CSC 347
Computer Hardware and Maintenance

Lecture 4
Data Storage

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- This is mandatory for everyone including students in all interactions and communications as of January 1, 2014.
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- Violation of English as the First Language in the Campus will lead to administrative and disciplinary action.
- All are urged to help each other to develop the Facility of Communicating in English as the First Language in the Campus

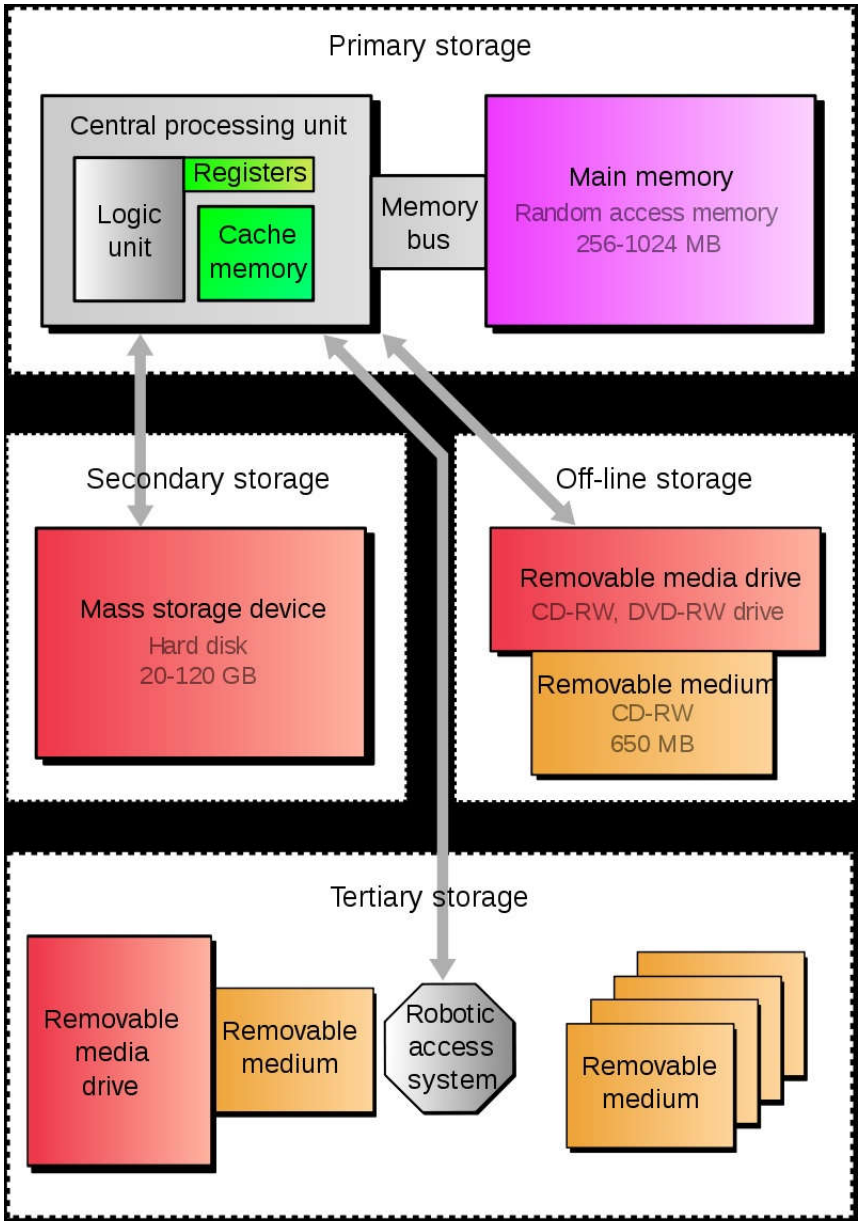
Data Storage

- Computer data storage is a technology consisting of computer components and recording media used to retain digital data
- Storage device stores the data and instruction in a computer
  - Known as memory
- Memory is divided into large number of small parts
  - Each part is called a cell
  - Each cell can store a fixed number of bits
- Each cell has a unique number assigned to it
  - Known as address of cell
  - Address varies from *0 to memory size – 1*
    - Example: A *64k* words computer memory unit has:

