**Chapter 7**

**Memory and Storage Devices**

*Lesson 7.1:* Memory Basic

*Lesson 7.2:* Primary Memory

*Lesson 7.2:* Secondary Memory

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***Lesson 7.1***

***Memory Basics***

**7.1.0 Objectives**

*On completion of this lesson you will know:*

* *Classification of memories*
* *Characteristics of memory devices*
* *Memory hierarchy*

**7.1.1 Classification of Memory**

The term "memory" applies to any component capable of storing data temporarily. There are three main categories of memories as shown in Figure 7.1.1:

* **Internal processor memory**: Internal processor memory comprises of a small set of high-speed register used as a working memory for temporary storage of instructions and data. Some microprocessors also employ another type of build in memory called cache memory.
* **Primary memory:** Main memory or primary memory memorizes data temporarily while programs are running. It includes CPU registers, Cache and Random access memory (RAM).
* **Secondary memory:** Secondary memory stores information over the long term, including after the computer is turned off. Secondary memories are broadly divided into online storage, e.g., hard disk, and offline storage, e.g., optical storage devices such as CD-ROMs and DVD-ROMs.



***Figure 7.1.1: Different types of computer memories***

**7.1.2 Properties of Memory Devices**

The main characteristics of a memory are:

**Capacity**: Capacity representing the global volume of information (in bits) that the memory can store.

**Access time:** The amount of time that it takes for the memory to produce the required data from the start of the access until when the valid data is available for use is called the memory's access time, sometimes abbreviated as tAC. It is normally measured in nanoseconds (ns). Today's memory normally has access time ranging from 5 to 70 nanoseconds.

**Cost:** The cost of a memory unit is most significantly measured by the purchase price to the user. The price should include not only the cost of the information storage but also the cost of the peripheral equipment or access circuitry essential to the operation of the memory.

**Cycle time and Data transfer rate:** Cycle time represents the minimum time interval between two successive memory accesses operations. It is generally convenient to assume that cycle time is the time needed to complete any read or write operation in the memory. The maximum amount of information that can be transferred to or from the memory per unit time is called the data transfer rate

**Memory Bandwidth**: Memory bandwidth is the rate at which data can be read from or stored into a semiconductor memory by a processor. Memory bandwidth is usually expressed in units of bytes per second (Bps), though this can vary for systems with natural data sizes that are not a multiple of the commonly used 8-bit bytes.

**Non-volatility:** It characterizes the ability of a memory to store data when it is not being supplied with electricity.

**7.1.3 Memory Capacity**

Memory capacity is the number of 0s or 1s that a memory can hold. The following terms are used to denote memory capacity.

**Bit**: In binary system 0 or 1 is called a bit which is short for binary digit.

**Byte**: A group of eight bits (also called octet) is called a byte (B). It is the number of bits used to encode a character (e.g., A, a, etc) or digit (e.g., 0,1, etc) or some other special character (e.g., %, $, etc) in the computer. The capacity of a computer memory is expressed in number of bytes.

**Nibble**: A group of four bits (i.e. half a byte) is called a nibble. This unit is most often used in the context of hexadecimal number representations, since a nibble can store precisely one hexadecimal digit

Terms for large quantities of bits can be formed using the standard range of SI prefixes for powers of 10, e.g., kilo = 103 = 1000 (kilobit or Kbit), mega- = 106 = 1000000 (megabit or Mbit) and giga = 109 = 1000000000 (gigabit or Gbit). These prefixes are more often used for multiples of bytes, as in kilobyte (KB = 8000 bits), megabyte (1 MB = 8000000 bits), and gigabyte (1 GB = 8000000000 bits). Table 7.1.1 shows range of SI prefixes and corresponding binary meaning.

**Table 7.1.1** SI prefixes and corresponding binary meaning

|  |  |  |  |
| --- | --- | --- | --- |
| Symbol | Prefix | SI Meaning | Binary Meaning |
| K | kilo | 103 | 210 |
| M | mega | 106 | 220 |
| G | giga | 109 | 230 |
| T | tera | 1012 | 240 |
| P | peta | 1015 | 250 |
| E | exa | 1018 | 260 |
| Z | zetta | 1021 | 270 |

**7.1.4 Memory Hierarchies**

A variety of factors are considered to explore the hierarchy of memories. The main factors are: nature of connection between memory and processor, cost per bit, access time, and storage capacity. As a memory device gets larger, it tends to get slower. For example, cache memories are very fast but are also small and expensive. Secondary memory is inexpensive and large, but is slow. The memory hierarchy is a mechanism of comparing the cost and performance of the various places we can store data and instructions. Figure 7.1.2 provides a look at one possible form of the memory hierarchy.

|  |
| --- |
|  |

**Figure 7.2.2** Memory Hierarchy

At the top level of the memory hierarchy are the CPU's general purpose registers. The registers provide the fastest access to data on CPU. The register file is the smallest memory object in the memory hierarchy. It is virtually impossible to add more registers to CPU as registers are the most expensive memory locations.

