UNIT-3 MEMORY UNIT

UNIT STRUCTURE

3.1 LEARNING OBJECTIVES

After going through this unit, you will be able to :

- learn about main memory
- describe the role of RAM, ROM and their types
- learn the concept of locality of reference
- learn about cache and virtual memory
- describe different types of mapping techniques
- decribe the mechanism of paging
- illustrate the organization of data in magnetic disks as well as magnetic tapes
- learn about RAID technology
- describe the technology of optical memory

3.2 INTRODUCTION

In the previous unit, we have learnt about the peripheral devices associated with a computer system and various techniques with the help of which data transfers between the main memory and the input-output devices takes place.

In this unit we shall discuss about various types of memory associated with a computer system including main memory, cache and virtual memory and various technology associated with these memory units. Finally, we conclude the unit discussing the concept of secondary memory along with their types.

3.3 MEMORY HIERARCHY

The computer stores the programs and the data in its memory unit. The CPU fetches the instructions out of the memory unit to execute and process them.

Memory can be primary (or main) memory and secondary (or auxiliary) memory. Main memory stores programs and data currently executed by the CPU of a computer. Auxiliary memory provides backup storage of information. Data as well as instructions are transferred from the secondary memory to the main memory whenever it is needed by the CPU.

The capacity of the memory is typically expressed in terms of bytes or words (1 byte = 8 bits). Word lengths are commonly 8 bits, 16 bits and 32 bits. The size of a word is generally the number of bits that are transferred at a time between the main memory and the CPU.

Memory has different locations, which are called its addresses, to store the data. There are different methods for accessing those address locations such as ***sequential access***, direct access and ***random access***.

- In ***Sequential access*** method, the records or the data are accessed in a linear fashion, from its current location in the memory to the desired location moving through each and every record in the memory unit. For example , in case of the magnetic tapes this method is used.

- In ***Direct Access***, each record has different addresses based on the physical location of the memory and the shared Read/ Write head moves directly to the desired record. This method is used in magnetic disks.

- In ***Random access*** each location can be randomly selected and accessed directly. Main memory can be randomly accessed.

Memory has two basic operations: *Read* and *Write* operations. In Read operation, the processor reads data from a particular memory location and transmits that data to the requesting device via bus. On the other hand, a memory Write operation causes the memory to accept data from a bus and to write that particular information in a memory location.

Regarding the speed of the memory, there are two useful measures of the speed of memory units : *Memory Access Time* and *Memory Cycle Time*.

Memory Access Time is the time between the initiation of a memory operation and the completion of that operation. Memory Cycle Time is the minimum time delay that is required between the initiation of two successive memory operations, for example between two successive memory read operations.

The computer system has a memory hierarchy consisting of the storage devices in it. A typical memory hierarchy is illustrated in the figure below :

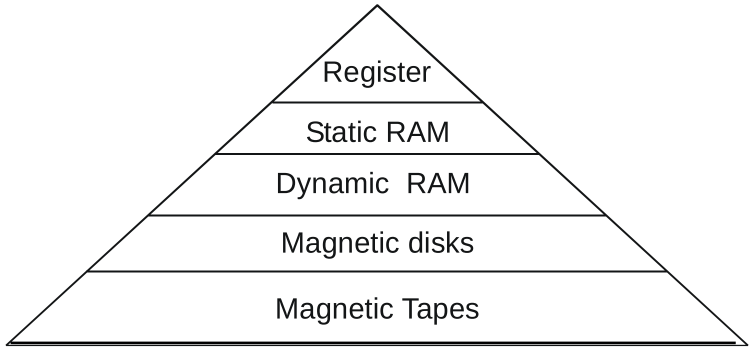


Fig. 3.1 : Memory Hierarchy

There are three key characteristics of the memory. They are *cost*, *capacity* and *access time*. On moving down the memory hierarchy, it is found that the cost of the storage devices decreases but their storage capacity as well as the memory access time increases. In other words, the smaller memories are more expensive and much faster. These are supplemented by the larger, cheaper and slower storage devices.

Thus from the above figure it can be seen that the registers are at the top of the hierarchy and so provides the fastest, the smallest and the most expensive type of memory device for the CPU to access data. Registers are actually small amount of storage available on the CPU and their contents can be accessed more quickly than any other available storage. They may be 8–bit registers or 32-bit registers according to the number of bits that they can hold in them.

Magnetic disks and Magnetic Tapes are the secondary storage mediums whose data holding capacities are much larger than the Processor Registers and the semiconductor memories which cannot hold all the data to be stored in the computer system. The magnetic tapes are more suited for the off-line storage of the large amounts of the computer data. The data are kept as records which are again separated by gaps.

3.4 MAIN MEMORY

The main memory is the central storage unit of the computer system. Main memory refers to the physical memory which is internal to a computer. The word “Memory” when used usually refers to the Main Memory of the computer system. The computer can process only those data which are inside the main memory. For execution, the programs and the data must be first brought into the main memory from the storage device where they are stored. Computer memory has a crucial role in the performance, reliability and the stability of the system. It is also an important factor in the software support of the system. More number of software can be used with more memory than with lesser ones. There are two types of main memory :

- ***RAM*** (Random Access Memory) and
- ***ROM*** (Read Only Memory).

RAM : In RAM, it is possible to both read and write data from and to the memory in a fixed amount of time independent of the memory location or address. RAM is also a volatile memory which means it stores the data in it as long as power is switched on. Once the power goes off, all the data stored in it is also lost. Therefore, a RAM cell must be provided a constant power supply.

ROM : ROM is a non-volatile semiconductor memory; that is, it doesn't lose its contents even when the power is switched off. ROM is not re-writable once it has been written or manufactured. ROM is used for programs such as bootstrap program that starts a computer and load its operating system.

3.5 SEMICONDUCTOR RAM

The basic building block of the semiconductor memories is the RAM chip. RAM is actually made up of a number of RAM chips. They contain a number of memory cells, which are electronic circuits having two stable states : 0 and 1. The binary information are stored in the form of arrays having rows and columns in the memories. With the advent and advances of VLSI (Very Large Scale Integration) circuits, thousands of memory cells can be placed in one chip. As a result, the cost of the semiconductor memories has dropped dramatically.

3.5.1 Static and Dynamic RAM

There are two main types of semiconductor RAM Memories : Static RAM (SRAM) and Dynamic RAM (DRAM) and also their variations.

Static RAM consists of internal flip-flops to store the binary information. Each flip-flop has four to six transistors in them. SRAM can hold its data as long as the power is supplied to the circuit. Also SRAM cells can keep the data intact without any external refresh circuitry. This fact makes SRAM simple and contrasted to Dynamic RAM, which needs to be refreshed many times per second in order to hold its data contents.

The figure below shows the implementation of a SRAM cell. A latch is formed by cross-connecting two inverters. The latch is then connected to two bit lines by the transistors T1 and T2. T1 and T2 are controlled by a word line. They are in the off-state when the word line is at the ground level.

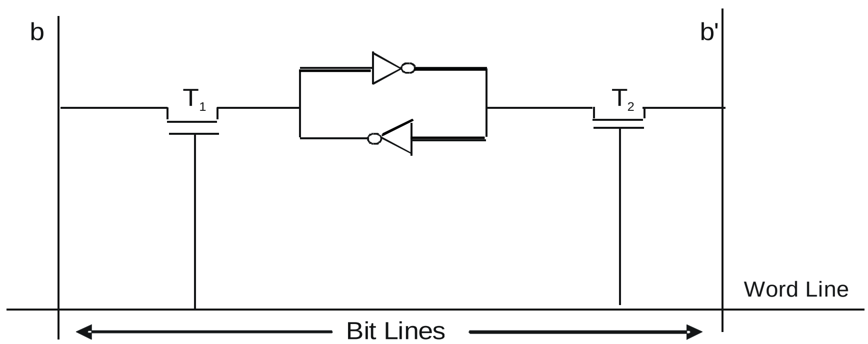


Fig. 3.2 : Implementation of SRAM cell

Static RAM is so called as they can retain their state as long as the power is applied. As SRAM never has to be refreshed, it is very fast. However, because it requires several transistors, it takes up more space on a RAM chip than the Dynamic RAM cells. Thus, there is less memory per chip which makes it lot more expensive. The size of SRAM is so larger comparatively than DRAM. In other words performance-wise SRAM is superior to the DRAM. But because of the size and cost of the SRAMs, DRAM is used for the system memory or main memory instead and SRAM are used for Cache memory as cache memory needs to be more faster and small. D-type and RS-type flip-flops are generally used for SRAM.

Dynamic RAM are so named because their cells do not retain their states indefinitely. DRAM stores the information in the form of a charge on capacitors. The capacitor holds a charge if the bit is a “1” and holds no charge if the bit is a “0”. Unlike SRAM, DRAM uses only one transistor to read the contents of the capacitor. The capacitors are very tiny and can hold a charge only for a short period of time, after which it starts fading away. Therefore a refresh circuitry is required in case of DRAM cells to read the contents of the cell and to refresh them with a fresh charge before the contents are lost. This refreshing of the cells are done hundreds of time in every second irrespective of whether the computer is using the DRAM memory at that time or not. So the DRAM is slower than the SRAM just because of the refresh circuitry overhead.

