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## 2.1 CONCEPTS OF DATA STORAGE IN DIGITAL COMPUTERS

Computer data storage, often called **storage** or **memory**, refers to computer *components* and recording *media* that **retain** digital **data** used for computing for some interval of *time*. They basically serve I/O requests.

Computer data storage provides one of the core functions of the modern computer, that of **information retention**. It is one of the fundamental components of all modern computers, and coupled with a central processing unit (CPU, a processor), implements the basic computer model used since the 1940s (Von-nuemann architecture).

In contemporary usage:

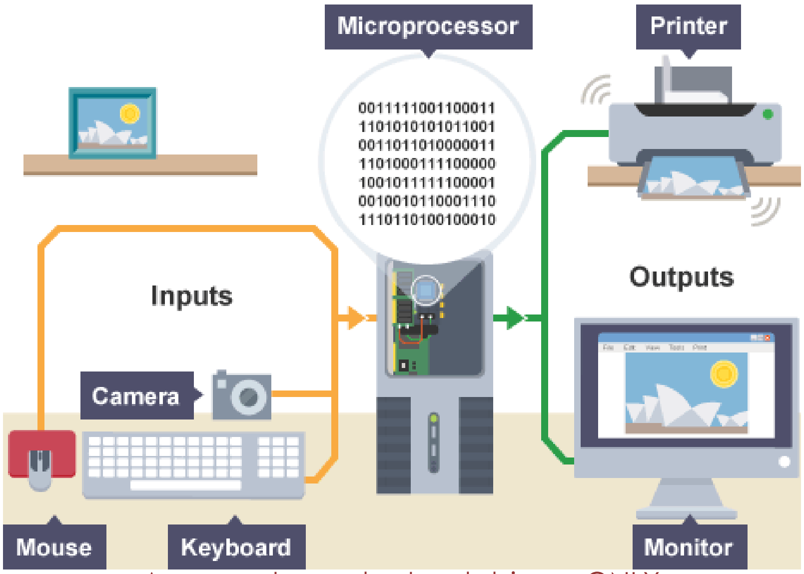
1) **Memory** (or **main memory** or **internal memory**) usually refers to a form of semiconductor storage known as random-access memory (RAM) and sometimes other forms of fast but temporary storage.
2) **Storage** (or **secondary storage** or **auxiliary storage** or **external memory**) today more commonly refers to mass storage — optical discs, forms of magnetic storage like hard disk drives, and other types slower than RAM, but of a more permanent nature.

Computers use binary - the digits **0** and **1** - to store data. A binary digit, or bit, is the smallest unit of data in computing. It is represented by a 0 or a 1. Binary numbers are made up of binary digits (bits), eg the binary number 1001.

The circuits in a computer's processor are made up of billions of transistors. A transistor is a tiny **switch** that is activated by the electronic **signals** it receives. The digits **1** and **0** used in binary reflect the **on** and **off** states of a transistor.

Computer programs are sets of ***instructions***. Each instruction is translated into machine code (binary codes that activate the CPU. Programmers write computer code and this is **converted** by a translator into binary instructions that the processor can execute.

All *software*, *music*, *documents*, *videos*, *graphics* and any other information that is processed by a computer, is also stored using **binary**.




A computer understands binary ONLY

**Encoding**

Everything on a computer is represented as streams of binary numbers. *Audio*, *images* and *characters* all look like binary numbers in machine code. These numbers are encoded in different data formats to give them meaning, e.g. the **8-bit** pattern 01000001 could be the number **65**, the character '**A**', or a **colour** in an image.

Encoding formats have been standardized to help compatibility across different platforms. For example:

- **audio** is encoded as audio file formats, eg **mp3**, **WAV**, **AAC**
- **video** is encoded as video file formats, eg **MPEG4**, **H264**
- **text** is encoded in character sets, eg **ASCII**, **Unicode**
- **images** are encoded as file formats, eg **BMP**, **JPEG**, **PNG**

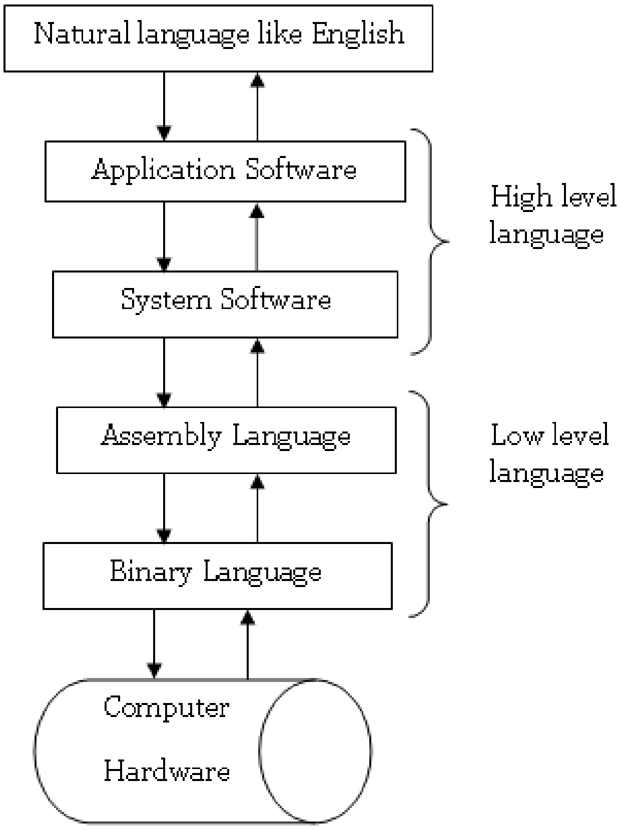
The more bits used in a pattern, the more combinations of values become available. This larger number of combinations can be used to represent many more things e.g. a greater number of different symbols, or more colours in a picture.

## Early Computers

In the early days of computing, the only way to enter **data** into a computer was by flicking **switches** or by feeding in punched cards or punched paper tape.

Since computers work using binary, with data represented as 1s and 0s, both switches and punched holes were easily able to reflect these two states - 'on' to represent 1 and 'off' to represent 0; a hole to represent 1 and no hole to represent 0.

Charles Babbage's **Analytical Machine** (in 1837) and the **Colossus** (used during the Second World War) were operated using punched cards and tapes. Modern computers still read **data** in binary form but it is much faster and more convenient to read this from microchips or from magnetic or optical disks.




Platforms that data must go through to communicate with hardware

### 2.1.1 Data representation in Digital computers

Data and instructions cannot be entered and processed directly into computers using human language. Any type of data, be it **numbers**, **letters**, **special symbols**, **sound** or **pictures** must first be converted into *machine-readable* form i.e. **binary form**. Due to this reason, it is important to understand how a computer together with its peripheral *devices* handles data in its electronic circuits, on magnetic media and in optical devices.

### 2.1.2 Data representation in digital circuits

Electronic components, such as microprocessors, are made up of millions of electronic circuits. The availability of high voltage(**on**) in these circuits is interpreted as '**1**' while a low voltage (**off**) is interpreted as '**0**'.This concept can be compared to switching on and off an electric circuit. When the **switch** is **closed** the high voltage in the circuit causes the bulb to **light** ('**1**' **state**).on the other hand when the ***switch*** is *open*, the bulb goes ***off*** ('**0**' **state**). This forms a basis for describing data representation in **digital computers** using the binary number system.

### 2.1.3 Data representation on magnetic media

The presence of a magnetic field in one direction magnet media is interpreted as '1', while the field in the opposite direction is interpreted as '0'. Magnetic technology is mostly used on storage devices which are coated with special magnetic materials such as **iron oxide**. Data is written on the media by arranging the **magnetic dipoles** of some iron oxide particles to face in the same direction and some others in the opposite direction.

### 2.1.4 Data representation on optical media

In optical devices, the presence of light is interpreted as '1' while its absence is interpreted as '0'. Optical devices use this technology to read or store data. Take an example of a CD-ROM. If the shiny surface is placed under a powerful microscope, the surface can be observed to have very tiny **holes** called ***pits***. The areas that do **not** have pits are called ***land***. Land reflects laser **light** that hits on the surface but **pits** don't reflect. The reflected pattern of light from the rotating disk falls on a receiving photoelectric detector that transforms the patterns into digital form.

### 2.1.5 Reasons for use of binary system in computers

Binary systems are:

1) Reliable
2) Occupy less space
3) Use less energy

### 2.1.6 Bits, bytes, nibble and word

- **Bits:** a bit can be defined as a binary digit which can either be **0** or **1**. It is the *basic* unit of data or information in digital computers.
- **Byte:** a group of **8 bits** used to represent a character is called a **byte**. A byte is used to measure the memory of a computer.
- A **nibble**: half a byte, which is usually a grouping of **4 bits.**
- **Word**: **two** or **more bytes** make a word.
- **Kilobyte**: **1024 bytes**
- **Megabyte**: **1024 KB**
- **Gigabyte**: **1024 MB**
- **Terabyte**: **1024 GB**
- **Petabyte: 1024 TB**
- **Exabyte: 1024 PB**

Word length refers to the number of bits in each word.