Level 1 Cache system is the next highest performance subsystem in the memory hierarchy. On the 80x86 CPUs, the Level 1 Cache is provided on-chip by Intel and cannot be expanded. The size is usually quite small (typically between 4KB and 32KB), though much larger than the registers available on the CPU chip. The cost per byte of cache memory is much lower than that of the registers.

Level 2 Cache is present on some CPUs, e.g., Pentium II, III, and IV CPUs. On other CPUs it is the system designer's task to incorporate this cache. It is generally much larger (e.g., 256 or 512KB) than Level 1 Cache. On CPUs where Intel includes Level 2 Cache as part of the CPU package, the cache is not expandable. It is still lower cost than the Level 1 Cache. On systems where the Level 2 Cache is external, many system designers let the end user selects the cache size and upgrades the size.

Main memory subsystem is the general-purpose, relatively low-cost memory found in computer systems. Typically, this is DRAM or some similar inexpensive memory technology.

Most modern computer systems implement a virtual memory scheme that simulates main memory using storage on a disk drive. While disks are significantly slower than main memory, the cost per bit is also significantly lower. Therefore, it is far less expensive to keep some data on magnetic storage rather than in main memory. A virtual memory subsystem is responsible for transparently copying data between the disk and main memory as needed by a program.

**7.1.5 Key points**

* There are three main categories of memories, these are Internal processor memory, main memory and auxiliary memory.
* Internal processor memory comprises of a small set of high-speed register used as a working memory for temporary storage of instructions and data.
* Primary memory memorizes data temporarily while programs are running. Random access memory (RAM) is an example of main memory.
* Auxiliary memory stores information over the long term, including after the computer is turned off. Auxiliary memory corresponds to magnetic or optical storage.
* Capacity represents the global volume of information (in bits) that the memory can store.
* Access time corresponds to the time interval between the read/write request and the availability of the data.
* A byte represents 28 = 256 distinct values, such as the integers 0 to 255, or -128 to 127
* Memory bandwidth is the rate at which data can be read from or stored into a semiconductor memory by a processor.
* Non-volatility characterizes the ability of a memory to store data when it is not being supplied with electricity.
* A group of eight bits (also called octet) is called a byte (B). A group of four bits (i.e. half a byte) is called a nibble.
* The main factors are: nature of connection between memory and processor, cost per bit, access time, and storage capacity.
* Most modern computer systems implement a virtual memory scheme that simulates main memory using storage on a disk drive.

**7.1.6 Practice Set**

**Multiple Choice Questions**

1. Which one is fastest?
   1. Register
   2. Cache memory
   3. RAM
   4. Hard disk
2. Which one of the following is the example of online storage?
   1. Hard disk
   2. CD
   3. DVD
   4. None
3. Cycle time represents\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
   1. The maximum time interval between two successive memory access operations.
   2. The maximum time interval between two simultaneous memory access operations.
   3. The minimum time interval between two successive memory access operations.
   4. None of them
4. Cost/bit of a primary memory as compared to secondary memory is
   1. Low
   2. High
   3. Similar
   4. None of them

**Review Questions**

1. What do you understand by access time?
2. What do you understand by memory bandwidth?
3. Show the memory hierarchy by a diagram.
4. What are the categories of memory components of computer system?

**Analytical questions**

1. Describe the categories of computer memories with a diagram.
2. Describe the general physical properties of memory devices
3. Describe the memory hierarchy with a diagram.

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***Lesson 7.2***

***Main Memory and ROM***

**7.2.0 Objectives**

*On completion of this lesson you will know:*

* *Permanent and programmable memories*
* *ROM and RAM characteristics.*
* *Different types of Memory cards*

**7.2.1 Random Access Memory (RAM)**

Random access memory (RAM) is the main memory of a system. It allows space to temporarily store data when a program is running. Unlike data storage on an auxiliary memory such as a hard drive, RAM is volatile, meaning that it only stores data as long as it supplied with electricity. Thus each time the computer is turned off, all the data in the memory are irremediably erased. There are generally two broad categories of random access memory:

* **SRAM:** Static Random Access Module (SRAM) is faster and more reliable than DRAM. SRAM memories are used in particular for the processor's cache memory. It is also more expensive than DRAM.
* **DRAM:** Dynamic Random Access Memory (DRAM) is the main system memory used in home and office PCs, being cheaper and more common than SRAM. DRAM must have an electric current to maintain electrical state (refresh).