DRAMs are used for the computer’s main memory system as they are cheaper and take up much less space than the SRAM. Even though there is the overhead of the refresh circuitry, it is but possible to use a large amount of inexpensive main memory. The figure given below is a DRAM cell consisting of a capacitor C and a transistor T.

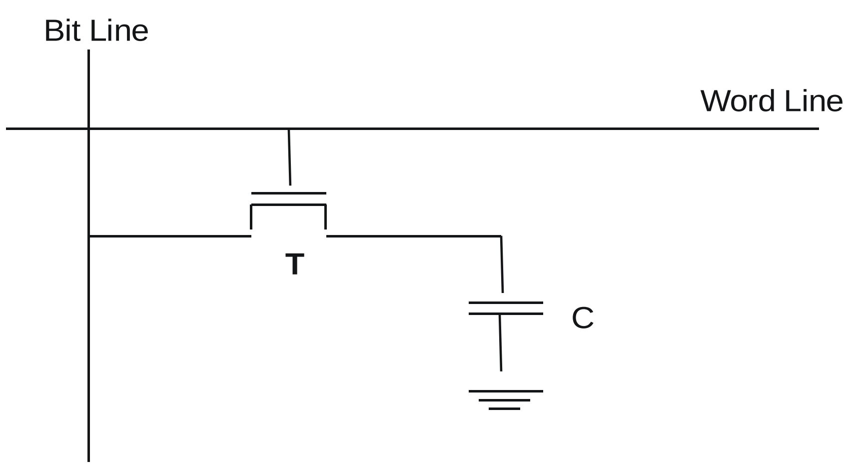
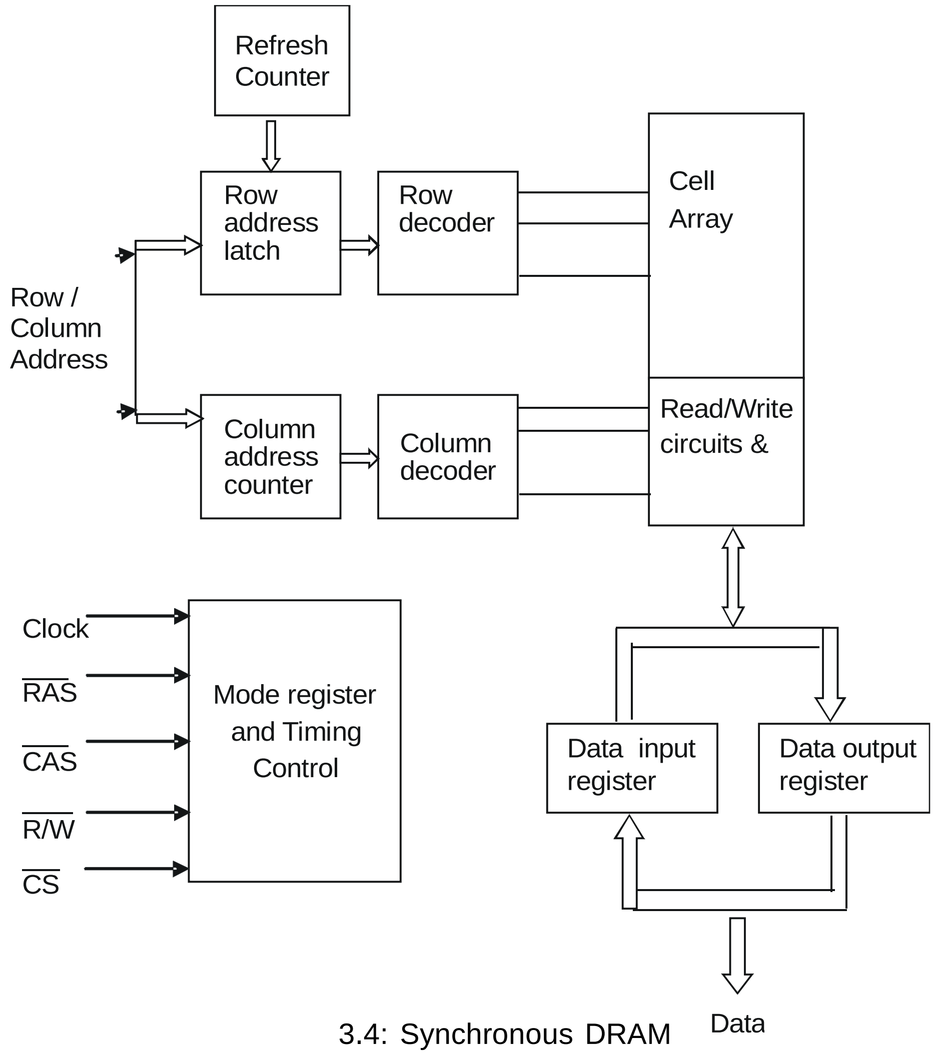


Fig. 3.3 : A DRAM cell

To store the binary information in this cell, the transistor T is first turned on and voltage is applied to the bit line. This causes the capacitor to get some amount of charge. After the transistor is turned off, the capacitor begins to discharge. Therefore, the cell contents can be got correctly only if it is read before the capacitor’s charge falls below some threshold value. During a

Read operation, the transistor in a DRAM cell is first turned on. To check whether the amount of charge on the capacitor is above the threshold value, there is a sense amplifier connected to the bit line. If so, the amplifier pulls the bit line to full voltage to represent logical 1. This voltage then recharges the capacitor to its full voltage.



3.4: Synchronous DRAM

On the other hand, if it was detected that the amount of charge on the capacitor is below the threshold value, then the bit line is pulled down to the ground level so that the capacitor now has no charge at all, that is it will represent logical 0. Thus, reading the cell contents automatically refreshes its cell contents. The time taken in doing all this is very short and is expressed in nanoseconds.

DRAM can again be Synchronous DRAM and Asynchronous DRAM. The DRAM discussed above is Asynchronous DRAM, that is, the memory is not synchronized to the system clock. The memory signals are not at all coordinated with the system clock.

The Synchronous DRAM or SDRAM is synchronized with the system clock; that is, it is synchronized with the clock speed of the microprocessor. All signals are according to the clocks so the timings are controlled and tight. The figure below shows the structure of SDRAM.

The speed of the DRAM has become more critical as the electronic systems that utilizes these devices are now operating at increasing speeds. Thus SDRAM will soon be replacing the conventional DRAM as it is designed to work with higher operating bus speeds in the computer systems.

3.5.2 Internal Organization of Memory Chips

Internally, the memory in the computer system is organized in

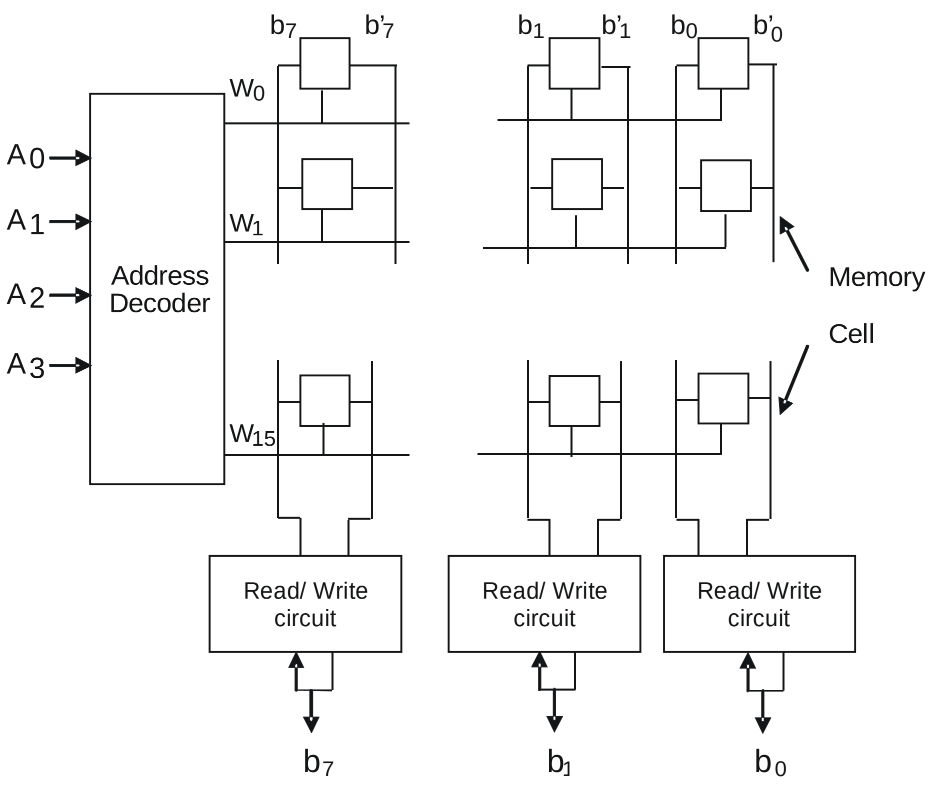


Fig.3.5: Organization of cells in a memory chip

the form of array of rows and columns. Each cell in the array can hold one bit of information. Each row in the array forms a memory word. The cells in the column are all connected to a Read/Write circuit. The figure below presents a possible organization of the memory cells.