Example: let 11110000 represent a binary figure

There are 8 bits in the figure. Count

These 8 figures make up a byte

1111 or 0000 is a nibble this is because they are 4 of the 8 figures thus half

11110000 and 11110000 are two figures thus a word

1111000011110000 makes a **word** that has **16 bits** thus word length

Computer storage is measured in bytes, kilobytes (KB), megabytes (MB), gigabytes (GB) and increasingly terabytes (TB). One byte is one character of information, and is comprised of **eight bits** (or eight digital 1's or 0's). Technically a kilobyte is **1024** bytes, a megabyte **1024** kilobytes, a gigabyte **1024** megabytes, and a terabyte **1024** gigabytes. This said, whilst this remains true when it comes to a computer's internal RAM and solid state storage devices (like USB memory sticks and flash memory cards), measures of hard disk capacity often take 1MB to be 1,000,000 bytes (not 1,024,768 bytes) and so on. This means that the storage capacity of two devices labeled as the same size can be different, and which remains an ongoing source of debate within the computer industry.

Any sensible computer user will plan for two categories of storage. These will comprise the storage necessary to keep **files internally** on their computer, as well as those media required to **back-up**, **transfer** and **archive data**. In turn, when deciding on suitable external storage devices, the key questions to be asked should be how much data actually needs to be stored, and whether the external data archive will be subject to random-access or incremental change.

## 2.2 STORAGE CAPACITY AND REQUIREMENTS

If a computer user is usually only going to create word processor documents and spreadsheets, then most of their files will probably be in the order of a few hundred KB or maybe occasionally a few MB in size. If, however, a computer is being used to store and manipulate digital photographs, then average file sizes will be in the region of several MB in size (and potentially tens of MB if professional digital photography is being conducted). Yet another level of storage higher, if a computer is being used to edit and store video, individual file sizes will probably be measured in hundreds of MB or even a few GB. For example, an hour of DV format video footage consumes about 12GB of storage. Non-compressed video requires even more space -- for example 2GB for every minute of standard definition footage, and 9.38GB for each minute of non-compressed 1920x1080 high definition video. Knowing what a computer is going to be used for (and of course many computers are used for a variety of purposes) is hence very important when planning storage requirements.

In addition to capacity requirements, whether the data in a user's back-up archive will have to change in a random-access or incremental fashion can be a critical factor in the choice of external storage devices. A digital photographer, for example, will probably have incremental back-up requirements where each time they complete a shoot they will want to take a back-up of several hundred MB or a few GB of photographs that will subsequently never change. In other words they will want to keep a permanent record of an historical digital state of the world. Writing data like photographs to write-once media (such as CD-R or DVD-R as discussed below) would hence be perfectly acceptable. The photographer's total archive may be hundreds of GB in size, but would only be added to incrementally with previously stored data never being changed.

In contrast, somebody producing 3D computer animation may be re-rendering tens of GB of output on a regular basis to replace previous files in a random-access fashion. In this situation not only would re-writable media be more suitable, but the speed of the back-up device would become far more critical. Having to take a copy of even 50GB of data at the end of a working day is a very different proposition to a few GB, let alone a few tens or hundreds of MB. Further discussion of the suitability of different media for incremental and random-access back-up continues within the following explanation of available storage devices and technologies.

Different types of data require different amounts of storage space. Some examples of different memory requirements are shown in the table below:

| Data | Storage |
|---|---|
| One extended-ASCII character in a text file (eg 'A') | 1 byte |
| The word 'Monday' in a document | 6 bytes |
| A plain-text email | 2 KB |
| 64 pixel x 64 pixel GIF | 12 KB |
| Hi-resolution 2000 x 2000 pixel RAW photo | 11.4 MB |
| Three minute MP3 audio file | 3 MB |
| One minute uncompressed WAV audio file | 15 MB |
| One hour film compressed as MPEG4 | 4 GB |

### 2.2.1 Types of Data storage

A data storage component is a computer component used for data recording (storing) such as: CPU registers and cache, ROM, Flash disks, hard disks, CD-ROMs (optical discs),

The storage components can be differentiated by their **characteristics** or **properties** but to simplify, there are three main or basic characteristics:

a) **Latency/response time**: how much time it takes between making a request and receiving the data requested.
b) **Capacity**: how much it can hold (remember).
c) **Throughput**: how fast can this data be retrieved or stored.

Based on the above characteristics, in a typical computer there are **four** physical types of data storage devices:

1) CPU registers – this is where the CPU manipulates the data – no latency, very low capacity.
2) CPU cache – memory directly accessible to the CPU unit – some latency for requesting memory.
3) RAM – some noticeable latency associated with accessing this memory but at the same time, significantly larger **capacity**.
4) Disk – significant latency – very large capacity (in database world). This is also sometimes referred to as "main storage" as it is the only non-volatile memory. That is memory that does not get reset on computer shut-down.

A modern computer uses sophisticated rules and techniques to manage these. Typically the hardware manages the CPU cache automatically, and the software controls how CPU registers, RAM, and Disk are used. The CPU registers are a bit more special, as usually they are not dynamically controlled. Rather when a given program is compiled, it has a built-in specific CPU registers usage.

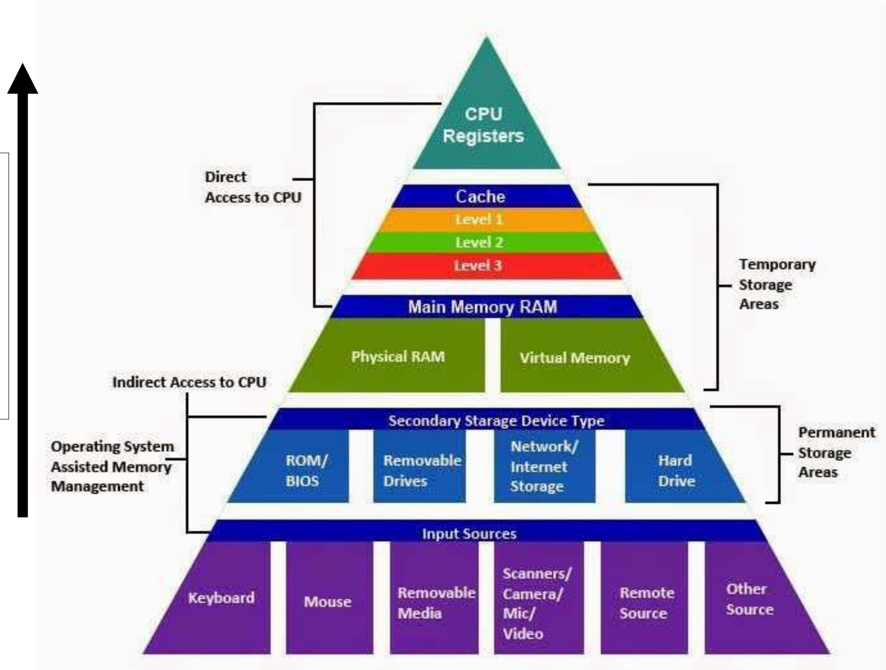
The total memory capacity of a computer can be visualized by hierarchy of components. The memory hierarchy system consists of all storage devices contained in a computer system from the slow Auxiliary Memory to fast Main Memory and to smaller Cache memory.

Increase in **speed**

Increase in **cost**

Reduction in storage **capacity**

Decrease in data **persistency**




Memory Hierarchy

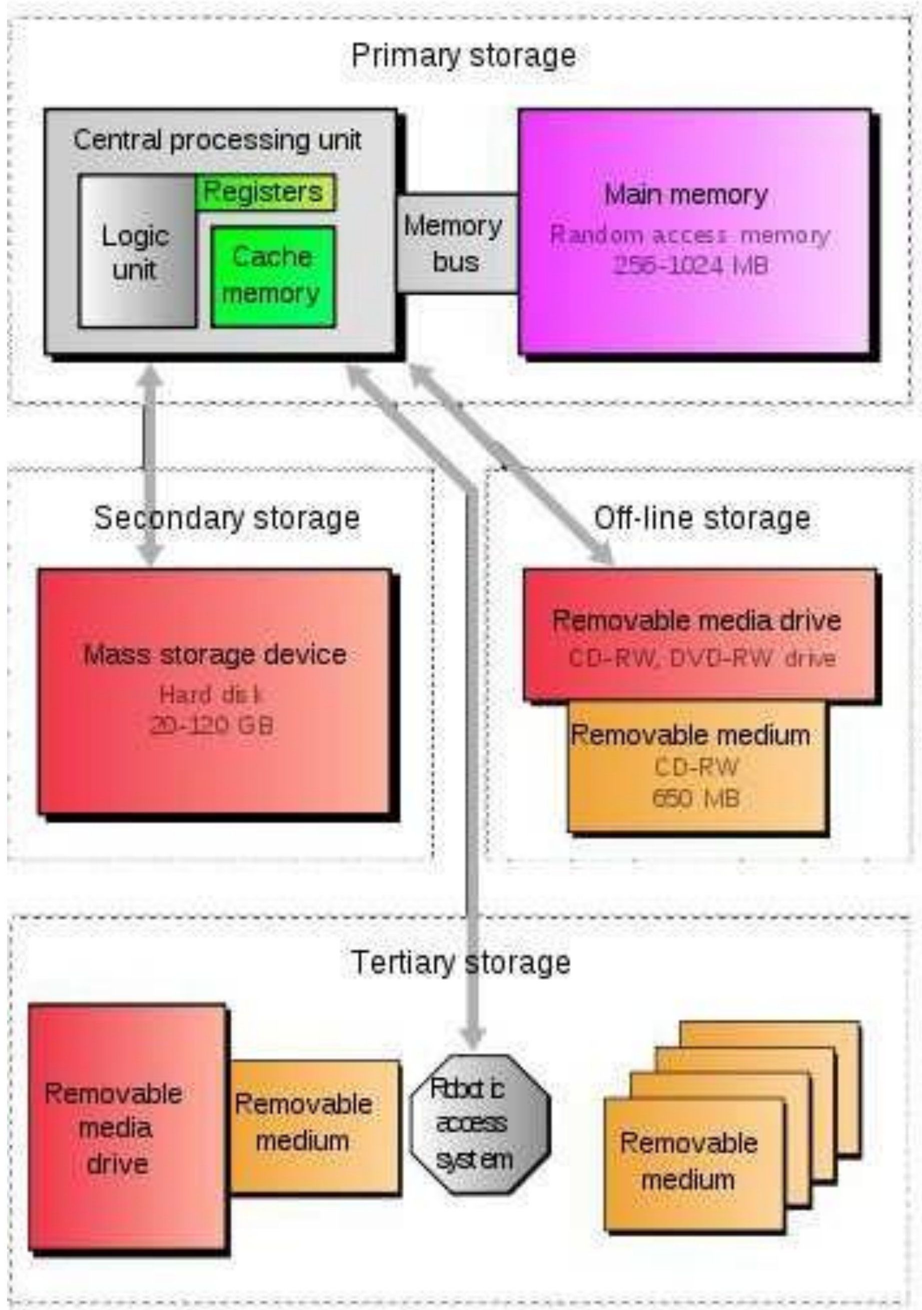
Auxiliary memory access time is generally **1000 times** that of the main memory, hence it is at the bottom of the hierarchy.