Table 7.2.1 shows distinguish between SRAM and DRAM

**Table 7.2.1:** Comparison between SRAM and DRAM

|  |  |  |
| --- | --- | --- |
| Features | SRAM | DRAM |
| Stands for | Static Random Assessable Memory | Dynamic Random Assessable Memory |
| Speed | SRAM is faster compared to DRAM | DRAM is slower compared to SRAM |
| Access time | SRAM can give access times as low as 10 nanoseconds | DRAM supports access times of about 60 nanoseconds |
| Power consumption | consumes high power | consumes relatively less power |
| Transistors/bit of memory | It uses more transistors per bit of memory compared to DRAM | It uses fewer transistors per bit of memory. |
| Cost | Expensive | Cheaper |
| Use | Cache memory | Main memory |
| Refreshing | SRAM does not need to be refreshed | DRAM needs to be refreshed thousands of times per second |

**7.2.2 Different Types of RAM Module**

There are different types of SRAM, these are

* ***Async SRAM***: Asynchronous SRAM is an older type of SRAM. It is asynchronous, that is, it works independently of the system clock.
* ***Sync SRAM***: Sync SRAM is synchronized with the system clock, and increased speed.
* ***Pipeline Burst SRAM***: Pipeline Burst SRAM is the most common type of SRAM. It is able to operate at bus speeds higher than 66MHz.

There are different types of DRAM, these are

* ***FPM DRAM*** - Fast Page Mode DRAM (FPM DRAM) is only slightly faster than regular DRAM. This used to be the main type of memory used in PCs but was eventually replaced by EDO RAM, due to its slow speed. FPM DRAM, is now considered to be obsolete. It was mainly used in the older 386 and 486 computers. It is not suitable for memory buses over 66 MHz.
* ***EDO DRAM*** - Extended Data Out DRAM (EDO DRAM) provided a better performance increase over FPM DRAM. EDO RAM cannot operate on a bus speed faster than 66MHz. With a need for speed, BEDO DRAM was introduced.
* ***BEDO DRAM*** - Burst EDO DRAM (Burst EDO DRAM) is a type of EDO DRAM that can process four memory addresses in one burst. BEDO DRAM can only stay synchronized with the CPU clock for short periods (bursts).  It is faster than it's predecessor, EDO DRAM.
* ***SDRAM*** - Synchronous DRAM (DRAM), a type of DRAM that can run at much higher clock speeds than conventional memory. SDRAM actually synchronizes itself with the CPU's bus. SDRAM is the new memory standard for modern PCs.
* ***RDRAM*** - Rambus DRAM (RDRAM), a type of memory (DRAM) developed by Rambus, Inc. Whereas the fastest current memory technologies used by PCs (SDRAM) can deliver data at a maximum speed of about 100 MHz, RDRAM transfers data at up to 800 MHz. RDRAM (and DDR-SDRAM) are the two technologies expected to replace SDRAM.
* ***DDR SDRAM*** : Short for Double Data Rate-Synchronous DRAM, a type of SDRAM that supports data transfers on both edges of each clock cycle (the rising and falling edges), effectively doubling the memory chip's data throughput. DDR-SDRAM also consumes less power, which makes it well-suited to notebook computers. DDR-SDRAM is also called SDRAM II. and DDRAM. DDR-SDRAM and RDRAM are the two technologies expected to replace SDRAM.
* ***DDR2 SDRAM***: DDR2 SDRAM is the next step up from DDR SDRAM. DDR2 SDRAM offers new features and functions that enable higher clock and data rate operations. DDR2 transfers 64 bits of data twice every clock cycle. DDR2 SDRAM memory is not compatible with current DDR SDRAM memory slots.

**7.2.3 Cache Memory**

Cache memory is local memory that reduces waiting times for information from the random access memory (RAM). The main memory of a micro-computer main memory is slower than that of the processor. However, there are different types of memory that are much faster, but which have a greatly increased cost. Thus, the solution is to include this type of local memory close to the processor and to temporarily store the primary data to be processed in it. Recent micro-computers have many different levels of cache memory:

* Level-one cache (L1 Cache) memory: It is directly integrated into the processor. It is subdivided into two parts:
  + The first part is the instruction cache, which contains instructions from the RAM that have been decoded.
  + The second part is the data cache, which contains data from the RAM and data recently used during processor operations.

L1 caches can be accessed very rapidly. Access waiting time approaches that of internal processor registers.

* Level-two cache (L2 Cache) memory: The level two caches is an intermediary between the processor, with its internal cache, and the RAM. It can be accessed more rapidly than the RAM, but less rapidly than the level one cache.
* Level-three cache (L3 Cache) memory: It is located on the motherboard.