Let us consider a simple example of the organization of a 64-bit memory. If the memory is organized into 16 groups or words, then it can be arranged as 16 x 4 memory, that is, it contains 16 memory words and each of the word is 4 bits long. There are also other ways of organizing the same memory, like for example, it can be arranged as 64 x 1, 32 x 2 or 8 x 8.

CHECK YOUR PROGRESS

1. Compare the characteristics of SRAM and DRAM.
2. Fill in the blanks :

(a) Data and _____ are transferred from the secondary memory to the _______ whenever it is needed by the CPU.

(b) The records or the data are accessed in a linear fashion, from its current location in the memory in _________ access.

(c) Memory _______time is the time between the initiation of a memory operation and the completion of that operation.

(d) Memory ________ time is the minimum time delay that is required between the initiation of two successive memory operations.

(e) Memory access time is _________ in Magnetic disks than in magnetic tapes.

(f) Registers are small storage inside the ___________.

(g) RAM can access data in a fixed amount of time _______ of the memory location or address.

(h) RAM is a ______ memory and ROM is a _______memory.

(i) Registers are measured by the number of _____ that they can hold.

(j) The magnetic tapes are more suited for the __________ of the large amounts of the computer data.

3.6 ROM

ROM (Read Only Memory) is another type of main memory that can only be read. Each memory cell in ROM is hardware preprogrammed during the IC (Integrated Circuit) fabrication process. That is the code or the data in ROM is programmed in it at the time of its manufacture. The data stored in ROM is not lost even if the power is switched off. For this reason, it is called a non-volatile storage. It is used to store programs that are permanently stored and are not subject to change. The system BIOS program is stored in ROM so that the computer can use it to boot the system when the computer is switched on.

The figure below shows a possible configuration for a ROM memory cell.

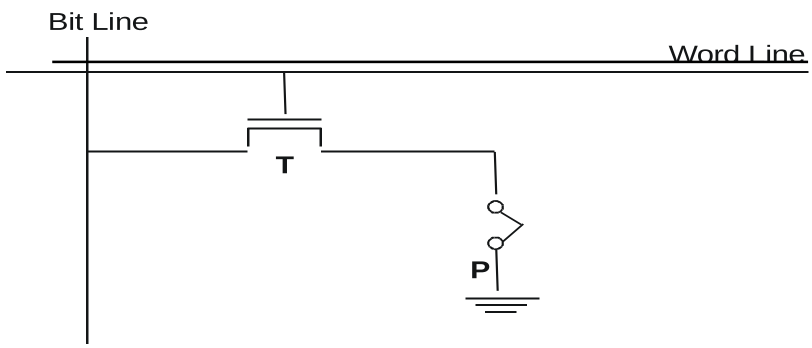


Fig. 3.6 : A ROM memory cell

If the point at P is connected to ground, then a logic value 0 is stored in the cell and if it is not connected then a logic value 1 is stored in the cell. To read the cell contents, the word line is activated. A sense circuit connected at the end of the bit line generates the output value.

ROM can also be randomly accessed as RAM. Only unlike RAM it cannot be written.

3.6.1 Types of ROM

There are five types of ROM :

1. ROM (Read Only Memory)
2. PROM (Programmable Read Only Memory)
3. EPROM (Erasable Programmable Read Only Memory)

4. EEPROM (Electrically Erasable Programmable Read Only Memory)
5. Flash EEPROM Memory

1. ROM (Read Only Memory)

The contents of ROM are permanent and is programmed at the factory. It is designed to perform a specific function and cannot be changed. It is reliable.

2. PROM (Programmable Read Only Memory)

As the name indicates, this type of ROM chips allows the user to code data into it. They were created as making ROM chips from scratch. It is time-consuming and also expensive in creating small numbers of them. PROM chips are like ROM chips but the difference is that PROM chips are created by inserting a fuse at the point P (in the above diagram). Before programming, all the memory cells in PROM contains 0. The user then can insert 1's wherever needed by burning out the fuses at those locations by sending high current pulses. However, PROMs can be programmed only once. They are more fragile than ROMs.

3. EPROM (Erasable Programmable Read Only Memory)

An EPROM is another type of ROM chip that allows data to be erased and reprogrammed. They can be rewritten many times. It is also similar to a ROM chip. However, an EPROM cell has two transistors. One of the transistors is known as the floating gate and the other is known as the control gate. In an EPROM cell, the connection to ground is always made at point P. The erasing of the contents is done by exposing the chip to ultraviolet light. EPROM chips are mounted in packages that has a small glass window through which the UV light is sent into it.

4. EEPROM (Electrically Erasable Programmable Read Only Memory)

The drawbacks of EPROMs are that they must be physically removed to be rewritten and also the entire chip has to be completely erased to just change a particular portion of it. EEPROM was introduced to remove these drawbacks of

EPROM. EEPROM chips can be both programmed and the contents can be erased electrically. They are versatile but slow as they are changed one byte at a time.

5. Flash EEPROM Memory

As EEPROM is slow to be used in products that have to make quick changes to the data on the chip, so the Flash EEPROM devices were developed. Although the flash memory devices are similar to EEPROM, there are also differences between them. In EEPROM, a single cell contents can be read and written while in flash memory single cell contents can be read but it is possible to write an entire block of cells. Also, before writing, the previous contents of the block are erased.

The advantage is that they work faster and the power consumption is low.

CHECK YOUR PROGRESS

3. Write True or False :

(a) SRAM and DRAM are the two types of semiconductor memories.

(b) SRAM stores the data in flip-flops and DRAM stores the data in capacitors.

(c) Main memory is actually the Static RAM.

(d) DRAM is more expensive as compared to SRAM.

(e) The capacitors have their own tendency to leak their charge.

(f) Conventional DRAM is the Synchronous DRAM.

4. Fill in the blanks :

(a) A refresh circuitry is required in case of ____________.

(b) SRAM are used for ________________ memory and DRAM is used for _______________ memory

(c) DRAM uses one transistor to read the contents of the_______________________.

(d) The type of RAM that can hold its data without external refresh for as long as power is supplied to the circuit is called __________________.

(e) SDRAM is synchronized to the ______________________.

(f)__________________ is rapidly becoming the new memory standard for modern PC's.

3.7 LOCALITY OF REFERENCE

During program execution, memory access time is of utmost importance. It has been observed that data and instructions which are executed repeatedly are located near to each other. Many instructions in localized areas of the program are executed repeatedly during some time period and the other remaining instructions of the program are accessed relatively infrequently. This characteristic of the program is referred to as the *"**locality of reference**"*. There are two types of locality of references. These are : *temporal locality* and *spatial locality*.

- ***Temporal locality of reference*** means that a recently executed instruction is likely to be executed again very soon. This is so because when a program loop is executed the same set of instructions are referenced and fetched repeatedly. For example, loop indices, single data element etc.

- ***Spatial locality of reference*** means that data and instructions which are close to each other are likely to be executed soon. This is so because, in a program, the instructions are stored in consecutive memory locations. For example, sequential code, array processing, code within a loop etc.

3.8 CACHE MEMORY

To make use of the locality of reference principle, a small high-speed memory can be used to hold just the active portions of code or data. This memory is termed as ***cache memory***. The word *cache* is pronounced as *cash*. It stores data and instructions which are to be immediately executed. Two types of caching are commonly found in computers. These are : *memory* caching and *disk caching.*

- **Memory Caching**

In case of memory caching, the cache is made up of high-speed static RAM (SRAM). Static RAM is made up of transistors that do not need to be constantly refreshed. It is much faster than the dynamic RAM; access time is about 10 nanoseconds(ns). The main memory is usually made up of dynamic RAM(DRAM) chip. It is directly addressed by the CPU and its access time is about 50 ns. Data and instructions stored in cache memory are transferred to the CPU many times faster as compared to main memory. By using an intelligent algorithm, a cache contains the data that is accessed most often between a slower peripheral device and the faster processor. SRAM chips are much more expensive as compared to DRAM chips. If the whole main memory is made using SRAM chips, then the need of cache memory will be eliminated.

Some memory caches are built into the architecture of microprocessors. These are called ***internal cache***. For example, the *Intel 80486* microprocessor contains a 8K memory cache and the *Pentium* has a 16K cache. Such internal caches are often called **Level 1(L1)** caches. Cache outside the microprocessor i.e., on the motherboard is called ***external cache*** *or* **Level 2(L2)** cache. External caches are found in almost all modern personal computers. These caches are placed between the CPU and the DRAM. Like L1 caches, L2 caches are composed of SRAM but they are much larger.

- **Disk Caching**

Disk caching works under the same principle as memory caching, but instead of using high-speed static RAM, it uses dynamic RAM. The most recently accessed data from disk is stored in the main memory which is made up of DRAM. When a program needs to access data from the disk, it first checks the disk cache to see if the data is there. Disk caching can improve the performance of applications, because accessing a byte of data in DRAM can be thousands times faster than accessing a byte on a hard disk.

3.8.1 Cache Operation - an overview

When the CPU sends an address of instruction code or data, the *cache controller* examines whether the content of the specified address is present in the cache memory. If the requested data or instruction code is found in the cache, the cache controller enables the cache memory to send the specified data/instruction to the CPU. This is known as a '**hit**'. If it is not found in the cache memory, then it is said that a '**miss**' has occured and the cache controller enables the controller of the main memory to send the specified code or data from the main memory. The performance of cache memory is measured in terms of ***hit ratio***. It is the ratio of number of hits divided by the total number of requests made. By adding number of hits and number of misses, the total request is calculated.