The main memory occupies the central position because it is equipped to communicate directly with the CPU and with auxiliary memory devices through Input/output processor (I/O).

When the program not residing in main memory is needed by the CPU, they are brought in from auxiliary memory. Programs not currently needed in main memory are transferred into auxiliary memory to provide space in main memory for other programs that are currently in use.

The cache memory is used to store program data which is currently being executed in the CPU. Approximate access time ratio between cache memory and main memory is about 1 to 7~10

# Hierarchy Storage




Memory Hierarchy

In practice, a memory system is a **hierarchy** of storage devices with different **capacities**, **costs**, and **access times**. CPU registers hold the most frequently used **data**. Small, fast **cache** memories nearby the CPU act as **staging areas** for a subset of the data and instructions stored in the relatively slow main memory. The main memory stages data stored on large, slow disks, which in turn often serve as staging areas for data stored on the disks or tapes of other machines connected by networks.

Memory hierarchies work because well-written programs tend to **access** the storage at any particular level more frequently than they access the storage at the next lower level. So the storage at the next level can be **slower**, and thus **larger** and **cheaper** per bit. The overall effect is a large pool of memory that costs as much as the cheap storage near the bottom of the hierarchy, but that serves data to programs at the *rate* of the **fast storage** near the top of the hierarchy.

As a programmer, you need to understand the memory hierarchy because it has a big impact on the **performance** of your applications. If the data your program needs are stored in a CPU register, then they can be accessed in **zero cycles** during the execution of the instruction. If stored in a cache, **1 to 30 cycles**. If stored in main memory, **50 to 200 cycles**. And if stored in disk tens of **millions of cycles**!

Here, then, is a fundamental and enduring idea in computer systems: If you understand how the system **moves data** up and down the memory hierarchy, then you can write your application programs so that their data items are stored **higher** in the **hierarchy**, where the CPU can access them more quickly.

This idea centers on a fundamental property of computer programs known as locality. Programs with good locality tend to access the same set of data items over and over again, or they tend to access sets of nearby data items. Programs with good locality tend to access more data items from the upper levels of the memory hierarchy than programs with poor locality, and thus run faster. For example, the running times of different matrix multiplication kernels that perform the same number of arithmetic operations, but have different degrees of locality, can vary by a factor of 20!

## 2.3 TYPES OF COMPUTER MEMORY

Much of the success of computer technology stems from the tremendous progress in storage technology. Early computers had a **few** kilobytes of random-access memory. The earliest IBM PCs **didn't** even **have** a hard disk. That changed with the introduction of the IBM PC-XT in 1982, with its **10-megabyte disk**. By the year 2010, typical machines had 150,000 times as much disk storage, and the amount of storage was increasing by a factor of 2 every couple of years.

A memory is just like a **human brain**. It is used to store data and instructions. Computer memory is the **storage space** in the computer, where data is to be processed and instructions required for processing are stored. The memory is divided into a large number of small parts called cells. Each location or cell has a unique address, which varies from zero to 'memory size minus one'. For example, if the computer has 64k words, then this memory unit has 64 * 1024 = 65536 memory locations. The address of these locations varies from **0** to **65535**.

A memory unit is the collection of storage units or devices together. The memory unit stores the binary information in the form of bits.

Based on **data retention** capabilities, memory/storage is classified into 2 categories:

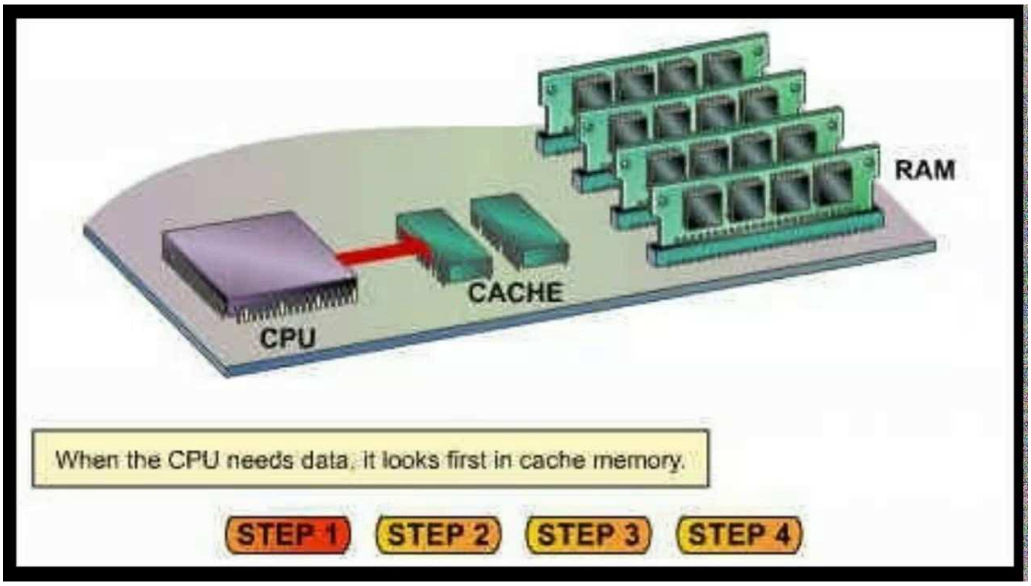
- Volatile Memory: is computer storage that only maintains its **data** while the device is **powered** and **loses**, when power is switched **off**. e.g. RAM (Random Access Memory)
- Non-Volatile Memory: This is a **permanent** storage and does **not lose** any data when power is switched off. E.g. ROM

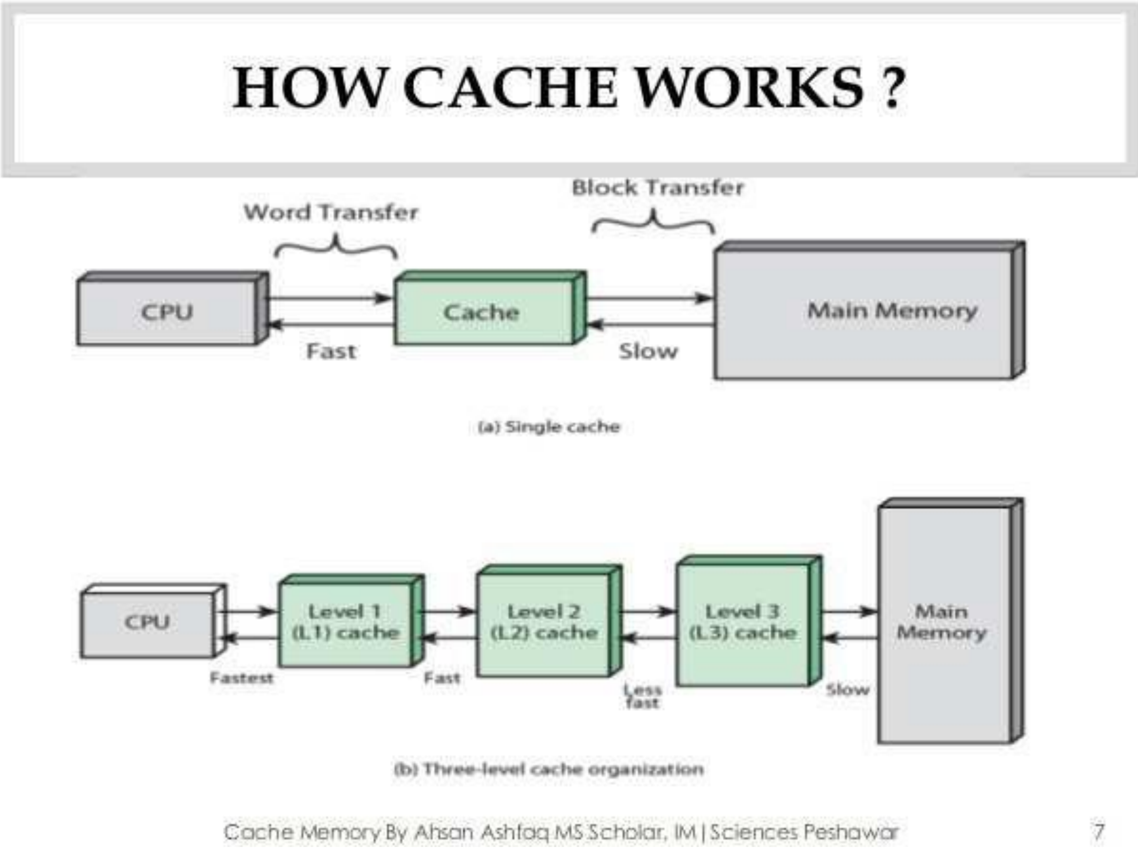
The **physical** computer memory is primarily of three **types**:

1) Cache Memory
2) Primary Memory/Main Memory
3) Secondary Memory

### 2.3.1 Cache Memory

Cache memory is a very high speed **semiconductor** memory which can **speed up** the CPU. It acts as a **buffer** between the **CPU** and the **main memory**. It is used to hold those parts of data and program which are most *frequently* used by the CPU. The parts of data and programs are transferred from the disk to cache memory by the **operating system**, from where the CPU can access them.






