td>
</tr>
<tr>
<td>Pentium with MMX Technology 166 MHz</td>
<td>150</td>
</tr>
<tr>
<td>Pentium with MMX Technology 200 MHz</td>
<td>182</td>
</tr>
<tr>
<td>Pentium with MMX Technology 233 MHz</td>
<td>203</td>
</tr>
<tr>
<td>Pentium II 233 MHz</td>
<td>267</td>
</tr>
<tr>
<td>Pentium II 266 MHz</td>
<td>303</td>
</tr>
<tr>
<td>Pentium II 300 MHz</td>
<td>332</td>
</tr>
<tr>
<td>Pentium II 333 MHz</td>
<td>366</td>
</tr>
<tr>
<td>Pentium II 350 MHz</td>
<td>386</td>
</tr>
<tr>
<td>Pentium II 400 MHz</td>
<td>440</td>
</tr>
</tbody>
</table>
Physical Characteristics of the CPU

- CPU speed is also limited by physical constraints. Most CPUs are collections of digital circuits, imprinted on silicon (Si) wafers or chips.

- The size and material of the chips determine the electrical characteristics (resistance) of the chips. Reducing the size of the chips and changing the material to Gallium Arsenide (GaAs) may increase the performance of the processor.

Moore’s Law

- A hypothesis that states transistor densities in a single chip will double every 18 months.
CPU: RISC versus CISC

- CISC (Complex Instruction Set Computing) is used in Intel Pentium processors, which places as many microcode instructions to the CPU as possible.

- RISC (Reduced Instruction Set Computing) is faster than CISC, because it uses fewer number of steps for an instruction processing than a CISC processor. This reduces processing time and hence increasing computer speed.

- RISC is popular for network servers and technical workstations, which require high processing power.

- Digital Equipment’s Alpha chips and Sun Microsystems Sparc chips are RISC processors.

- Power PC by Motorola is another example, which is used in Apple Macintosh computers.
Memory Characteristics and Functions

Primary Storage (Main Memory)

- As it was mentioned before, memory is physically located close to the CPU (to reduce access time).

- Memory provides the CPU with a working storage area for program instructions and data.

- Primary storage has three main functions:
  1. It stores all or part of the program that is being executed.
  2. It also holds data that are being used by the program.
  3. It also stores the operating system programs that manage the operation of the computer.

- Primary memory is an integrated circuit composed of arrays of thousands of semiconductor transistors. Each transistor can be on or off representing either 1 or 0. Arrays of eight transistors make a memory location, which is equivalent to a byte. Thus, each location can hold a number, character, or symbol.

- Memory size is typically measured in megabyte (1 MB = one million byte). A primary memory of 128-256 MB is common nowadays.
**Types of Primary Memory**

Primary memory can be divided into volatile and nonvolatile memories. There are also several forms of primary memory: RAM, ROM, and Cache.

**Random Access Memory (RAM)**

- Temporary and volatile memory. It is called RAM because it can directly access any randomly chosen location.

- It is the primary and temporary storage area for program instructions and data. Contents are lost if current is turned off.

- RAM comes in many different varieties, Dynamic RAM (DRAM), Synchronous Dynamic RAM (SDRAM), and Extended Data Out RAM (EDO RAM).

- Having more memory helps computer run faster as more software can be loaded at the same time. A 128-256 MB of RAM is common nowadays.

**Read-Only Memory (ROM)**

- It is permanent and non-volatile memory. It can only be read from, but can not be written to.

- ROM provides permanent storage for data and instructions that do not change - like programs and data from the computer manufacturer.

- There are two subclasses of ROM chips: programmable read-only memory (PROM) and erasable read-only memory (EPROM).
Cache Memory

- It is volatile, high-speed memory that a processor can access more rapidly than main memory.

- Frequently used data is stored in easily accessible cache memory instead of slower memory like RAM. The CPU can thus execute instructions faster and overall performance of the computer increases.

### Different Types of Primary Memory

<table>
<thead>
<tr>
<th>Types of Primary Memory</th>
<th>Volatility</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAM (random access memory)</td>
<td>Volatile</td>
<td>Memory in which data and instructions are stored temporarily</td>
</tr>
<tr>
<td>ROM (read-only memory)</td>
<td>Nonvolatile</td>
<td>Memory in which some basic instructions are permanently stored</td>
</tr>
<tr>
<td>Cache memory</td>
<td>Volatile</td>
<td>Memory used to complement RAM. Speeds up retrieval of data and instructions</td>
</tr>
</tbody>
</table>
Computer Processing

All computers do not process data the same way. The speed of a computer can be increased by implementing few improved processing techniques.

Multiprocessing

• Simultaneous execution of two or more instructions at the same time, is termed as multi-processing.

• One form of multiprocessing involves coprocessors. Examples are, math coprocessor or graphic coprocessor. These processors speed up processing by performing specific functionality while the CPU works on another activity.