All these levels of cache reduce the latency time of various memory types when processing or transferring information. While the processor works, the level one cache controller can interface with the level two controllers to transfer information without impeding the processor. As well, the L2 cache interfaces with the RAM (L3 cache) to allow transfers without impeding normal processor operation. Figure 7.2.1 shows how CPU access main memory through cache memory.



Figure 7.2.1: Cache and Main memory

**7.2.4 Read Only Memory**

Read-only memory (ROM) is used for storing programs and data permanently. Data and programs required for some applications are permanently stored in the ROM chip. Thus a user may read a program or data from ROM but may not read on it. The content of ROM is not altered when power is removed from the computer. It is therefore referred to a non-volatile memory. ROM is generally used to store programs, routines and language interpreters for immediate access by the user of the system. Such a program usually supplied by the manufacturer is referred to as firmware. This type of memory stores the data needed to start up the computer. Indeed, this information cannot be stored on the hard disk since the disk parameters are part of these data which are essential for booting.   
Different ROM-type memories contain these essential start-up data, i.e.:

* The BIOS is a programme for controlling the system's main input-output interfaces, hence the name BIOS ROM which is sometimes given to the ROM chip of the mother board.
* The bootstrap loader is a programme for loading (random access) memory into the operating system and launching it from the floppy drive, hard dish or flash drive.
* The CMOS setup is the screen displayed when the computer starts up and which is used to amend the system parameters (often wrongly referred to as BIOS).
* The Power-On Self Test (POST) is a programme that runs automatically when the system is booted, thus allowing the system to be tested.

Given that ROM are much slower than RAM memories (access time for a ROM is around 150 ns whereas for SDRAM it is around 10 ns), the instructions given in the ROM are sometimes copied to the RAM at start-up; this is known as shadowing, and is usually referred to as shadow memory.

**7.2.5 Different Types of ROM:**

ROM memories have gradually evolved from fixed read-only memories to memories than can be programmed and then re-programmed. The first ROMs were made using a procedure that directly writes the binary data in a silicon plate using a mask. This procedure is now obsolete.

**PROM:** Programmable Read Only Memory (PROM) was developed at the end of the 1970 by Texas Instruments of USA. They are chip that can be "burnt" using a device called a "ROM programmer", applying high voltage (12V) to the memory boxes. PROMs are black chips which have nothing recorded on them. The PROM chip permanently stores the information like ROM once data are recorded into the chip by a special programming device. The programming of the PROM chip is generally done by the manufacturer of the computer systems. PROMs are used primarily to provide special purpose programs that can be plugged into the main computer board.

**EPROM: Erasable** Programmable Read Only Memory (EPROM) is PROM that can be erased. These chips have a glass panel that allows ultra-violet rays to pass through. When the chip is subjected to ultra-violet rays with a certain wavelength, the fuses are reconstituted, meaning that all the memory bits return to 1. This is why this type of PROM is called erasable.

**EEPROM:** Electrically Erasable Read Only Memory **(**EEPROM) is also erasable PROMs, but unlike EPROMs, they can be erased by a simple electric current, meaning that they can be erased even when they are in position in the computer.

**Flash ROM:** Flash ROM is also called Flash EPROM. Unlike the classic EEPROMs that use 2 to 3 transistors for each bit to be memorized, the EPROM Flash uses only one transistor. Moreover, the EEPROM may be written and read word by word, while the Flash can be erased only in pages.

Lastly, the Flash memory is denser, meaning that chips containing several hundred mega octets can be produced. EEPROMs are thus used preferably to memorize configuration data and the Flash memory is used for programmable code.  Table 7.2.2 shows differences between RAM and ROM

***Table 7.2.2: Differences between RAM and ROM***

|  |  |  |
| --- | --- | --- |
| Features | RAM | ROM |
| Stands for | Random Access Memory | Read-Only Memory |
| Read/write | RAM is used for read and write operation. | ROM is used for reading only. It can be written once and read many times. |
| Speed | RAM is generally faster than ROM. | ROM, is generally slower than RAM. |
| Storing | RAM is the temporal workspace for microcomputer. | ROM is a storage device that stores information about the operating system. |
| Volatile and non-volatile | RAM is volatile because data is lost when power goes. | ROM is non-volatile i.e. written information stored permanently even after power goes. |

**7.2.6 Solid State Storage Devices**

**Flash Memory**

Flash memory is a kind of semiconductor-based, non-volatile, rewritable computer memory; that is, it has many of the same characteristics as RAM, except that the data is not wiped out when the machine is turned off. Flash memory stores bits of data in memory cells, but the data remains saved even when electrical power is cut.