**Advantages of cache memory:**

a) Cache memory is **faster** than main memory.

b) It consumes ***less*** **access time** as compared to **main** memory.

c) It stores the program that can be executed within a **short** period of **time**.

d) It stores data for temporary use.

Disadvantages of cache memory

a) Cache memory has limited capacity.

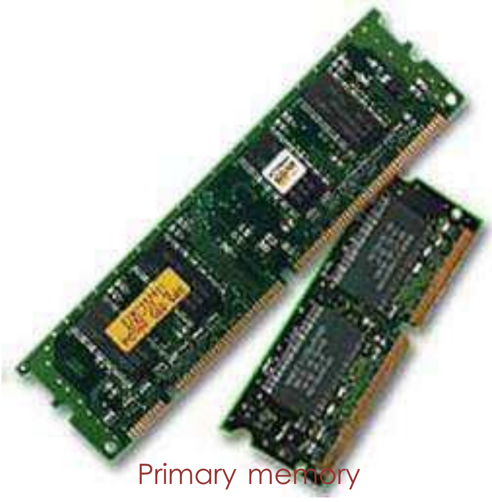
b) It is very expensive.

### 2.3.2 Primary Memory (Main Memory)

Primary memory holds only those data and instructions on which the computer is *currently* working. It has a limited capacity and data is lost when power is switched off. It is generally made up of **semiconductor** device. These memories are **not** as **fast** as registers. The data and instruction required to be processed resides in the main memory. It is divided into two subcategories RAM and ROM.

### 2.3.2.1 Random Access Memory (RAM)

RAM (Random Access Memory) is the internal memory of the CPU for **storing** data, program, and program result. It is a **read/write** memory which stores data when the machine is working. As soon as the machine is switched **off**, data is **erased**.




Access time in RAM is **independent** of the **address**, that is, each storage location inside the memory is as easy to reach as other **locations** and takes the **same** amount of **time**. Data in the RAM can be accessed **randomly** but it is very expensive.

RAM is volatile, i.e. data stored in it is lost when we switch off the computer or if there is a power failure. Hence, a backup Uninterruptible Power System (UPS) is often used with computers. RAM is **small**, both in terms of its physical size and in the amount of data it can hold.

The contents of volatile storage, like RAM, are **erased** when the system's power is turned **off** or **interrupted**. When you are working on a document, it is kept in RAM, and if the computer loses power, your work will be lost. For this reason, you should **save** your document to a file on a non-volatile storage medium, such as your **hard drive**.

A part of the RAM is allocated for the 'clipboard'. This is the area that stores the information when you CUT, COPY and PASTE from within programs such as Microsoft Word and Excel.

As computer programs and operating systems have become more complex, the size of RAM has increased. Today most computers are sold with 2GB, 4GB, 8GB, etc of RAM.

RAM comes in two varieties—**static** and **dynamic**.

Static RAM (SRAM) is faster and significantly more expensive than Dynamic RAM (DRAM). **SRAM** is used for **cache** memories, both on and off the CPU chip. **DRAM** is used for the **main** memory plus the **frame buffer** of a graphics system.

Typically, a desktop system will have no more than a few megabytes of SRAM, but hundreds or thousands of megabytes of DRAM.

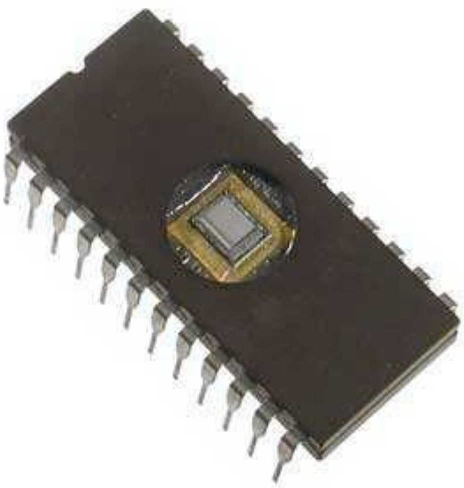
**Note:** A computer cannot run without the primary memory.

#### 2.3.2.2 Read-only Memory

Data stored in Read Only Memory (ROM) is not erased when the power is switched off - The information is stored **permanently** in such memories during manufacture.

A Motherboard within a PC may contain a ROM chip. This chip contains the instructions required to start up the computer.

Whenever some data needs to be stored on a permanent basis, a ROM is the best solution. ROM chips are not only used in the computer but also in other electronic items like washing machine, microwave oven and cars. (Car computers will contain ROM chips that store the basic information required to run the car engine).



The **BIOS** in a PC is stored on a **ROM chip**. Early PCs used a **ROM BIOS**, but PCs today use a **flash memory** BIOS because it can be updated in place. In order to update a ROM BIOS, the computer case had to be opened, and the ROM chip had to be located and replaced.

Nevertheless, a BIOS stored in ROM is more secure than one in flash memory, because it cannot be changed from an external source.


ROM BIOS

- **PROM** - (programmable read-only memory) is a memory chip on which data can be written only once. Once a program has been written onto a PROM, it remains there forever. Unlike main memory, PROMs retain their contents when the computer is turned off.

  The difference between a PROM and a ROM (read-only memory) is that a PROM is manufactured as blank memory, whereas a ROM is programmed during the manufacturing process. To write data onto a PROM chip, you need a special device called a **PROM programmer** or **PROM burner**. The process of programming a PROM is sometimes called burning the PROM.
- **EPROM** - (erasable programmable read-only memory) is a special type of PROM that can be erased by exposing it to ultraviolet light. Once it is erased, it can be reprogrammed. An EEPROM is similar to a PROM, but requires only electricity to be erased.
- **EEPROM** - (electrically erasable programmable read-only memory). Pronounced e-e-prom, an EEPROM is a special type of PROM that can be erased by exposing it to an electrical charge. Like other types of PROM, EEPROM retains its contents even when the power is turned off. Also like other types of ROM, EEPROM is not as fast as RAM. A special **type** of EEPROM, referred to as flash memory or flash EEPROM, can be **rewritten** while it is **in** the **computer** rather than requiring a PROM reader.

### 2.3.3 Secondary Memory

This type of memory is also known as **external memory** or **auxiliary memory**. It is *slower* than the main memory. These are used for storing data/information permanently. CPU does not directly access these memories; instead they are accessed via input-output routines. The contents of secondary memories are first transferred to the main memory, and then the CPU can access it.

- **Examples:** Secondary memory devices include magnetic disks like **hard drives**, **external hard drives** and **floppy disks**; optical disks such as **CDs** and **CD-ROMs, DVD-ROMs**; magnetic tapes and solid state .

Characteristics of Secondary Memory

- Based on the technologies used to make them, storage devices can be grouped into: Magnetic devices, Optical devices, Solid state devices
- It is known as the backup memory.
- It is a non-volatile memory.
- Data is permanently stored even if power is switched off.
- It is used for storage of data in a computer.
- Computer may run without secondary memory.
- Slower than primary memories.

### 2.3.4 Network and Online Storage

Many computer users may never have to back-up their data to a removable media or external hard drive (and indeed may be discouraged or banned from doing so) because their files will be stored and backed-up on their company's network servers. Even in the home, back-up to a server is also now an option for many. Far more fundamentally, all of those switching in whole or part to **cloud computing** are now **storing** at least some of their *data* **ou**t on the Internet. And even those not using **online applications** and **processing power** now have the option of backing up moderate amounts of *data* online, and often for **free**!

Files stored and/or backed-up **online** are still **saved** to a **hard disk** rather than to some magic, new alternative media. However, the fact that the disk is *located* **remotely** to your computer, can be *accessed* from **anywhere**, and is probably *backed up* by the service provider, can make online storage and back-up very **attractive**. Indeed, when Google added 1GB of free online storage for any type of file to its **Google Docs** online office suite it even stated in the press release that one of their intentions was to remove the need for people to use and carry USB memory keys.

Cloud data storage services come in **two** flavours. Some simply provide **online filespace**, whilst others additionally include a **back-up synchronization service**. An online filespace can be thought of as a **hard disk** in the **cloud** that can be accessed with a *web browser* to upload or download files. (Google Docs offers 15GB of free online storage. Another popular online filespace provider is **box.net**).