It is not necessary for the processor to know about the existence of cache. Processor simply issues READ and WRITE requests using addresses that refer to locations in the memory. Both the main memory and the cache are divided into equal-size units called *blocks*. The term *block* is usually used to refer to a set of contiguous address locations of some size. In a **READ** operation, the main memory is not involved. When a READ request is received from the processor, the contents of a block of memory words containing the location specified are transferred into the cache, one word at a time. Subsequently, when the program references any of the locations in this block, the desired contents are read directly from the cache. Usually, the cache memory can store a reasonable number of blocks at any given time.The correspondence between the main memory blocks and those in the cache is specified by a *mapping function*. When the cache is full, it becomes necessary to implement a *replacement algorithm*. The replacement algorithm decides which block should be moved out of the cache to make room for the new block. Normally, the block that will be replaced is the one that will not be accessed or needed again for the longest time. Cache provides a timer to control this situation.

When the memory operation is a **WRITE**, there are two ways to proceed: *write-through method* and *write-back method*.

- **Write-through method:** In this method, the cache location and the main memory location are updated simultaneously.
- **Write-back method:** This method is to update only the cache location and to mark it as updated with an associated *flag bit* also known as *dirty bit* . Here, the update of main memory occurs only when the block containing this marked word is to be removed from the cache to make room for a new block.

CHECK YOUR PROGRESS

5. Choose the appropriate option:

(i) The cache is made up of high-speed ______ in case of memory caching.

(a) EPROM (b) SRAM
(c) ROM (d) none of these

(ii) Cache memory is used in computer sytem to

(a) Replace static RAM (b) Replace ROM
(c) Ensure first booting (d) Speed-up memory access

(iii) Compared with primary storage, secondary storage is

(a) fast and inexpensive (b) fast and expensive
(b) slow and inexpensive (d) slow and expensive

6. Fill in the blanks:

(i) ______ occurs when the requested word is not present in the cache memory.

(ii) __________ states that data and instruction which are close to each other are likely to be accessed in near future.

(iii) Level 2 cache are also termed as _________ cache.

(iv) The performance of cache memory is measured in terms of _____.

3.9 MAPPING FUNCTIONS

To search for a word in the cache memory, cache is mapped to the main memory. There are three different ways that this mapping can generally be done. These are:

- *Direct Mapping*
- *Associative Mapping*
- *Set-Associative Mapping*

Mapping functions are used as a way to decide which main memory block occupies which line of cache. As there are less lines (or block) of cache than main memory blocks, an algorithm is needed to decide this. Let us take an example, a system with a cache of 2048 (2K) words and 64K (65536) words of the main memory. Each block of the cache memory is of size 16 words. Thus, there will be 128 such blocks (i.e., 16*128 = 2048). Let the main memory is addressable by 16 bit address (i.e., 2^{16} = 65536 = 64*1024).

3.9.1 Direct Mapping

The simplest way for determining the cache location for placement of a main memory block is the *direct mapping* technique. Here, the ***block i*** of the main memory maps onto ***block i modulo 128*** of the cache memory. For example,

Block 0 of main memory = 0 %128 = 0, i.e., Block 0 of cache memory

Block 128 of main memory = 128%128 = 0, Block 0

Block 256 of main memory = 256%120 = 0, i.e., Block 0

Block 1 of main memory = 1%128 =1, i.e., Block 1

Block 129 of main memory = 129%128 =1, i.e., Block 1

Block 257 of main memory = 257%128 =1, i.e., Block 1

Thus, whenever one of the main memory *blocks 0, 128, 256,...* is loaded in the cache, it is stored in cache *block 0*. *Block 1, 129, 257*, ... are stored in cache *block 1*, and so on. Since more than one main memory block is mapped onto a particular cache block, contention may arise for that position even when the cache is not full. Currently resident block in the cache is overwritten by new block. The detailed operation of the direct mapping technique is as follows:

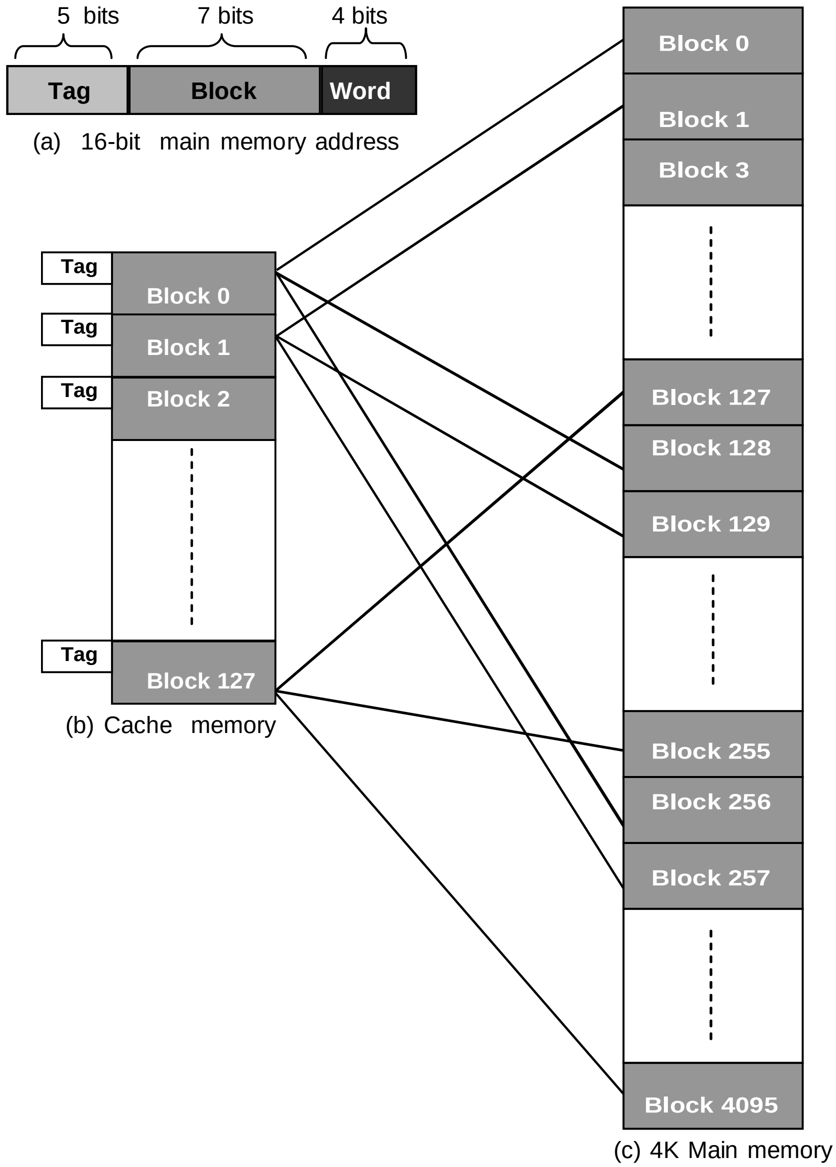


Fig.3.7 : Direct Mapping Technique

In the figure 3.7(c), the 64K words main memory is viewed as 4K (4096) blocks of 16 words each. In direct mapping technique, the 16 bit address sent by CPU is interpreted a tag, a block and a word field as shown in figure 3.7(a). The low-order 4 bits are used to select one of 16 words in a block. When a new block enters the cache, the 7 bits block field determines the cache position in which this new block can be stored. The high-order 5 bits of the memory address of the block are stored in 5 tag bits associated with its location in the cache. These bits identify which of the 32 blocks that are mapped into this cache block field of each address generated by the processor points to a particular block location in the cache. The tag field of that block is compared to the tag field of the address. If they match, then the desired word specified by the low-order 4 bits of the address is in that block of the cache. If there is no match, then the block containing the required word must first be read from the main memory and loaded into the cache.

The advantage of direct mapping is that it is simple and inexpensive. The main disadvantage of this mapping is that there is a fixed cache location for any given block in main memory. If a program accesses two blocks that map to the same cache line repeatedly, then cache misses are very high.