Due to its higher speed, durability, and low energy consumption, flash memory is ideal for many applications, such as digital cameras, mobile phones, printers, PDAs, laptop computers, and device that can record and play back sound, such as mp3 players.

**Memory cards**

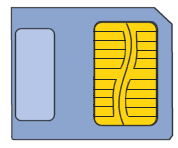
There are many competing, incompatible memory card formats, almost one for every manufacturer. Among these formats of memory cards, the most common are: secure digital cards, memory stick; smart media; MMC; xD picture card etc.

**Secure Digital:** Secure Digital (SD) memory or SD Card is a type of memory card created by Matsushita Electronic, SanDisk and Toshiba in 2000. SD memory is a memory specifically developed to meet new safety requirements in the field of electronic audio and video devices. It therefore includes a copyright protection system that satisfies the SDMI (Secure Digital Music Initiative) standard. The architecture of the SD cards is based on NAND-type flash memory circuits (EEPROM). The SD memory has small dimensions, equivalent to those of postage stamp.

**Memory Stick:** The Memory Stick (MS) or MS Card is a type of memory card created jointly by Sony and SanDisk in 2000.  The architecture of Memory Stick cards is based on NAND flash memory circuits (EEPROM).

|  |  |
| --- | --- |
| SD Card - Secure Digital  ***Figure 7.2.3 : Secure Digital (SD) memory card*** | MS Card - Memory Stick  ***Figure 7.2.4 : The Memory Stick (MS) card*** |

**Smart Media**: Smart Media memory is a type of memory card created by Toshiba and Samsung. Its architecture is based on NAND type flash memory circuits (EEPROM) SmartMedia memory is equivalent in size to a postal stamp as shown in Figure 7.2.4

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***Figure 7.2.5: Smart Media Card***

**MMC**: Multimedia memory card (MMC) is a type of memory card created jointly by SanDisk and Siemens in 1997. Its architecture is based on a combination of read-only memory (ROM) for read-only applications and flash memory for read/write purposes. Multimedia cards are very small which is equivalent to the size of a postage stamp. Figure 7.2.6 shows MMC card.

|  |  |
| --- | --- |
| MMC Card - Multimedia Card  ***Figure 7.2.6: Multimedia memory card*** | xD picture card  ***Figure 7.2.7: xD Picture memory card*** |

**xD Picture card**: eXtreme Digital (xD) Picture memory is a type of memory card created by Fuji and Olympus in 2002 as shown in Figure 7.2.7.  The architecture of xD cards is based on NAND type flash memory circuits (EEPROM). It is smaller in size than a postal stamp. Access to the data is carried out via a lateral connector with 18 pins, allowing a transfer rate of 1.3 Mbps to be reached and potentially up to 3 Mbps for writing and around 5 Mbps for reading. 16, 32 and 64 GB xD picture cards are available in market.

**7.2.7 Key points**

* Random access memory (RAM) is the main memory of a system.
* DRAM memories (stands for Dynamic Random Access Module), which are inexpensive. They are used essentially for the computer's main memory.
* SRAM memories (stands Static Random Access Module), which are fast and costly. SRAM memories are used in particular for the processor's cache memory
* DRAM is a memory whose transistors are arranged in a matrix in rows and columns.
* DRAM Fast Page Mode uses a technique called paging to speed up access to the DRAM.
* DDR2-SDRAM achieves speeds that are twice as high as those of the DDR with the same external frequency.
* Cache memory is local memory that reduces waiting times for information stored in the random access memory (RAM).
* ROM  is sometimes called non-volatile memory as it is not erased when the system is switched off.
* PROM chips permanently stores the information like ROM.
* EPROM memories are PROMs that can be erased.
* The action involving reprogramming of an EEPROM is known as flashing.
* The access times of flash memories are longer than the access times of RAM.
* Flash memory is a kind of semiconductor-based, non-volatile, rewritable computer memory.
* The most common memory cards are Compact Flash; Secure Digital cards (called SD Card); Memory Stick; Smart Media; MMC (MultimediaCard); xD picture card.
* SD memory is a memory specifically developed to meet new safety requirements in the field of electronic audio and video devices.
* MMC architecture is based on a combination of read-only memory (ROM) for read-only applications and flash memory for read/write purposes.
* The architecture of xD cards is based on NAND type flash memory circuits (EEPROM).