For those people who may forget to regularly **back-up** their data to one of the above, there are **cloud** storage services that **automate** the process. These require the installation of a piece of software on each computer that uses them. This local application then **automatically** *backs up* data to the **cloud**, and may also *synchronize* it across PCs and devices. Such a service is offered by **Dropbox**, which describes itself as a kind of 'magic pocket' that becomes available on all of your computing devices.

## 2.4 SECONDARY MEMORY

### 2.4.1 Hard Disk Storage

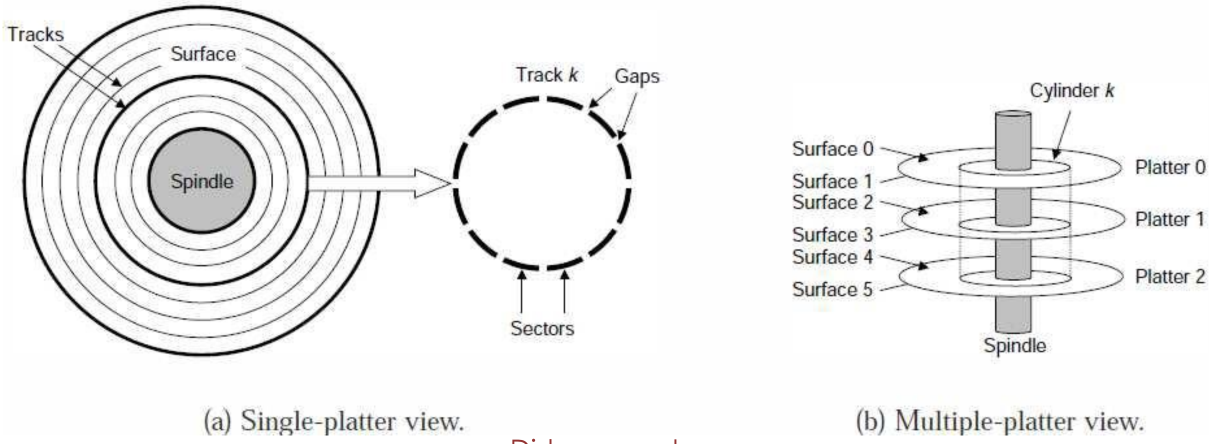
Disks are workhorse storage devices that hold enormous amounts of **data**, in the order of hundreds to thousands of gigabytes, as opposed to the hundreds or thousands of megabytes in a RAM-based memory.

However, it takes a hundred thousand times longer to **read** information from a **disk** than from DRAM and a million times longer than from SRAM.

**Hard disk drive** (HDD), **hard disk**, **hard drive** or **fixed disks** are today the most common means of high capacity computer storage, with most desktop and laptop computers still relying on a spinning hard disk to store their operating system, application programs and at least some user data.

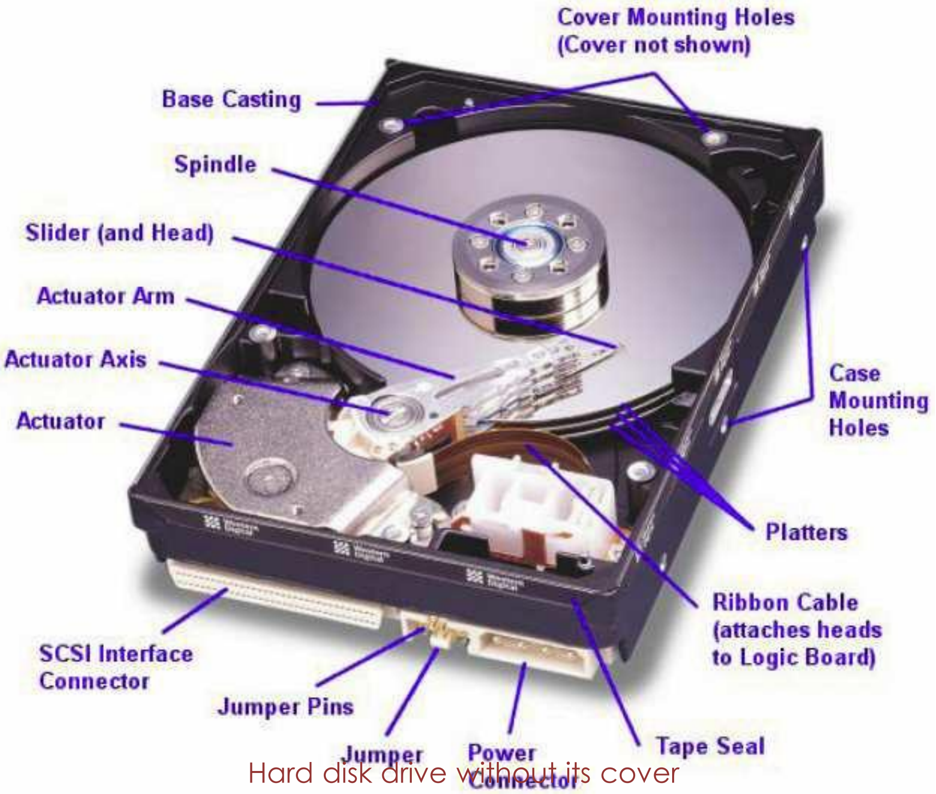
#### 2.4.1.1 Disk Geometry

Disks are constructed from **platters**. Each platter consists of **two** sides, or surfaces, that are coated with magnetic **recording material**. A rotating spindle in the **center** of the platter spins the platter at a **fixed** rotational **rate**, typically between 5,400 and 15,000 *revolutions per minute* (RPM) - which is why it makes that **whirring noise**. A disk will typically contain one or more of these platters encased in a **sealed** container. Less than a hairs breadth above the disk, a magnetic **read** and **write** **head** (**drive head**) creates the **1s** and **0s** on to the circular tracks beneath.



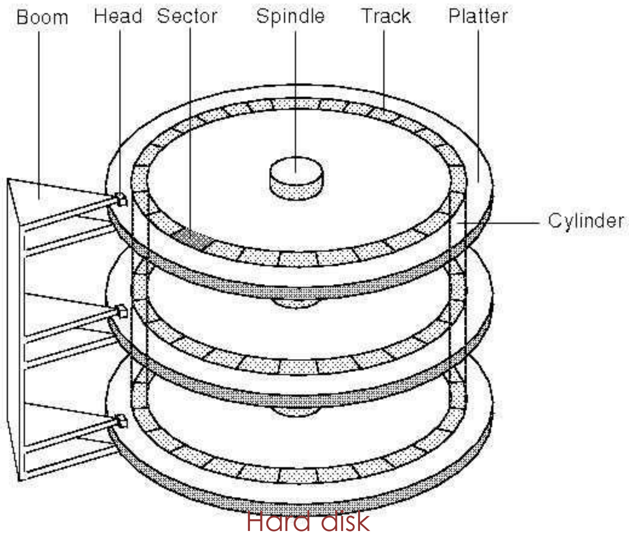

Disk geometry

The figure above shows the geometry of a typical disk surface. Each **surface** consists of a collection of concentric **rings** called <u>tracks</u>. Each track is **partitioned** into a collection of <u>sectors</u>. Each sector contains an **equal number** of data **bits** (typically 512 bytes) encoded in the magnetic material on the <u>sector</u>. Sectors are **separated** by **gaps** where <u>no data</u> bits are stored. Gaps store <u>formatting bits</u> that **identify** sectors.




Hard disk drive without its cover

Hard disk drives can transfer data directly to other computer hardware via a range of three interface types (SATA, IDE/UDMA, or SCSI - *Each kind of interface has a different type of* *socket so they cannot get mixed up accidentally*) and come in a range of speeds from 4200 to 15000 revolutions per minute (RPM). The hard disk shown in the above image has a SCSI 'interface'.




Hard disk

A disk consists of one or more platters stacked on top of each other and encased in a sealed package, as shown in the figure above. The entire assembly is often referred to as a **disk drive**, although we will usually refer to it as simply a **disk**. We will sometime refer to disks as rotating disks to distinguish them from flash-based solid state disks (SSDs), which have **no moving** parts. Disk manufacturers describe the geometry of multiple-platter drives in terms of **cylinders**, where a cylinder is the **collection** of **tracks** on **all** the surfaces that are equidistant from the center of the **spindle**. For example, if a drive has **three** platters and **six** surfaces, and the tracks on each surface are numbered consistently, then cylinder **k** is the collection of the **six** instances of track k.