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3.9.2 Associative Mapping

This type of mapping overcomes the disadvantage of direct mapping by permitting each main memory block to be loaded

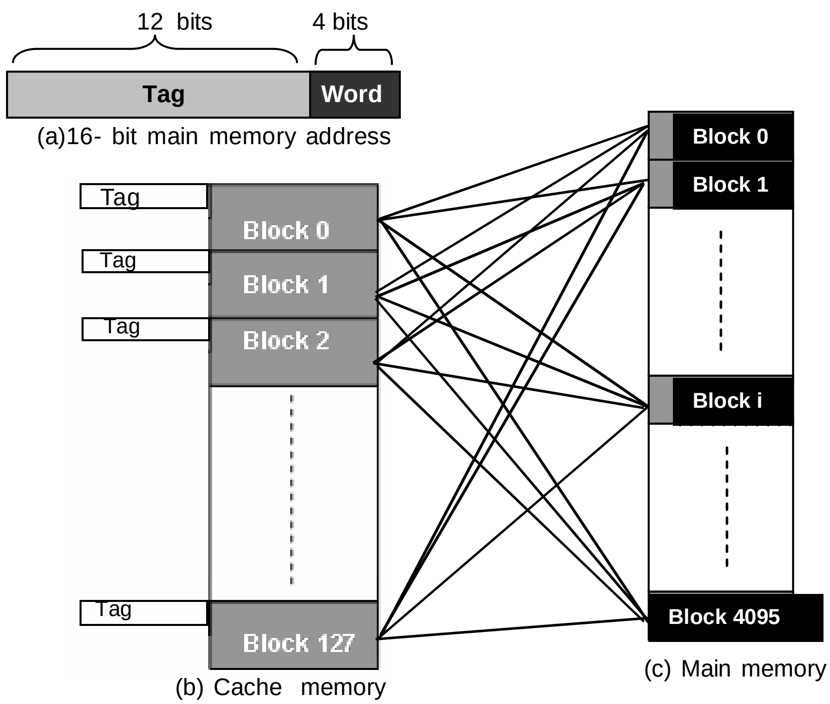

Fig.3.8 : Associative Mapping Technique

into any line of cache. To do so, the cache conroller interprets a memory address as a *tag* and a *word* field. The tag uniquely identifies a block in main memory. For a 16 bit memory address, 12 bits are used as tag field and 4 bits are used as word field as shown in figure 3.8(a).

With this mapping, the space in the cache can be used more efficiently.The primary disadvantage of this method is that to find out whether a particular block is in cache, all cache lines would have to be examined. Using this method, replacement algorithms are required to maximize its potential.

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3.9.3 Set-Associative Mapping

Set-associative mapping combines the best of *direct* and *associative* cache mapping techniques. In this mapping, cache memory blocks are grouped into ***sets***. It allows a block of the main memory to reside in any block of a specific set. Thus, the contention problem which usually arise in direct mapping can be avoided by having a few choices for placement of block. In the figure 3.9, set-associative mapping technique is shown. Here, the cache is divided into sets where each set contains 2 cache blocks. Thus, there will be 64 sets in the cache of 2048(2K) words. Each memory address is assigned a set, and can be cached in any one of those 2 locations within the set that it is assigned to. In other words, within each set the cache is associative, and thus the name set associative mapping.

The 6 bits **set** field of the address determines which set of the cache might contain the desired block. The **tag** field of the address must then be associatively compared to the tags of the two blocks of the set to check if the desired block is present. For the main memory and cache sizes shown in figure 3.9, four blocks per set can be accommodated by a *5 bits set* field, eight blocks per set by a *4 bits set* field, and so on. If there is 128 block per set, then it requires no set bits and it becomes a fully associative technique with 12 tag bits. The other extreme condition of one block per set is the direct-mapping method. A cache that has ***N*** blocks per set is referred to as ***N-way set-associative cache***. Figure 3.9(b) is a *2-way set-associative* cache.

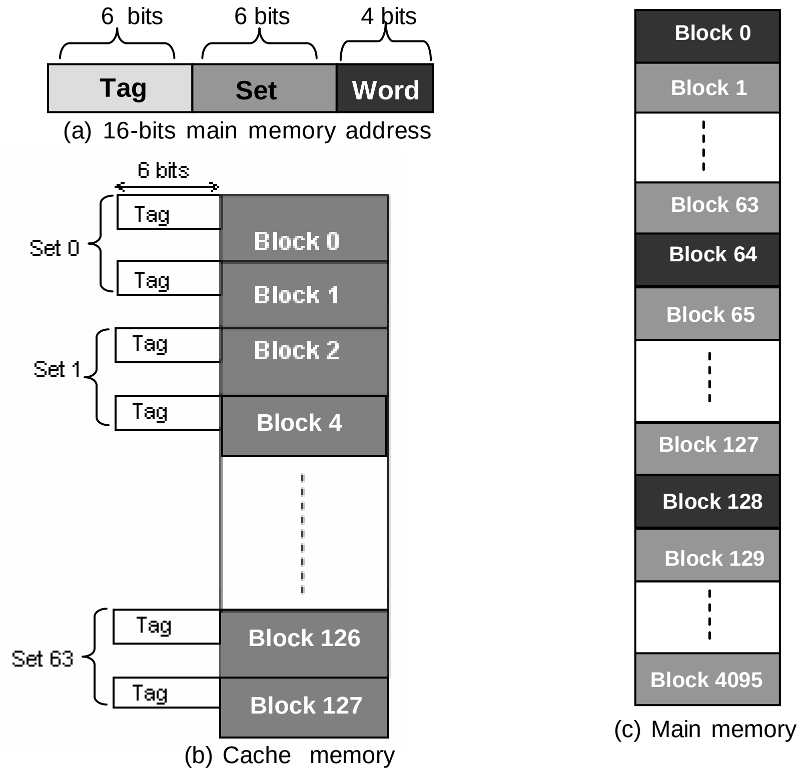


Fig.3.9 : Set-Associative Mapping Technique

CHECK YOUR PROGRESS

7. Fill in the blanks :

(i) Main memory block can reside in any cache position in case of ________ mapping.

(ii) In Set-associative mapping blocks of the cache are grouped into _______.

(iii) In _______ mapping, main memory address consists of tag, block and word fields.

(iv) A cache that has 4 blocks per set is referred to as _____.

3.10 REPLACEMENT ALGORITHMS

For direct mapping where there is only one possible line for a block of memory, no replacement algorithm is required. For associative and set associative mapping, however, an algorithm is needed. At this point, we will describe the one most common replacement algorithm, called *LRU algorithm.* This algorithm is easy to understand and provides a good background to understand the more advanced replacement algorithms. Several other replacement algorithms are also used in practice such as: *first in first out* replacement algorithm, *random replacement* algorithm etc.

Least Recently Used (LRU) : Due to locality of reference, programs usually stay in localized areas for reasonable period of time. So there is a high probability that the blocks that have been referenced recently will be referenced again soon. Therefore, it overwrites block in cache memory that has been there the longest with no reference to it. That block is known as the least recently used block and the technique is known as ***least recently used*** (***LRU***) replacement algorithm. In this method, a counter is associted with each page in the main memory and it is incremented by 1 at fixed intervals of time. When a page is referenced, its counter is set to 0. Thus, counter gives the age of a page. When a page needs to be removed, the page with the highest counter is removed.

3.11 VIRTUAL MEMORY

Before coming to the point *virtual memory,* let us review some basics: *physical memory(RAM)* versus *secondary memory(disk space)*.

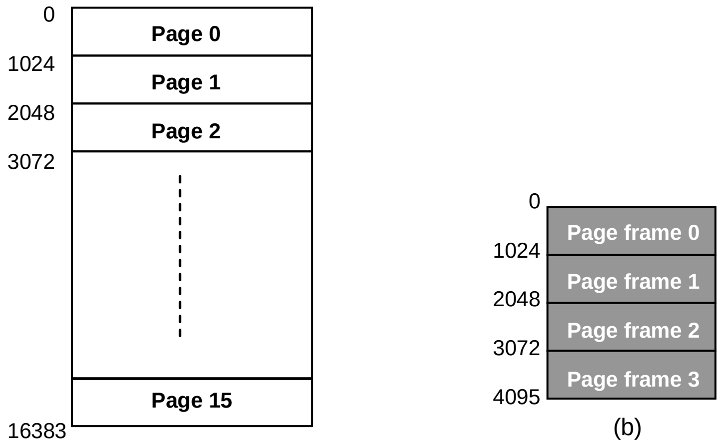
Computers these days typically have somewhere between 128 megabytes (128 million bytes) and 4 gigabytes (4 billion bytes) of main memory (RAM). What is important is that when we turn the computer off or if it crashes - anything stored in RAM is gone. That is why when we are editing a document it is a better to save to disk often. When we talk about *disks*, we are talking about the hard disk address of main memory. In such a case, an address generated by the CPU is called ***virtual address*** or *logical address*. A set of such addresses is called the *address space*. Virtual addresses might be the same as physical addresses. ***Physical address*** refers to the address of a location of the main(physical) memory. A set of physical addresses is termed as *memory space*. If virtual and physical addresses are different, then virtual addresses must be mapped into physical addresses and this mapping is done by Memory Management Unit (MMU).

3.11.1 Paging

Paging is a method for achieving virtual memory. It is the most common memory management technique. Here, the virtual address space and memory space are broken up into several equal sized groups. To facilitate copying the virtual memory into the main memory, the operating system divides *virtual address space* into fixed size ***pages***. Physical address space(memory space) is also broken up into fixed size ***page frames***. *Page* in virtual address space fits into *frame* in physical memory. Each page is stored on a secondary storage (hard disk) until it is needed. When the page is needed, the operating system copies it from disk to main memory(RAM), translating the virtual addresses into physical addresses. This process of copying the virtual pages from disk to main memory is known as ***paging***.

To illustrate these, let us consider a computer with 14 bit address field in its instruction and 4096(4K) words of memory(RAM). A program on this computer can address 2^{14} = 16384 = 16 K words of memory. Thus the virtual address space is from 0 to 16383. If the address space and the memory space is divided into groups having 1K=1024 words each, then 16K virtual address space will consist of 16 pages [figure

3.10(a)] and 4K memory space will consist of 4 page frames [figure 3.10(b)].