Parallel processing

• A form of multiproessing that speeds the processing by linking several processors to operate at the same time or in parallel. Accomplishing this difficult task requires software that can allocate, monitor, and control multiple processing jobs at the same time.
Secondary Storage

Storage and Accessing Data from the Storage Devices

Computer systems store data on secondary storage devices. Data can be arranged in several ways, and the arrangement determines the manner in which individual records can be accessed or retrieved.

Storage of Records

Records are stored in files in two different ways:

- **Sequential Storage**: In this method records are stored sequentially, as records are added one after another, in a file. Thus, the location of a record is in relation of another.

- **Direct or Random Storage**: In this method, records are stored randomly in a file. An internal key field is used to locate the physical address of the record.

Certain storage devices support only sequential data storage. These are termed *sequential storage devices*. Magnetic tape is an example.

Other devices, such as magnetic disks and optical disks, support both sequential and direct data storage. These are termed as *direct storage devices*. 
Accessing Records

Records may be accessed from files in three different ways.

- **Sequential Access:** Records are accessed sequentially as it is physically stored in the secondary storage device. Retrieval of records from a magnetic tape is only sequential, i.e., to access a record in the middle of a tape one has to read all records from the beginning of the tape.

- **Indexed Sequential Access Method (ISAM):** Although records may be stored sequentially on direct storage devices, individual records can be accessed directly without being passed over data in sequence. This method relied on an index of key fields to locate individual records. An index-table is created which lists the key fields of all records along with their physical locations on the disk. Thus searching for a record is only limited to the index-table. ISAM is faster than the sequential method.

- **Direct Access:** This method is used with direct file storage. This method uses a key field to locate the physical address of a record.

The process is accomplished using a transform algorithm, which performs some mathematical calculation on the record key, and the result is the record’s physical location.
Secondary Storage: RAID (Redundant Array of Independent Disks)

- RAID is a magnetic disk, like a hard disk in a PC.

- It combines many (6 to more than 100) small hard disk drives and their control microprocessors into a single unit.

- It provides large data capacity with high-speed access, as data are accessed in parallel over multiple paths from many disks.

- It offers multiple copies of data on several disks.

- Thus, if one disk fails, data can be automatically recovered from backup copies stored on other disks.

- It is becoming very popular in companies, for obvious reasons.
Types of Computers

Computer systems can range from handheld palms to supercomputers, as illustrated below. Depending on the type, their speeds, costs, uses, and weights are different.

<table>
<thead>
<tr>
<th>Type of computer</th>
<th>Typical Processor Speed</th>
<th>Weight</th>
<th>Cost</th>
<th>How Used</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handheld</td>
<td>&gt; 50 MHz</td>
<td>&lt; .5 lb</td>
<td>&lt; $500</td>
<td>Personal organizer</td>
<td>Palm</td>
</tr>
<tr>
<td>Notebook</td>
<td>&gt; 500 MHz</td>
<td>&lt; 4 lbs</td>
<td>&lt; $1000</td>
<td>Improvement of individual worker’s productivity</td>
<td>IBM</td>
</tr>
<tr>
<td>Laptop</td>
<td>&gt; 500 MHz</td>
<td>&lt; 7 lbs</td>
<td>&lt; $2000</td>
<td>Improvement of individual worker’s productivity</td>
<td>Apple iBook</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hewlett-Packard</td>
</tr>
<tr>
<td>Network</td>
<td>&gt; 200 MHz</td>
<td>&lt; 15 lbs</td>
<td>&lt; $750</td>
<td>Support for data entry and Internet connection</td>
<td>Oracle</td>
</tr>
<tr>
<td>Desktop</td>
<td>&gt; 800 MHz</td>
<td>&lt; 25 lbs</td>
<td>&lt; $2000</td>
<td>Improvement of individual worker’s productivity</td>
<td>Apple iMac</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dell</td>
</tr>
<tr>
<td>Workstation</td>
<td>&gt; 2 GHz</td>
<td>&lt; 30 lbs</td>
<td>$4000 - $40,000</td>
<td>Engineering, CAD, software development</td>
<td>Sun Microsystems</td>
</tr>
<tr>
<td>Midrange</td>
<td>&gt; 1 GHz</td>
<td>&gt; 50 lbs</td>
<td>$20,000 - $250,000</td>
<td>Computing for a department or small company</td>
<td>IBM AS/400</td>
</tr>
<tr>
<td>Mainframe</td>
<td>&gt; 300 MIPS</td>
<td>&gt; 200 lbs</td>
<td>&gt; $250,000</td>
<td>Computing for a large company</td>
<td>IBM Z/900</td>
</tr>
<tr>
<td>Supercomputer</td>
<td>&gt; 2 Teraflops</td>
<td>&gt; 200 lbs</td>
<td>&gt; $1,000,000</td>
<td>Scientific applications, marketing, customer support, product development</td>
<td>Compaq Terascale</td>
</tr>
</tbody>
</table>

Computers Used as Servers

Although there are various computers to be used for general-purpose tasks, some computers are used for specific purpose such as managing a network users or a Web server. Thus there is a mail server for managing e-mails of an organization, a network server for managing the network traffic, a Web server for managing web sites. A PC or a mainframe can work a server.