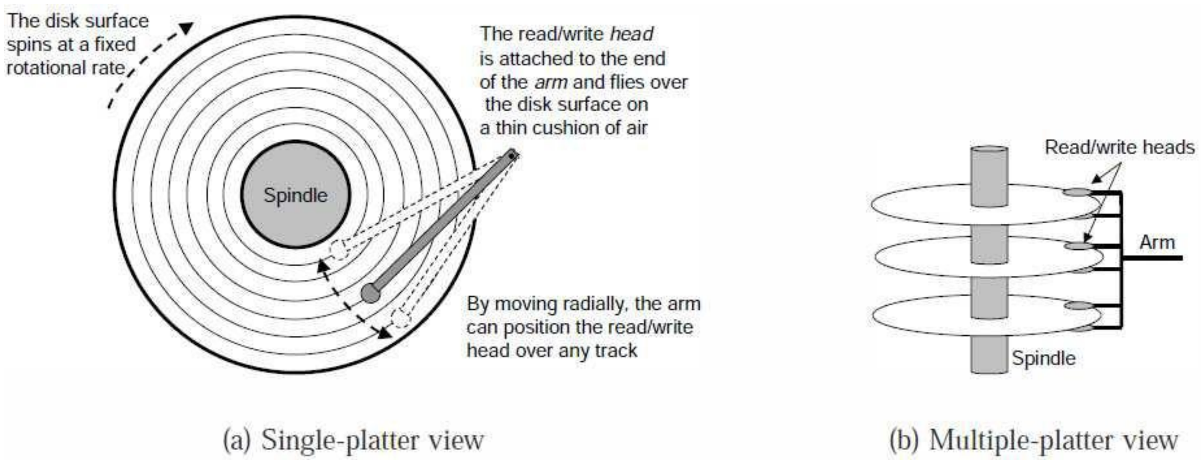
Hard disks are almost always manufactured with either 3.5" or 2.5" platters (although just to break the rule a few smaller -- most notably 1.8" -- and even some larger platter disks are made by some manufacturers). For many years 3.5" hard disks have been standard for desktop computers and servers, and 2.5" hard disks for laptops. Yet this is now starting to change, with enterprise class 2.5" hard disks now increasingly being used in servers and some desktop computers due to their low power requirements. Indeed, the fact that Western Digital's top-of-the-range Velociraptor hard drives now use a 2.5" rather than a 3.5" mechanism speaks volumes and probably indicates that within a few years most spinning hard disk drives are likely to be 2.5". (Note that some raptor models are supplied in a metal "sled" for fitting into a 3.5" bay)

A 3.5" (left) and 2.5" (right) hard disk drive.

Whilst at least one hard disk is usually required inside a computer as the "**system disk**", additional hard disk drives can be located either "<u>internally</u>" inside the main computer case, or connected "<u>externally</u>" as an independent hardware unit. A second internal hard disk is highly recommended where a user regularly works on very **large media files** (typically digital video files) that are always accessed directly **off** the hard disk, rather than loaded into RAM. Where such files are loaded off a computer's system disk, the disk drive heads are inevitably constantly nipping back and forth between accessing the large media file and writing temporary operating system files, and this both degrades performance and reduces the life of the disk.

### 2.4.1.2 Disk Operation and Capacity

Disks **read** and **write** bits stored on the <u>magnetic surface</u> using a read/write **head** connected to the end of an **actuator arm**, as shown in the figure (a) below. By moving the arm back and forth along its radial axis, the drive can **position** the head over <u>any track</u> on the surface. This mechanical motion is known as a <u>**seek**</u>. Once the head is positioned over the desired track, then as each bit on the track passes underneath, the head can either **sense** the value of the bit (**read** the bit) or **alter** the value of the bit (**write** the bit). Disks with **multiple** platters have a **separate** read/write **head** for <u>each surface</u>, as shown in figure (b). The heads are lined up vertically and move in unison. At any point in time, all heads are positioned on the same cylinder.




Disk dynamics

The read/write **head** at the end of the arm flies (literally) on a thin cushion of air over the disk surface at a height of about **0.1 microns** and a speed of about **80 km/h**. This is analogous to placing a *25 meter* (83 ft) **tower** on its side and flying it around the world at a height of 2.5 cm (1 inch) **above** the ground, with each **orbit** of the earth taking only 8 seconds! At these tolerances, a tiny piece of dust on the surface is like a huge boulder.

If the head were to strike one of these boulders, the head would cease flying and crash into the surface (a so-called **head crash**). For this reason, disks are always **sealed** in airtight packages.

Disks read and write data in **sector-sized** blocks. The **access time** for a sector has three main components: *seek time*, *rotational latency*, and *transfer time*:

a) **Seek time**: To read the contents of some target sector, the arm first positions the head over the track that contains the target sector. The time required to move the arm is called the seek time. The seek time, $T_{seek}$, depends on the **previous position** of the head and the **speed** that the arm moves across the surface. The **average seek time** in modern drives, $T_{avg\ seek}$, measured by taking the mean of several thousand seeks to **random sectors**, is typically on the order of **3** to ***9 ms***. The maximum time for a single seek, $T_{max\ seek}$, can be as high as **20** ***ms***.

b) **Rotational latency**: Once the head is in position **over** the track, the drive **waits** for the **first bit** of the target sector to **pass under** the head. The performance of this step depends on both the **position** of the **surface** when the head arrives at the target sector and the rotational **speed** of the disk. In the worst case, the head just misses the target sector and waits for the disk to make a full rotation. Thus, the maximum rotational latency, in seconds, is given by:

$$T_{max\,rotation} = \frac{1}{\text{RPM}} \times \frac{60\text{ secs}}{1\text{ min}}$$

c) **Transfer time**: When the **first bit** of the target sector is **under** the **head**, the drive can begin to **read** or **write** the **contents** of the sector. The transfer time for one sector depends on the rotational **speed** and the **number** of sectors per track. Thus, we can roughly estimate the average transfer time for one sector in seconds as:

$$T_{avg\,transfer} = \frac{1}{\text{RPM}} \times \frac{1}{(\text{average \# sectors/track})} \times \frac{60\text{ secs}}{1\text{ min}}$$

We can estimate the average time to **access** the **contents** of a disk sector as the **sum** of the average seek time, the average rotational latency, and the average transfer time. For example, consider a disk with the following parameters:

| **Parameter** | **Value** |
|---|---|
| Rotational rate | 7200 RPM |
| $T_{avg\ seek}$ | 9 ms |
| Average # sectors/track | 400 |

For this disk, the average rotational latency (in ms) is

$$\begin{aligned} T_{avg\,rotation} &= 1/2 \times T_{max\,rotation} \\ &= 1/2 \times (60\text{ secs} / 7200\text{ RPM}) \times 1000\text{ ms/sec} \\ &\approx 4\text{ ms} \end{aligned}$$

The average transfer time is

$$\begin{aligned} T_{avg\,transfer} &= 60 / 7200\text{ RPM} \times 1 / 400\text{ sectors/track} \times 1000\text{ ms/sec} \\ &\approx 0.02\text{ ms} \end{aligned}$$

Putting it all together, the total estimated access time is

$$\begin{aligned} T_{access} &= T_{avg\,seek} + T_{avg\,rotation} + T_{avg\,transfer} \\ &= 9\text{ ms} + 4\text{ ms} + 0.02\text{ ms} \\ &= 13.02\text{ ms} \end{aligned}$$

This example illustrates some important points:

- The time to access the 512 bytes in a disk sector is dominated by the **seek time** and the **rotational latency**. Accessing the first byte in the sector takes a **long time**, but the remaining bytes are essentially **free**.
- Since the **seek time** and **rotational latency** are roughly the same, twice the seek time is a simple and reasonable rule for **estimating** disk access time.

## Disk Capacity

The maximum number of bits that can be recorded by a disk is known as its **maximum capacity**, or simply **capacity**. Disk capacity is determined by the following technology factors:

1) **Recording density** (**bits/in**): The number of bits that can be squeezed into a 1-inch segment of a track.
2) **Track density** (**tracks/in**): The number of tracks that can be squeezed into a 1-inch segment of the radius extending from the center of the platter.
3) **Areal density** (**bits/in$^2$**): The product of the recording density and the track density.

Disk manufacturers work tirelessly to **increase** areal density (and thus capacity), and this is doubling every few years. The **original** disks, designed in an age of **low areal density**, partitioned every track into the **same number** of sectors, which was determined by the **number** of **sectors** that could be recorded on the innermost track. To maintain a fixed number of **sectors per track**, the sectors were spaced farther apart on the **outer tracks**. This was a reasonable approach when areal densities were relatively low. However, as areal densities increased, the gaps between sectors (where no data bits were stored) became unacceptably large. Thus, modern high-capacity disks use a technique known as **multiple zone recording**, where the set of **cylinders** is partitioned into disjoint subsets known as recording zones. Each zone consists of a **contiguous** collection of cylinders. Each **track** in each **cylinder** in a zone has the **same** number of sectors, which is determined by the **number** of **sectors** that can be packed into the innermost **track** of the zone.

The capacity of a disk is given by the following **formula**:

$$\text{Disk capacity} = \frac{\#\text{ bytes}}{\text{sector}} \times \frac{\text{average }\#\text{ sectors}}{\text{track}} \times \frac{\#\text{ tracks}}{\text{surface}} \times \frac{\#\text{ surfaces}}{\text{platter}} \times \frac{\#\text{ platters}}{\text{disk}}$$

For example, suppose we have a disk with five platters, 512 bytes per sector, 20,000 tracks per surface, and an average of 300 sectors per track. Then the capacity of the disk is:

$$\begin{aligned}\text{Disk capacity} &= \frac{512 \text{ bytes}}{\text{sector}} \times \frac{300 \text{ sectors}}{\text{track}} \times \frac{20{,}000 \text{ tracks}}{\text{surface}} \times \frac{2 \text{ surfaces}}{\text{platter}} \times \frac{5 \text{ platters}}{\text{disk}} \\ &= 30{,}720{,}000{,}000 \text{ bytes} \\ &= 30.72 \text{ GB.}\end{aligned}$$

**Notice** that manufacturers express disk capacity in units of gigabytes (GB), where 1 GB = $10^9$ bytes.

Practice Problem:

What is the capacity of a disk with two platters, **10,000 cylinders**, an average of **400 sectors** per track, and **512 bytes** per sector?