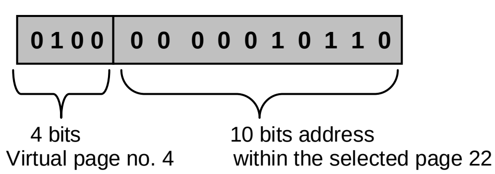
(a)
16K Virtual memory is divided into 16 pages each of size 1K

(b)
4K Main memory (RAM) is divided into 4 page frames each of size 1K

Fig. 3.10: A possible way to divide up 16K address space and 4K memory space

Out of these 16 pages, only 4 pages can accommodate in the main memory at a time. The physical address must be specified with 12 bits (as $2^{12} = 4096 = 4K$). At any instant of time 4096 words of memory can be directly accessible but they need not correspond to address 0 to 4095. For the execution of the program, the 14 bit virtual address needs to be mapped into 12 bit physical address.

When the program refers to memory in fetching data or instruction or to store data, it would first generate a 14 bit address corresponding to a virtual address between 0 and 16383. This 14 bit addresses are interpreted as follows (figure 3.11) :



i.e., 22[nd] word of page number 4 (as decimal equivalent of 0100 and 0000010110 is 4 and 22 respectively)

Fig.3.11

Here, 4 bits are shown as virtual page number and 12 bits as address within the selected page. The decimal equivalent of 14 bit address 01000000010110 is 4118, which is interpreted as address 22 of page 4. Having discovered that virtual page number 4 is needed, the operating system must find out where virtual page 4 is located. The page 4 may reside in any of the four page frame in the main memory or somewhere in the secondary memory. To find out where it is, the operating system searches it in the *page table* which is in the main memory. A ***page table*** is a table stored in main memory or in some fast memory which has one entry for each of the virtual pages. The *page table* contains the list of all the 16 pages of virtual memory and the page frame number where the page is stored in the main memory. A ***presence bit*** is also there to indicate whether the page is present in the main memory or not. If the page is present in the main memory then the presence bit will be 1 otherwise it will be 0. For example, if the pages 2, 4, 5, 8 are present in the main memory, the the content of memory page table will be as shown in the figure 3.12.

Let us assume that the virtual page 4 is in main memory. The first 4 bits of a virtual address will specify the *page number* where the word is stored. Similary, the first 2 bits of a physical address will specify the page frame number of the memory where the word is stored. The 4 bit page number is taken from the virtual address and it is compared with the memory page table entry. If the presence bit against this page number is 1, then the block number (2 bits) is taken and is written in the place of page number in the address (figure 3.12). Thus, a 14 bit virtual address is mapped into a 12 bit physical address. The block number is searched in the main memory and then the word located at that address is fetched.

When a reference is made to an address on a page not present in main memory, it is called a ***page fault***. After a page fault has occured it is necessary for the operating system to read in the required page from the secondary memory, enter its new physical location in the page table and then repeat the instruction that cause page fault.

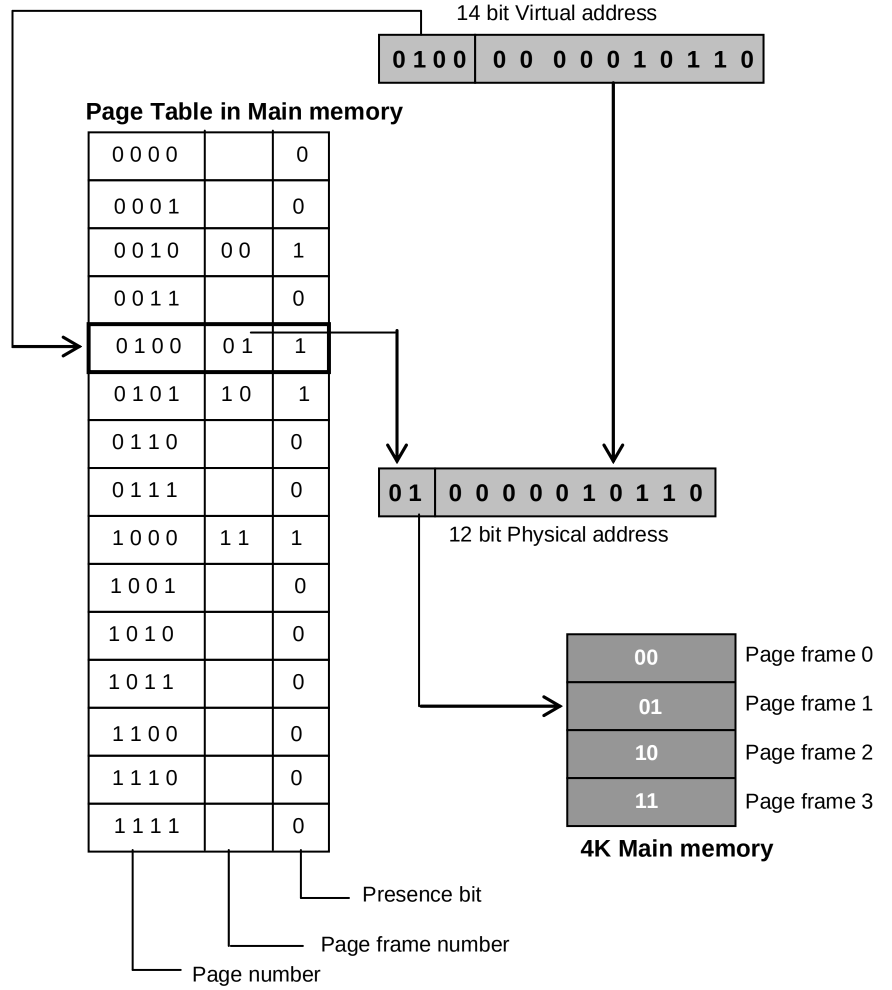


Fig.3.12:Contents of *memory page table* when pages 2, 4, 5 and 8 are present in the main memory and formulation of main memory address from virtual address

CHECK YOUR PROGRESS

8. Fill in the blanks :
   (i) A page replacement policy is not necessary in __________ mapped cache.
   (ii) Paging is a method of achieving ___________.
   (iii) Virtual address is also known as ____________ address.
   (iv) In paging, memory space is broken up into equal size _____ and address space is broken up into equal size _______.
   (v) Set of physical address is known as ___________.
   (vi) Set of virtual address is known as _________.

(vii) ________ in virtual address space fits into ________ in physical memory

(viii) Paging is the most common ______________ technique.

3.12 MAGNETIC DISKS

Magnetic disks are the widely used popular secondary storage medium.The magnetic disks are used for storing large amounts of data and programs. A magnetic disk is a circular plate which is constructed of metal or plastic coated with a magnetizable material on which electronic data are stored. Data can be stored on both sides of the disk. Several disks can be stacked on top of the other on a spindle. These disks are actually rotating platters with a mechanical arm that moves a read/write head between the inner and outer edges of the disks surface. A read/write head is available on each of the disk surface. A magnetic disk works on the principle of magnetic charge.

The disks rotates at very high speeds. During a read/ write operation, only the disk rotates and the head is always stationary.

3.12.1 Data Organization in Magnetic Disk

Data on the magnetic disks is organized in a concentric set of circles, called tracks. The bits of data are stored as magnetic spots in these tracks. A gap exist between each track to prevent errors due to interference of magnetic fields. The number of bits stored in each track is equal. Therefore, the data density is more in the inner tracks than the outer ones. The more the number of tracks, the more is the storage capacity of the disk.

Tracks are again divided into sections called sectors. A small gap also exists between two sectors so as to distinguish between them. Each sector usually contains 512 bytes of data.

The set of corresponding tracks on all surfaces of a stack of disks forms a **logical cylinder**. The disk platters rotates together at a very high speed.

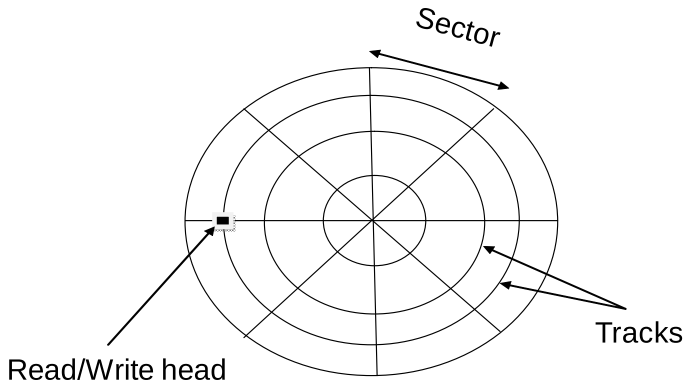


Fig. 3.13: Organization of data on Magnetic Disk

A write head is used to record the data bits as magnetic spots on the tracks and these recorded bits are detected by a change in the magnetic field produced by a recorded magnetic spot, on the disk surface, as it passes through a read head. The data on the disk surfaces are accessed by specifying the surface number, track number and sector number.

Some magnetic disk uses a single read/ write head for each disk surface while others uses separate read/ write heads for each track on the disk surface. Accordingly, the read/write head may be movable or fixed. If the magnetic disk uses a single head for each disk surface then the read/write head must be able to be positioned above any track in the surface. Therefore, the head has to be a movable head. In such case, the head is mounted on an arm and the arm can be extended or retracted to position the head on any track.