**7.2.7 Practice Set**

**Multiple Choice Questions**

1. \_\_\_\_\_\_\_\_\_\_\_\_ are used in particular for the processor's cache memory.
   1. SRAM
   2. DRAM
   3. ERAM
   4. XRAM
2. \_\_\_\_\_\_\_\_\_\_\_\_\_achieves speeds that are twice as high as those of the DDR with the same external frequency.
   1. DDR2-SDRAM
   2. DDR1-SDRAM
   3. DDR0-SDRAM
   4. None of them

**Review Questions**

1. Define SRAM and DRAM.
2. What do you understand by volatily?
3. What are L-1, L-2 and L-3 Caches?
4. Name different types of memory cards.

**Analytical questions**

1. What are the different types of RAM module, explain any two in details.
2. Distinguish between SRAM and DRAM.
3. What is ROM? Why it is necessary?
4. Distinguish between RAM and ROM.
5. Explain different types of ROM.

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***Lesson 7.3***

***Secondary Memory***

**7.2.0 Objectives**

*On completion of this lesson you will know:*

* *Importance of secondary storage.*
* *Magnetic storage devices*
* *Optical storage devices*
* *USB device and its features*

**7.3.1 Secondary Memory**

Auxiliary memory (also called physical memory or external memory) that stores information over the long term, after the computer is turned off. Auxiliary memory corresponds to magnetic storage devices such as the hard drive, optical storage devices such as CD-ROMs and DVD-ROMs, as well as read-only memories (ROM). As compared to primary memory it is slow, less costly and possesses high capacity. The data transfer between the secondary storage and RAM are measured in milliseconds.

**7.3.2 Magnetic Storage Devices**

**Floppy Disk:** A floppy disk (or diskette) is a form of magnetic data storage. It is thin, flexible, soft, flat piece of mylar plastic, packaged in a 3.5 inch plastic case. Floppy disks were invented by IBM and were a popular form of data storage from the 1970's to the 1990's. The key to their widespread use was low cost and ease of portability. Information could be transferred to a floppy disk, stored, disk removed, then inserted into another system to then be accessed. Floppy disks are obsolete now.

**Zip Drive**: Zip drive uses zip disks which are cartridges similar to floppy disks but capable of storing 70-500 times more memory. Zip disks are disks with a special high quality magnetic coating that have a capacity of 100, 250, or 750 MB. Zip drives are almost obsolete as CDs or memory sticks are much more convenient since they can be read by almost all computers.

**7.3.3 Hard drive**

The hard drive is the component which is used to permanently store data. Thus the term mass storage device is sometimes used to refer to hard drives. The hard drive is connected to the motherboard using a hard drive controller which acts as an interface between the processor and the hard drive. The hard drive controller manages the drives linked to it, interprets commands sent by the processor and routes them to the drive in question. Hard drives are generally grouped by interface as: IDE/ATA; Serial ATA; SCSI; Serial ATA and USB. When the USB standard appeared, external cases which could connect a hard drive using a USB port were released, making hard drives easy to install and increasing storage capacity for backups. These are called external hard drives.

A hard disk includes one or more platters mounted on a central spindle, like a stack of rigid diskettes as shown in Figure 7.3.1. Each platter is covered with a magnetic coating and the entire arrangement is encased in a sealed chamber. The disks turn very quickly in a counter-clockwise direction. Hard drives hold millions of bits and they are read/written using read heads located on both sides of the platters. These heads are electromagnets which raise and lower themselves in order to read or write data. The read heads are only a few microns from the surface, separated by a layer of air created by the rotation of the disks, which generates a wind of about 250km/h. However, the heads are linked to one another and only one of them can read or write at a given moment. The term cylinder is used to refer to all the data stored vertically on each of the disks. This entire precision mechanism is contained within a fully airtight case, as the smallest particle can degrade the disk's surface.



***Figure: 7.3.1: Internal diagram of a hard disk***

The read/write heads are inductive and generates a magnetic field. This is especially important in writing: The heads polarize the disk surface in a very tiny area. During reading, the polarity reversal completes a circuit with the read head. It is then transformed by an analog-digital converter (ADC) into a 0 or 1 which can be understood by the computer.

The heads start writing data from the edge of the disk (track 0), then move onward towards the centre. The data is organized in concentric circles called "tracks", which are created by low-level formatting. The tracks are separated into areas (between two radii) called sectors, containing data (generally at least 512 octets per sector). Sectors are wider at the edge then they are near the middle.



***Figure 7.3.2: Track and Sector***

Finally, the term clusters (also called allocation units) refers to minimum area that a file can take up on the hard drive. An operating system uses blocks, which are in fact groups of sectors (between 1 and 16 sectors). A small file may occupy multiple sectors (a cluster).

**7.3.4 CD, CD audio and CD-ROM**

The Compact Disc (CD) was invented by Sony and Philips in 1981 to serve as a high-quality compact audio storage device which allowed for direct access to digital sound tracks. The Compact Disc's specifications were extended so that it could store digital data.