**Advantages of Hard disk storage:**

a) Necessary to support the way your computer works.
b) Offers a large storage capacity.
c) Stores and retrieves data much faster than a CD-ROM/DVD-ROM.
d) Stored items not lost when you switch off the computer.
e) Usually fixed inside the computer so doesn't **easily** get lost or damaged.
f) Cheap on a cost per megabyte compared to other storage media.

**Disadvantages of Hard disk storage:**

a) Far slower to access data than the ROM or RAM chips because the read-write heads have to move to the correct part of the disk first.
b) Hard disks can crash which stops the computer from working
c) Regular crashes can damage the surface of the disk, leading to loss of data in that sector.
d) The disk is fixed inside the computer and cannot easily be transferred to another computer.

### 2.4.2 Redundant Array of Independent Disks (RAID)

On servers and high-end PC workstations (such as those used for high-end video editing), at least two hard disks are often linked together using a technology called RAID. This stands for "redundant array of independent disks" (or sometimes "redundant array of inexpensive drives"), and stores the data in each user volume on multiple physical drives.


Under RAID 1, the contents of each file are divided or "stripped" across two or more disks to increase read-write performance. Under RAID 1, a complete copy of each file is stored on two seperate drives, so protecting against a drive failure.

Many possible RAID configurations are available. The first is called "RAID 0". This divides or "strips" the data in a storage volume across two or more disks, with half of each file written to one disk, and half to another. This improves overall read/write performance without sacrificing capacity. So, for example (as shown above), two 1TB drives may be linked to form a 2TB array. Because this virtual volume is **faster** than either of its component disks, RAID 0 is commonly used on video editing workstations.

In contrast to RAID 0, "RAID 1" is primarily intended to protect data against **hardware failure**. Here data is duplicated or "mirrored" across two or more disks. The data redundancy so created means that if one physical drive fails there is still a complete copy of its contents on another drive. However, this does mean that drive capacity is sacrificed. For example (as shown above), a 1TB RAID 1 volume requires two 1TB disks. While data write performance is not improved by using RAID 1, data read times are increased as **multiple files** can be **accessed simultaneously** from different physical drives.


Under RAID 5, data is stripped across two drives, but with parity data (maintaining a record of the differences of the data blocks on each drive) written to a third to allow data recovery in the event of a drive failure. Under RAID 10, data is stripped and mirrored.

If more than two drives are used, several other configurations become possible. For example, using three of more drives, "RAID 5" strikes a **balance** between **speed** and **redundancy** by stripping data across two drives but also writing "parity" data to a third. **Parity data** maintains a record of the differences between the blocks of data on the other drives, in turn permitting file restoration in the event of a drive failure.

"RAID 10" strips and mirrors data across four or more drives to provide the **gold standard** in **performance** and **redundancy**.

Many modern personal computer motherboards permit two SATA hard disk drives to set up in a RAID configuration. However, for users who do not require the extra speed provided by RAID 0, RAID 5 or RAID 10, there are relatively few benefits to be gained. Not least, it needs to be remembered that any hardware setup featuring more than one internal hard disk -- whether or not in a RAID configuration -- at best provides **marginal improvements** in data **security** and **integrity**. This is simply because it provides no more tolerance to the theft of the base unit, nor to power surges or computer power supply failures (which can simply fry two or more hard drives at once rather than one).

### 2.4.3 External Hard Disks / Direct Attached Storage (DAS)

Except where two internal hard disks are considered essential on the basis of performance (and possibly convenience), a second hard disk is today most advisably connected as an external unit, or what is sometimes now known as a "DAS" or **direct attached storage** drive. DAS external hard disks connect via a USB, firewire or an E-SATA interface with USB being the most common. The highest quality external hard drives routinely include at least two of these interfaces as standard, hence maximising their flexibility for moving data between different computers. Today some external hard disks can also be purchased as NAS (network attached storage) devices that can easily be shared between users across a network.

For most purposes, external hard disks offer comparable performance to most internal hard disks -- even when used for highly disk intensive processes such as video editing. This will be especially the case when a drive is connected via an interface such as USB 3.0. External hard disks also have the added convenience of being **easily physically separable** from the computer for **secure** and/or **off-site storage**. A user can also purchase additional external hard disks as their data storage requirements dictate.

External hard disk units normally include one 3.5" or 2.5" hard disk inside their case. Units with a 3.5" disk tend to offer a cheaper cost per megabyte. Units based on 2.5" drives are smaller and usually do not require an external power adapter (as a computer can supply enough electricity down the USB or firewire hard disk connection cable). Some external hard disks now include several physical disks inside one unit in some form of RAID configuration.

External hard disks offer **fast** and **high-capacity** external **storage** with a low cost-per-megabyte. In most instances, they are the only real option where *high capacity*, *random access* data archives have to be maintained. This said, many users will never have such archives, and there are several other disadvantages to DAS-style external hard disks.

For a start, whilst their cost-per-megabyte is low, their **cost-per-unit** is **high** compared to most optical media and solid state storage devices. External hard disks are also fairly **easy** to **physically damage** via impact or by getting them wet. Reliance on a single external hard drive can also place an entire data archive "in one basket", and is of no use at all where data either needs to be physically exchanged between users (as still happens even in the days of the Internet), or has to be accessed via a media device to which an external hard disk cannot be connected.

External hard drive **units** are also somewhat **cumbersome** for those wrangling tens of terabyes of data. For this reason, some people now transfer and store large quantities of data on bare hard disk connected to their computer as required (and usually via a flying E-SATA lead). However, this is hardly ideal, not least because both connectors and the drives themselves can become damaged. One solution for those who need to work with a great many hard drives is to house the disks in **caddies** that then slot into **PC-mounted bay**. Such caddies can sometimes also be connected to other computers via USB or E-SATA.

As a consequence of the above limitations, computer users handling both small and large quantities of data tend not to rely entirely on hard disk technology, and will therefore also make use of optical, solid-state or online storage technologies.

### 2.4.4 Optical Disk Storage

Optical storage technology involves an electronic storage medium that uses low-power laser beams to record and retrieve digital (binary) data. In optical-storage technology, a laser beam encodes digital data onto an optical, or laser disk in the form of tiny pits arranged in concentric tracks on the disk’s surface. A low-power laser scanner is used to “read” these pits, with variations in the intensity of reflected light from the pits being converted into electric signals.

Almost all optical storage involves the use of a 5" disk from which data is read by a laser. Optical media can be **read only** (such as commercial software, music or movie disks), **write-**

**once**, or **rewritable**, and currently exists in one of three basic formats. These are compact disk (CD), digital versatile disk (DVD) and Blu-Ray disk (BD). A fourth format called High-Definition DVD (HD DVD) is now dead-in-the-water.

a) **Compact disk (CD)** is a very **mature**, **low-cost** and **reliable** storage media particularly well suited for most personal computer users for incremental data archiving, as well as for the physical exchange of moderate-sized qualities of data. Writable compact disks can be either CD-R (Compact disk – Read: which are a **write-one** media) or CD-RW (Compact disk – Read/Write: to which data can be written and erased typically a few **hundred times**). The storage capacity of a compact disk is up to about 700MB for CD-R and somewhat less for CD-RW media (and depending on the format used to write the data).

   For the reliable back-up or exchange of up to 700MB of data there is still little to beat a compact disk. **Problems** accessing a CD-R disk are now very **rare**, and the cost of the disks is low if bought in bulk in "pancakes" of 25, 50 or 100 disks. The media are also physically very **durable** -- and certainly considerably more so than an external hard disk. The only real drawbacks to compact disks for data storage are the **speed of access** (even if a modern drive will write and verify a CD-R in well under five minutes) and the relatively limited capacity.

b) **Digital Versatile Disk (DVD)** followed compact disk into the optical storage arena, and most new computers are now equipped with an optical drive that will read and write both CD and DVD media. Due to format battles as yet unresolved (and now unlikely ever to be resolved!), DVD comes in two write-once formats (DVD-R and DVD+R), as well as two re-writable formats (DVD+RW and DVD-RW). Many older DVD writers will only write to either DVD-R and DVD-RW or to DVD+R and DVD+RW, so users need to take care to purchase the right media. Also many DVD drives will only read one type of rewritable media, and again users need to carefully take this into account when producing disks for other people. In general, it is fairly widely accepted that **DVD+R** is the most "**stable**" widely-readable write-once format (especially in domestic DVD video players) due to having superior error correction and burning control than DVD-R, whilst DVD+RW is the most flexible re-writable format.

   To make matters a little more confusing, Panasonic also created a format called DVD RAM. This is actually a superb re-writable technology (disks can reliably be re-written tens of thousands of times, as opposed realistically to hundreds of times for DVD-RW or DVD+RW). DVD RAM disks are also starting to be widely used in domestic DVD recorders, and are available in caddy units that can be either single or double sided. For video recording purposes and stable data archiving, DVD RAM is the media of choice. The only constraint is that many DVD drives still won't read or write DVD RAM disks (although the number is rapidly growing), with even fewer drives accepting the caddied disks that offer the media the best protection from dust, and hence maximum durability.