In a fixed-head disk, there is one read/write head per track in the surface. All the heads are mounted on a rigid arm that extends across all tracks.

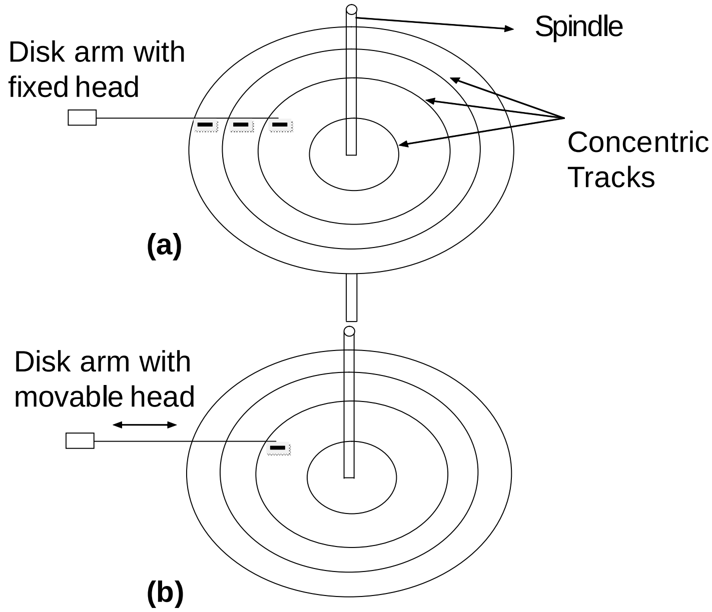


Fig. 3.14 (a) Fixed Read/Write Head, (b) Movable Read/Write Head

The read and write operations starts at the sector boundaries. The bits of data are recorded serially on each track. To read or write data, the head must be first positioned to that particular track.

The heads should be always be at very small distance from the moving disk surfaces so that the high bit densities and also due to this more reliable read/write operations can be performed.

Now a days, Winchester technology is used where both the disks and the read/write heads are placed in sealed enclosures. This technology has two advantages. First, in such disk units, the heads operates closer to the tracks as there are no dust particles, as in disk units which are not sealed. As such data can be more densely stored along the tracks and the tracks can also be closer to one another. These Winchester disk units has a larger capacity for storing data.

Secondly, in these disk units, the data integrity is more as they are not exposed to contaminating elements.

The disk system consists of three key parts. First is the stack of disk platters, usually referred to as the **disk.**

Second is the electromechanical mechanism that rotates the disk and moves the read/write heads, which is called the **disk drive.**

Third is the **disk controller**, which controls the disk system operation. It also provides an interface between the disk drive and the bus that connects it to the computer system.

The disks which are attached to the computer units and cannot be removed by the occasional users are called the hard disk. Those which can be inserted and removed from the system easily by the users are called floppy disks.

3.12.2 Disk Access Time

To perform a read or a write operation, the read/write head is first positioned on the desired track and sector. In fixed-head systems the head over the desired track is selected electronically. In a movable head system, the head is positioned on that particular track. In such systems, the time that is taken to move the head to the proper track is called the ***seek time***. It depends on the initial position of the head relative to the track specified in the address.

In either case, after the read/write head is positioned over the track, the system waits until the appropriate sector passes under the read/write head. This delay in time is called the ***rotational delay or latency time***.

The sum of these two delays, that is the seek time and the latency time is called the *disk access time*.

The storage capacity of a disk is a multiple of the number of recording surfaces, number of tracks per surface, number of sector per track, and the number of bytes per sector. That is,

Storage capacity of a disk system = Number of recording surfaces
x Number of tracks per surfaces
x Number of sector per track
x Number of bytes per sector

The following Fig. shows a typical disk pack. Always remember that- **the upper surface of the top plate, and the lower surface of the bottom plate are not used for information storing.**

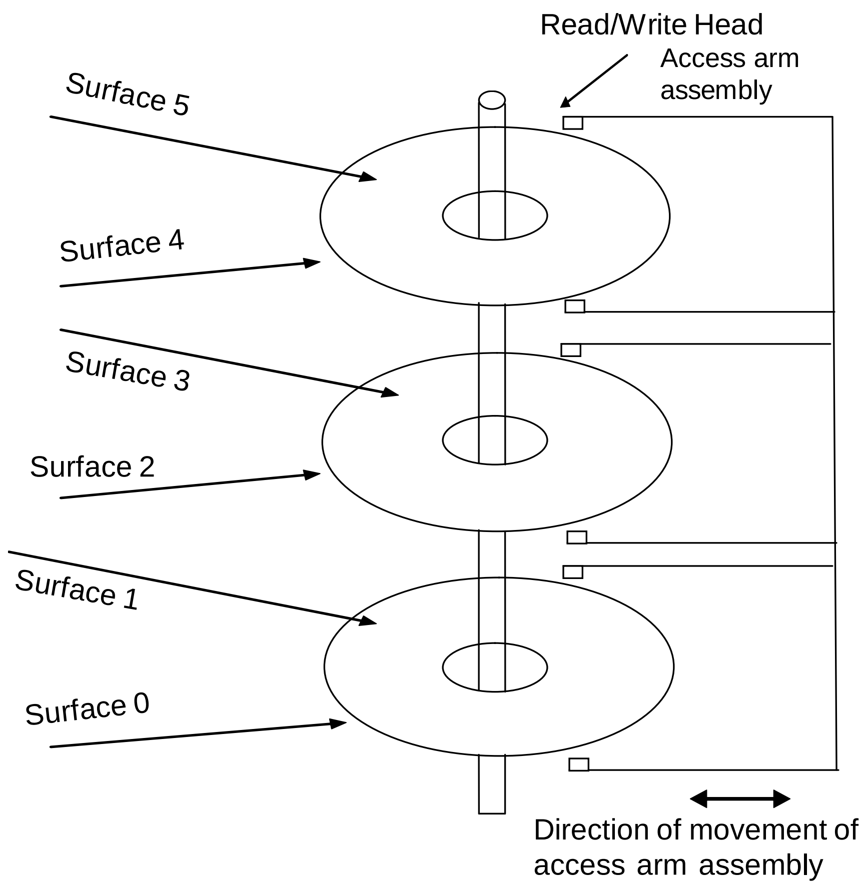


Fig. 3.15: Disk pack

CHECK YOUR PROGRESS

9. What are tracks, sectors and cylinders?

10. Fill in the blanks :

   a. The density of data is _______ in the inner tracks and _______ in the outer tracks.
   b. The inter-track gap prevents________.
   c. Data is recorded and accessed in magnetic disks with the help of a ______ mechanism.
   d. Read/write heads may be _________ or__________ .
   e. Data is stored as __________ in the magnetic disks.
   f. In case of Winchester disks, the disks and the heads are ________.
   g. The three vital parts of a disk system are ___, ____ and ________.
   h. ______ is the time required to position the head to the desired track.
   i. The seek time and the rotational delay together is called the _____ time.

3.13 RAID

The rate in the increase in the speeds of the processor and the main memory is much more than that in the improvement of the secondary storage devices. Of course there has been an increase in the storage capacities of these devices.

However, it was been recognized that high performance could be achieved at a reasonable cost by using multiple low-cost devices to operate in parallel. This lead to the use of arrays of disks that operate independently and in parallel.

In 1988, researchers at the University of California-Berkeley proposed a multiple disk storage system, called ***RAID (Redundant Array of Inexpensive Disks)***. There were six different configurations, which were known as thr RAID levels - **RAID 0, RAID 1, RAID 2, RAID 3, RAID 4** and **RAID 5**. All of these six levels share three common characteristics. They are -

1. RAID is a set of physical disk drives which operates as one logical drive.
2. The data is distributed across the physical drives of an array.
3. In case of a disk failure, the data can be recovered as identical data is stored on more than one disk in the set of the disks.

In RAID 0, data stripping is used. This means a single file is stored in several separate disks by breaking the file into a number of smaller pieces. Whenever a file is read, all the disks delivers their stored portion of the file in parallel. So the total transfer time of the file is equal to the transfer time that would be required in case of a single disk system divided by the number of disks used in the array.
The disk is divided into strips, which may be physical blocks or some sectors.

In the RAID 1 scheme identical copies of the same data are stored on two disks. Data stripping is also used here but the strip is mapped to both the physical disks. The two disks are mirrors of each other. If a disk failure occurs, then all the operations on its data can be done on its mirror disk. The disadvantage of RAID 1 scheme is the cost involved with it to improve the reliability.

RAID 2, RAID 3, RAID 4 and RAID 5 in all these schemes some parity calculations are done so as to achieve reliability and recover the errors. The data are not fully duplicated RAID 2 requires fewer disks but is still costly. RAID 5 distributes the parity strips across all disks.

RAID offers excellent performance and are generally used in high performance computers or in systems where higher degree of data reliability is required.