A CD is an optical disc of 12 cm in diameter and 1.2 mm in thick for storing digital information up to 650 MB. The diameter of the circular hole is 15mm.

A CD is built from a plastic (polycarbonate) substrate and a fine, reflective metallic film as shown in Figure 7.3.3. The reflective layer is then covered with an anti-UV acrylic finish, creating a protective surface for data. Finally, an additional layer may be added so that data can be written on the other side of the CD as well. The reflective layer contains tiny bumps as shown in Figure 7.3.3. When the laser passes over the polycarbonate substrate, light is reflected off the reflective surface, but when the laser reaches a bump, that's what allows it to encode information.

In contrast to a purchased CD, a blank CD has an additional layer made of a dye. It absorbs or reflects the beam of light emitted by the LASER.



***Figure 7.3.3: Different layers in a CD***

The read head is made of a LASER which emits a beam of light, and a photoelectric cell which captures the reflected beam as shown in Figure 7.3.4. CD players use an infrared LASER with a wavelength of 780 nm, as it is compact and inexpensive. A lens located near the CD focuses the laser beam onto the pits. A semi-reflective mirror allows the reflected light to strike the photoelectric cell, as shown in the following diagram:



***Figure 7.3.4 Operation of a CD***

Using CD rewriteable (CD-RW), data can be written or rewritten on special CD-RW disc. It will not play on every CD-ROM drive.

**7.3.5 Digital Versatile Disc (DVD)**

The Digital Versatile Disc (DVD) is an alternative to CD with six times much storage space. The DVD format was designed to provide a universal storage medium. DVDs are commonly used as a medium for digital representation of movies and other multimedia presentations that combine sound with graphics. It has complex structure which provides greater interactivity, but requires more advanced microprocessors. The DVD specification supports disks with capacities of from 4.7GB to 17GB and access rates of 600KBps to 1.3 [MBps](http://www.webopedia.com/TERM/M/MBps.html). One of the best features of DVD drives is that they are backward-compatible with CD-ROMs, meaning they can play old CD-R and [DVD-ROMs](http://www.webopedia.com/TERM/D/DVD_ROM.html). Newer DVD players can also read CD-R disks.

A DVD burners use a red laser with a wavelength of 635 nm or 650 nm. The main reason to use DVDs is their storage capacity, which makes them an excellent medium for video. A DVD can store more than two hours of compressed video in MPEG-2 (Motion Picture Experts Group), a format used for compressing images while still keeping them high-quality. DVDs exist in both "single layer" and "dual layer" versions. Dual layer discs are made up of a translucent, gold-based semi-reflective layer and an opaque, silver-based reflective layer, separated by a bonding layer. In order to read both these layers, the drive has a layer which can change its intensity by modifying its frequency and focus with:

* low intensity the beam is reflected off the outer gold surface;
* higher intensity, the beam passes through the first layer is reflected off the inner silver surface.

The inner layer, however, has a lower density. Additionally, it stores the information "upside down" on an inverted spiral, in order to limit latency when moving from one layer to the other.

***DVD-R/DVD+R***: DVD-Recordable (DVD-R) or DVD+Recordable (DVD+R) is a recordable DVD format similar to CD-R. A DVD-R or DVD+R can only record data once and then the data becomes permanent on the disc. The disc cannot be recorded onto a second time.

***DVD-RW/DVD+RW***: DVD-ReWritable (DVD-RW) or DVD+ReWritable (DVD+RW) is a re-recordable DVD format similar to CD-RW or DVD+RW. The data on a DVD-RW or DVD+RW disc can be erased and recorded over numerous times without damaging the medium.

***Blu-ray*:** An [HD-DVD](http://www.webopedia.com/TERM/H/HD_DVD.html) format that uses a 405[nm](http://www.webopedia.com/TERM/N/nanotechnology.html)-wavelength Blue-violet laser technology, in contrast to the 650nm-wavelength red laser technology used in traditional [DVD](http://www.webopedia.com/TERM/D/DVD.html) formats. The rewritable Blu-ray disc, with a data transfer rate of 36[Mbps](http://www.webopedia.com/TERM/M/mbps.html), can hold up to 27[GB](http://www.webopedia.com/TERM/G/GB.html) of data on a single-sided single layer disc, which amounts to about 12 hours of standard video or more than 2 hours of high-definition video. Blu-ray format was developed jointly by Sony, Samsung, Sharp, Thomson, Hitachi, Matsushita, Pioneer, Philips, Mistubishi and LG Electronics.