The standard **capacity** for any format of DVD media is **4.7GB**. Commercial read-only disks (as used to distribute movies) double this to 8.5GB by storing the data on two layers. Yet two more formats of DVD write-one disk (DVD-R DL and DVD+R DL) also exist to copy the same trick to raise writeable DVD data storage capacity to 8.5GB. However, once again not all drives will write these media, and in terms of cost per gigabyte it remains far cheaper (if less environmentally or archive-space friendly) to write two DVD-R or DVD+R disks rather than a single double layer (DL) disk. Double-sided DVD RAM disks -- that physically have to be turned over to read or write the other side -- have a capacity of 9.4GB.

c) **Blu-Ray disk** is the high-capacity successor to DVD, and the only surviving new optical disk media on the block. It was developed by the Blu-Ray Disk Association (BDA) as a higher-capacity replacement for DVD (and especially to allow for the distribution and home recording of movies in high definition). Whilst most of the attention in this area has until recently been focused on Blu-Ray's battle with HD DVD , for computer users Blu-Ray already offers write-once (BD-R) and re-writable (BD-RE) disk capacities of 25GB on a single-layer disk and 50GB on a dual layer disks. Just as importantly for the format, multi-hundred GB disks are already in the lab and on the consumer horizon.

More information on Blu-Ray can be found via the FAQ files at Blu-Ray.com.

It is worth noting for completeness that HD DVD was the contender to Blu-Ray Disk to replace DVD as the next generation optical storage media for both computer data storage and domestic video use. HD DVD disks had a 15GB capacity (lower than Blu-Ray disk at 25 or 50GB, and not that much higher than dual layer DVD-R DL or DVD+R DL disks at 8.5GB). HD DVD was created by Toshiba and NEC, and was backed by Microsoft. However, most movie studios and other computer industry players (including Sony, Panasonic, Philips, Samsung, Pioneer, Sharp, JVC, Hitachi, Mitsubishi, TDK, Thomson, LG, Apple, HP and Dell) were on the side of Blu-Ray. Indeed, it was following the defection in early 2008 of Warner Bros from HD DVD camp that Blu-Ray won the high capacity optical disk format wars.

Whatever format of optical disk media users choose, an ongoing debate concerns the **archival qualities** of all forms of optical media (ie how likely it is that data is going to remain on a disk in the long-term). Everybody seems to agree that archives should never be made on re-writable media (ie CD-RW, DVD+RW, DVD-RW or BD-RE), and advice to make new copies of optical media at least once every few years is not uncommon.

#### 2.3.4.1 A disc is not a Disk.

A **disc** refers to optical media, such as an audio CD, CD-ROM, DVD-ROM, DVD-RAM, or DVD-Video disc. Some discs are **read-only** (ROM), others allow you to burn content (**write** files) to the disc **once** (such as a CD-R or DVD-R, unless you do a multi-session burn), and some can be **erased** and **rewritten** over many times (such as CD-RW, DVD-RW, and DVD-RAM discs).

All discs are removable, meaning when you **unmount** or **eject** the disc from your machine, it physically comes out of your computer.

A **disk** refers to magnetic media, such as a floppy disk, the disk in your computer's hard drive, an external hard drive. Disks are always rewritable unless intentionally locked or write-protected. You can easily partition a disk into several smaller volumes, too.

Disks are usually sealed inside a metal or plastic casing (often, a disk and its enclosing mechanism are collectively known as a "hard drive").

### 2.4.5 Solid State Drives

Solid-state storage (SSS) is a type of computer storage media made from **silicon** microchips. SSS stores data **electronically** instead of magnetically, as spinning hard disk drives (HDDs) or magnetic oxide tape do. Solid-state storage is designed on the architecture and storage mechanism of **volatile** and **non–volatile** flash memory and stores data **electronically** by passing electrical charge across the memory chips.

Solid-state storage gets its name because such devices don't contain any **mechanical** or **moving** parts. This differs from the traditional electro-mechanical storage devices that read and write data from a rotating magnetic disk.

Solid-state storage is built on flash memory architecture, and therefore provides faster data read/write operation, consumes less power and is more resilient under **physical** shock. Solid-state storage media is developed using nonvolatile NAND and DRAM flash memory structure.

Solid state storage devices store computer data on **non-volatile** "flash" memory chips rather than by changing the surface properties of a magnetic or optical spinning disk. With no moving parts solid state drives (SSDs) -- are also very much the future for almost all forms of computer storage.


A solid state disk (left) and a traditional 2.5" hard disk (right).

It is very likely that **solid state drives** will replace **spinning hard disks** in most computers, with several manufacturers now offering hard-disk-replacement SSDs. These are often very fast indeed, extremely robust and use very little power. As pictured above, typically today most hard disk replacement SSDs are the same size -- and hence a direct replacement for -- a 2.5" hard drive. They also usually connect via a SATA interface.

Unfortunately the **prices** of solid state drives are currently **high**, with the lowest capacity disks (of 30 to 64GB) costing in the £60 to £120 bracket, and the highest capacity disks (currently up to 512GB) being in the region of £1,000. At present SSDs are therefore generally only being used in high-end PCs and laptops, and as a means of increasing robustness, reducing noise, decreasing power consumption, and often significantly decreasing boot-up times.

The above discussion of hard-disk replacement SSDs noted, at present for most people most solid state storage devices come in two basic forms: **flash memory cards** and **USB memory sticks**.

#### 2.4.5.1 Flash Memory Cards


Compact flash (CF) & secure digital (SD) cards, a Sony memory stick, and a USB memory key.

Flash memory cards were developed as a storage media for digital cameras and mobile computers. They consist of a small plastic package with a **contact array** that slots into a camera or other mobile computing device, or an appropriate memory card reader. Such readers usually have several slots (to accommodate the various formats of flash memory cards now available), and can either be integrated into a desktop computer or laptop's case, or connected via a USB port as an external hardware unit. In addition to still and video digital cameras, many mobile phones, tablets, netbooks, media players, audio recorders and televisions now also have slots for reading and writing a flash memory card.

The capacity of flash memory cards on the market currently ranges from 8MB to 64GB. There are also six major card formats, each with its own type of card slot. The most common format is the **secure digital** or **SD card** (see picture above). Next most popular are **compact flash** (CF) **cards,** which were the first popular format introduced, and which are used by many professional digital cameras and audio recorders. Finally come Sony's Memory stick format (and not to be confused with a USB memory stick), the **multi-media card** (MMC) and the **xD picture card** (XD card).

**a) SD CARDS**

SD cards are as noted above the most popular flash memory cards now on the market, and come in so many variants that they do require some explanation. For a start, SD cards come in three physical sizes. These comprise **standard-size SD cards** (first developed in 1999), smaller **mini SD cards** (introduced on some mobile phones in 2003), and the even smaller **micro SD cards**. The latter were invented in 2005 and are becoming increasingly popular on smartphones and tablets. While the larger cards cannot fit in smaller card slots, adapters are available to enable micro and mini cards to be accessed by any device that accepts a standard-size card.

SD cards also come in three capacity types known as **SD**, **SDHC** and **SDXC**. The first of these can store up to 2GB of data. SDHC (SD high capacity) cards are then available in capacities of between 4 and 32 GB, while SDXC (SD extended capacity) cards range from 32GB up to a theoretical 2TB (although at present only 64GB cards are on the market).

Because SD cards now come in three capacity styles, not all SD devices can access all SD cards of the same physical design. While standard SD cards can be read by anything, SDHC cards should only be inserted into SDHC or SDXC devices. SDXC cards must then only be used with the latest SDXC hardware. If you try to use an SDXC or SDHC card in a device that does not support it then you may lose data or even damage the card.

To further add to the confusion, SD cards are currently also available in five speed classes. These are known as **class 2**, **class 4**, **class 6**, **class 10**, and **UHS-1** (ultra high speed 1). Many manufacturers also label cards with a speed multiple that compares them to a CD-ROM drive. Absolute data transfer ratings are sometimes also included. However, in practical terms it is the speed class that really matters.

As may be expected, the higher an SD card's speed class, the faster it will be but the **more** it will **cost**. For most purposes class 4 or class 6 cards are fine. This said, class 10 or UHS-1 are best for high definition video or when otherwise handling large quantities of data.

#### 2.4.5.2 USB MEMORY STICKS

USB memory sticks (or USB memory keys, USB memory drives) are basically a combination of a flash **memory card** and a flash **memory card reader** in **one** handy and tiny **package**. Over the past five years, USB memory sticks have also become the dominant means of r*emovable, re-writable portable* data storage, and look set to remain so for some time. Not least this is because of their size, ever-increasing capacity (which currently ranges from about 512MB to 256GB), and perhaps most importantly their inherent durability.

As with other storage devices, there are two key factors to consider when selecting a USB memory stick: **capacity** and data **transfer speed**. Whilst most consumer attention remains on the former, the latter can be at least as critical. It is not uncommon for some USB memory sticks to transfer data at least ten or more times slower than others. The extent to which this matters depends on whether the data in your archive is only updated incrementally (with each new document), or more completely (with a large number or a few large files replaced on a regular basis). A USB memory stick that takes 30 minutes to shift a gigabyte of data is fine if you only copy a few tens of MB or less to it per day. However, if you regularly have to back-up multiple GB, you need a <u>fast</u> USB memory key if you are not to lose your sanity.

Fortunately, just why some solid state disks are slower than others is not a mystery. Rather, it is a function of the **type** of flash memory chips used to hold the data. Without going into great technicalities, these chips come in two varieties called **single level cell** (SLC) and **multi level cell** (MLC). Basically, MLC flash chips store two or more bits of data in each memory cell, whilst SLC chips store only one. MLC solid state disks are therefore cheaper to produce than SLC disks at any given capacity, but due to storing more than one bit of information in each memory cell take longer to write and read data. If you need a fast USB key, memory card or indeed hard-disk replacement SSD then you need to pay more to obtain an SLC device.

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