CHECK YOUR PROGRESS

11. Find true or false :

a. RAID combines two or more physical hard disks into a single logical unit using special hardware or software.
b. The full form of RAID is Redundant Array of Inexpensive Disks.
c. The levels of the RAID are hierarchy of one another.
d. All the disks in RAID behave as one logical disk drive.
e. In case of a disk failure, the data cannot be recovered in RAID.
f. RAID1 level uses parity calculations for error-recovery.

12. What are the three key concepts in RAID?

3.14 OPTICAL MEMORY

In optical memory, the data is stored on an optical medium like CD-ROM. The stored data can then be read with the help of a laser beam. Large amounts of data can be stored in optical memory at a very reasonable cost. The audio CD (Compact Disk) were the first application of such technology.

In the mid 1980's Sony and Philips companies developed the first generation of CDs. The CDs are non-volatile and they could not be erased.

Optical storage systems consist of a drive unit and a storage medium in a rotating disk form. In general the disks are pre-formatted using grooves and lands (tracks) to enable the positioning of an optical pick-up and recording head to access the information on the subsequently detected by a detector in the optical head. The disk media and the pick-up head are rotated and positioned through drive motors and servo systems controlling the position of the head with respect to data tracks on the disk. Additional peripheral electronics are used for control and data acquisition and encoding/decoding. Such a system is illustrated in Fig. 3.16.

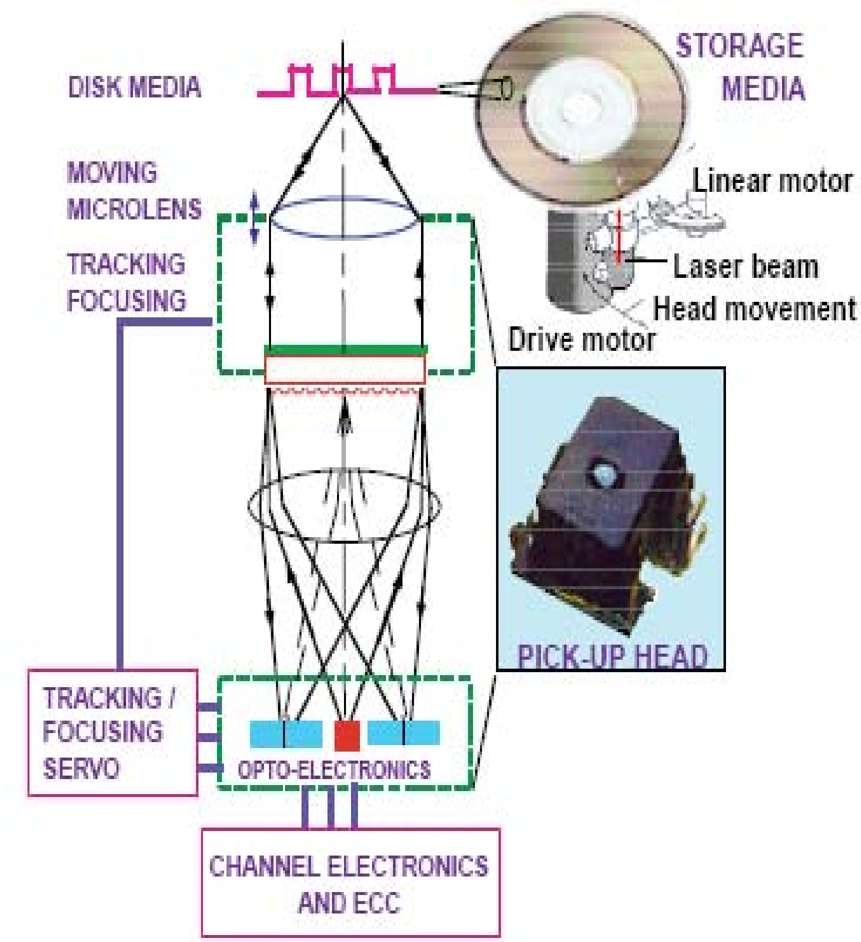


Fig. 3.16: Key components of an optical disk system

In the past few years a variety of optical disk systems have been introduced:

CD (Compact Disk)

CD-ROM (Compact Disk Read Only Memory)

WORM (Write Once Read Many)

Erasable Optical Disk, etc.

3.14.1 CD-ROM

CD-ROM disk is a shiny, silver color metal disk usually of 51/4-inch (12cm) diameter. It is made of polycarbonate plastic and thin layer of pure aluminum is applied to make the surface reflective. For some good quality disks, gold layer is used. A thin layer of lacquer protects it. The surface of an optical disk consists of *pits* and *land*. The information is read from pits and lands, like 1s and 0s. It is changed into binary so computers can read it. An optical reader reads the patterns of pits that stands for bytes. One CD can hold 650MB of data or 300,000 pages of text. Most CDs are read only, which means you cannot save data to the disk. This device is usually not used as a primary storage device for data.

An optical disk is mounted on an optical disk drive for reading/writing of information on it. An optical disk drive contains all the mechanical, electrical and electronic components for holding an optical disk and for reading/writing of information on it. That is, it contains the tray on which the disk is kept, read/write laser beams assembly, and the motor to rotate the disk. Access time for optical disks are in the range of 100 to 300 milliseconds.

Advantages of CD-ROM are -

a) Storage capacity is much more in optical disks.
b) Multiple copies of the disk along with its contents can be made inexpensively.
c) They are transportable from one computer to another very easily.

Disadvantages are -

a) They are read-only and contents cannot be changed or updated.

b) The access time in optical disks is more than in case of magnetic disks.

3.14.2 DVD Disks

The success of CD technology and the continuing quest for greater storage capability has led to the development of DVD. **DVD**, also known as **Digital Versatile Disk** or **Digital Video Disk**, is an optical disk storage media format, and was invented and developed by Sony, and Philips in 1995. Its main uses are video and data storage. DVDs are of the same dimensions as compact disks (CDs), but store more than six times as much data.

Variations of the term *DVD* often indicate the way data is stored on the disks : DVD-ROM (read only memory) has data that can only be read and not written; DVD-R and DVD+R (recordable) can record data only once, and then function as a DVD-ROM; DVD-RW (re-writable), DVD+RW, and DVD-RAM (random access memory) can all record and erase data multiple times. The wavelength used by standard DVD lasers is 650 nm thus, the light has a red color.

A DVD disk consists of two substrates (0.6mm thick) bonded together. Each side can contain two layers called ‘Layer 0’ and ‘Layer 1’ (the outermost layer). The physical format of a DVD determines the capacity of the DVD disk. DVD capacity is determined by pit size, track pit spacing and the number of layers the disk contains. In the following some list of disks (current) and their capacities are given :

Physical Format	Capacity	Layers	Side(s)
DVD -5	4.7GB	1	1
DVD -9	8.54GB	2	1
DVD -10	9.4 GB	1	2
DVD -14	13.24GB	2	2
DVD -18	17.08GB	2	2
DVD –R	4.7GB	1	1
DVD –R	9.4GB	1	2
DVD –RW	4.7GB	1	1
DVD –RW	9.4GB	1	2

3.15 MAGNETIC TAPE

The magnetic tape is mostly used for off-line storage of large amount of data. They are the cheapest and the slowest methods for data storage.

The magnetic tape is a strip of plastic coated with a magnetic film. The tape is very small and generally is of 0.5 or 0.25 inch wide. The data recording on the magnetic tape is same as in the case of magnetic disks. There are a number of parallel tracks on the tape. Seven or nine bits corresponding to one character are recorded simultaneously with a parity bit.

Earlier the tapes had nine tracks each but the newer tape systems use 18 or 36 tracks, corresponding to a word or a double word. A separate read/write head is mounted one in each track so that data can be recorded and read in a sequential manner.
Data are organized in the form of records and these records are separated by gaps referred to as inter-record gaps.

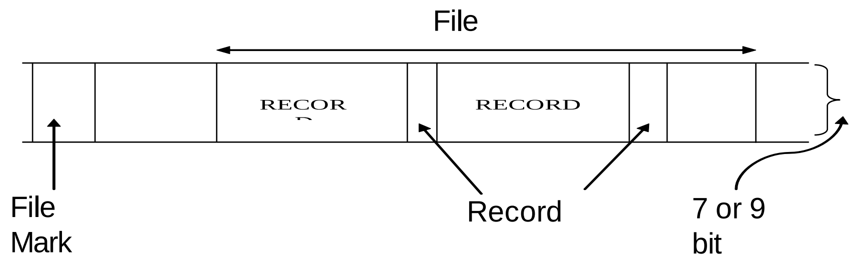


Fig. 3.17: Data Organization on a Magnetic Tape

The data on a magnetic tape is recorded and accessed in a sequential manner. Whenever the tape head reach a record gap, the tape motion can be stopped. Each record has an identification pattern both at the beginning and at the end. The starting bit pattern gives the record number and when the tape head reach the bit pattern at the record end, it comes to know that there is a gap after it.

A file is a collection of some related records. The starting of a file is always marked by a file mark as shown in the figure above. The gap after the file mark can be used as a header or identifier for the file. There are gaps after each record to distinguish between them. In addition to the read and write commands, there are a number of other control commands executed by the tape drive, which includes the following operations :

a. Rewind tape
b. Erase tape
c. Forward space one record
d. Backspace one record
e Forward space one file
f. Backspace one file

The end of the tape is marked by EOT (End of Tape). The records in a tape may be of fixed or variable length.