**7.3.6 USB Key**

A USB key is a compact-format removable storage device which can be plugged into a computer's USB port. A USB key is a plastic shell carrying a USB connector and flash memory, a solid-state, non-volatile, rewritable kind of memory; that is, it has many of the same characteristics as RAM, except that the data is not wiped out when the machine is turned off. For this reason, a USB key can store up to several gigabytes of data, and keep the data saved when electrical power is cut off. In practice, a USB key is very practical for users who go from one computer to another, as it is very easy to transport and can store a large quantity of documents and data. The features to take into account when choosing a USB key are:

* ***Storage capacity***: storage capacity is up to more than 64 GB
* ***Transfer rate***: This is the speed at which data is transferred. It should be noted that the transfer rate when reading is different from the transfer rate when writing, as the process of writing to flash memory is slower. The transfer rate depends on the read speed and writes speed of the Flash memory component, as well as the USB standard supported: USB 1.1 (low-speed USB), can reach 12 Mbps; USB 2.0 (high-speed USB) can reach 480 Mbps.
* ***Encryption features***: Some keys have tools for encrypting data or some of the data found on the key, in order to strengthen privacy.
* ***Write protection***: Some keys include a hardware switch for putting the key in read-only mode, to prevent data from being changed or erased.
* ***Multimedia functions***: When a USB key includes a headphone jack and can play audio files, it is called an MP3 player.

**7.3.7 Network-attached Storage:**

A network-attached storage (NAS) device is a [server](http://www.webopedia.com/TERM/S/server.html) that is dedicated to nothing more than file sharing. It allows more [hard disk](http://www.webopedia.com/TERM/H/hard_disk.html) storage space to be added to a [network](http://www.webopedia.com/TERM/N/network.html) that already utilizes servers without shutting them down for maintenance and upgrades. A NAS device delivers the data to the user and does not need to be located within the server but can exist anywhere in a [LAN](http://www.webopedia.com/TERM/L/local_area_network_LAN.html). It can be made up of multiple networked NAS devices.

**7.3.8 Key points**

* Auxiliary memory (also called physical memory or external memory) that stores information over the long term after the computer is turned off.
* A floppy disk (or diskette) is a form of magnetic data storage. It is thin, flexible, soft, flat piece of mylar plastic, packaged in a 3.5 inch plastic case.
* Zip drives use zip disks which are are cartridges similar to floppy disks but capable of storing 70-500 times more memory.
* The hard drive is the component which is used to permanently store data. Thus the term mass storage device is sometimes used to refer to hard drives.
* Hard drives are generally grouped by interface as: IDE/ATA; Serial ATA; SCSI; Serial ATA and USB.
* The read/write heads are inductive and generate a magnetic field.
* The term clusters (also called allocation units) refer to minimum area that a file can take up on the hard drive.
* The Compact Disc was invented by Sony and Philips in 1981 in order to serve as a high-quality compact audio storage device which allowed for direct access to digital sound tracks.
* The DVD is an alternative to the compact disc (CD) with six times as much storage space.
* An [HD-DVD](http://www.webopedia.com/TERM/H/HD_DVD.html) format that uses a 405[nm](http://www.webopedia.com/TERM/N/nanotechnology.html)-wavelength blue-violet laser technology, in contrast to the 650nm-wavelength red laser technology used in traditional [DVD](http://www.webopedia.com/TERM/D/DVD.html) formats.
* A USB key is a compact-format removable storage device which can be plugged into a computer's USB port.

**7.2.9 Practice Set**

**Multiple Choice Questions**

1. Zip drives use zips disks which are cartridges similar to floppy disks but \_\_\_\_\_\_\_\_.
   1. capable of reducing size
   2. capable of storing 70-500 times more memory
   3. capable of storing 2 times more memory
   4. none
2. Hard drives are generally grouped by interface as\_\_\_\_\_\_\_\_\_ .
   1. IDE/ATA, Serial ATA and USB
   2. Serial ATA
   3. SCSI and USB
   4. All of them
3. DVD is an alternative to CD \_\_\_\_\_\_\_\_\_ .
   1. with six times less storage space
   2. with six times much storage space
   3. with three times much storage space
   4. none of the above

**Review Questions**

1. What are floppy and zip drive?
2. How can a hard disk be connected to computer motherboard?
3. What are track and sector?
4. Name the different layer of a black CD.
5. Distinguish between DVD and CD.
6. What is Blu-ray?

**Analytical questions**

1. Distinguish between Floppy disk and Zip drive.
2. Write down the construction and working principle of a hard disk.
3. Explain the construction and working principle of a CD.
4. Different types of DVD disc, their characteristics and storage capacities.
5. Explain working principle of DVD-R/RW
6. Write short note on Blu-ray and USB key.