      *64 * 1024 = 65,536* memory locations

      The address of these locations varies from *0* to *65,535*

Types of Data Storage

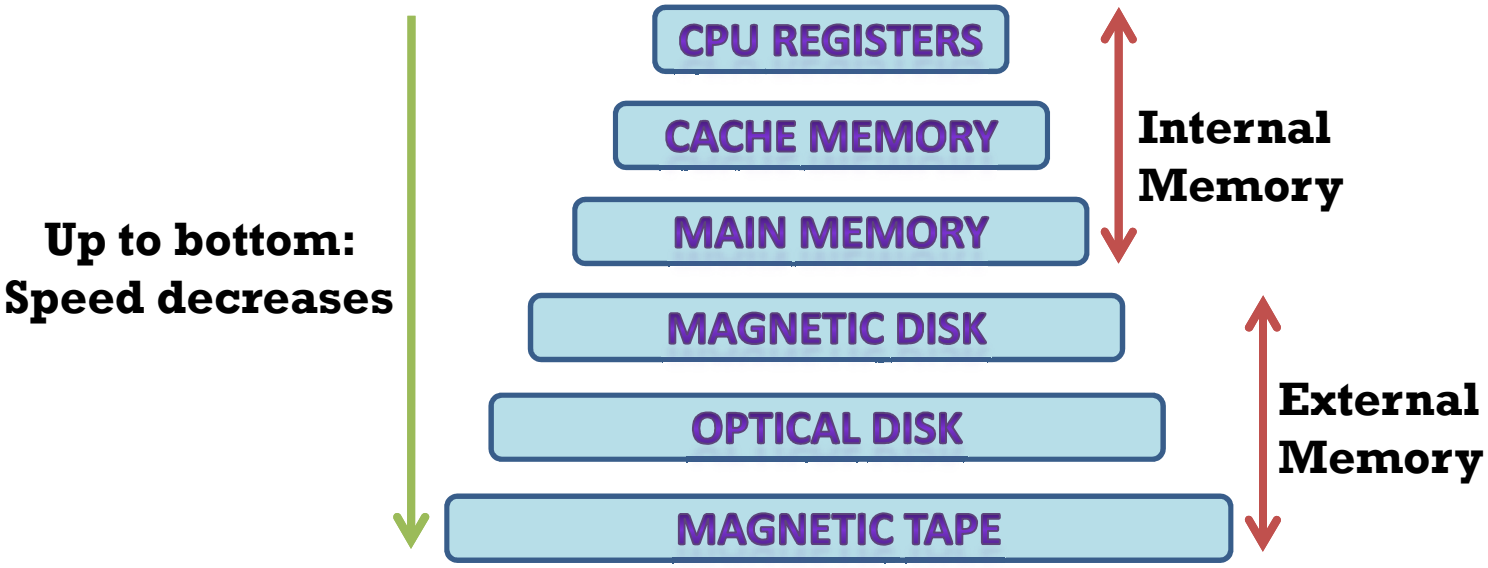


- There are four types of storage:
  - **Primary Storage**
    - RAM, Cache etc.
  - **Secondary Storage**
    - Hard Disk
  - **Off-line Storage**
    - USB flash drive, memory card etc.
  - **Tertiary Storage**
    - Magnetic Tape, Optical disk etc.
  - **Others**
    - Cloud storage, RAID etc.

Data Storage

- A computer system's storage unit is ranked according to the following criteria:
  - **Access Time** – Time required to retrieve the data
  - **Storage Capacity** – Amount of the data that can be stored in storage unit
  - **Cost per bit of storage** – Minimizing the cost is main goal

Memory Hierarchy



- Characteristics of Memory Hierarchy (from top to bottom) are as follows:
  - Access time by the CPU: increases
  - Frequency of access of the memory by the CPU: decreases
  - Capacity in terms of storage: increases
  - Cost per bit of storage: decreases

Memory/Storage Covered in this lecture

- **Primary Storage**
  - Random Access Memory (RAM)
- **Secondary Storage**
  - Hard Disk Drive (HDD)

Primary Storage
Random Access Memory (RAM)

- A RAM constitutes the internal memory of CPU for storing data, program, and program result
- Also know as Read/Write memory
- Access time in RAM is independent of the address to the word, resulting:
  - Each storage location inside the memory is easy to reach as other location and takes the same amount of time
- In the form of integrated circuits that allow the stored data to be accessed in any order
- Volatile in nature
- Small in terms of its physical size, and capacity

Primary Storage
Types of RAM

- Two basic types of RAM: Static RAM (SRAM), and Dynamic RAM (DRAM)
- **Static RAM (SRAM)**
  - Term *static* indicates that memory retains its contents as long as power remains applied
  - Chips use a matrix of 6-transistors and no capacitors
  - SRAM need not have to be refreshed on a regular basis
  - SRAM uses more chips than DRAM for the same amount of storage space
  - It's used as cache memory needs to be very fast and Small
  - It can give access time as low as *10 ns*
- **Dynamic RAM (DRAM)**
  - Term *dynamic* indicates that the memory must be constantly refreshed in order for it to maintain the data
    - This is done by placing the memory on a refresh circuit that rewrites the data several hundred times per second
  - All DRAMs made up of memory cells
    - These cells are composed one capacitor and one transistor
  - DRAM memory access time is *60 ns*

Primary Storage
SRAM Design

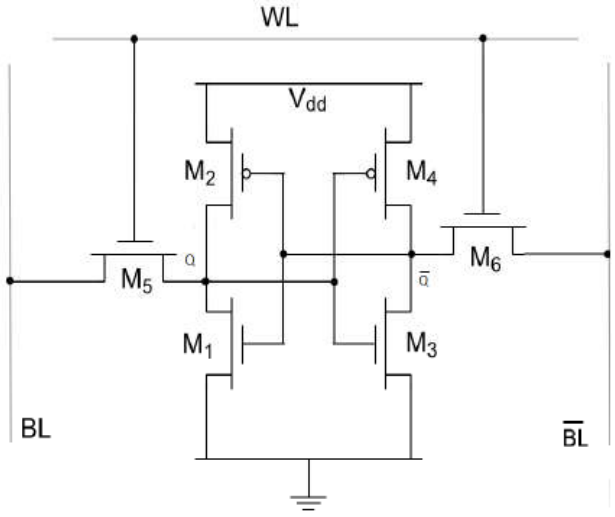


Figure2. A six-transistor CMOS SRAM cell

- A typical SRAM cell is made up of six MOSFETs (Metal Oxide Semiconductor Field Effect Transistors)
- Each bit in an SRAM is stored on four transistors (*M1, M2, M3, M4*) that form two cross-coupled inverters
- This storage cell has two stable states which are used to denote ***0*** and ***1***
- Two additional access transistors serve to control the access to a storage cell during read and write operations
- Access to the cell is enabled by the word line (*WL*) which controls two access transistors M_5 and M_6 which, in turn, control whether the cell should be connected to the bit lines: $\overline{BL}$ and *BL*
  - They are used to transfer data for both read and write operations

Primary Storage
SRAM Design

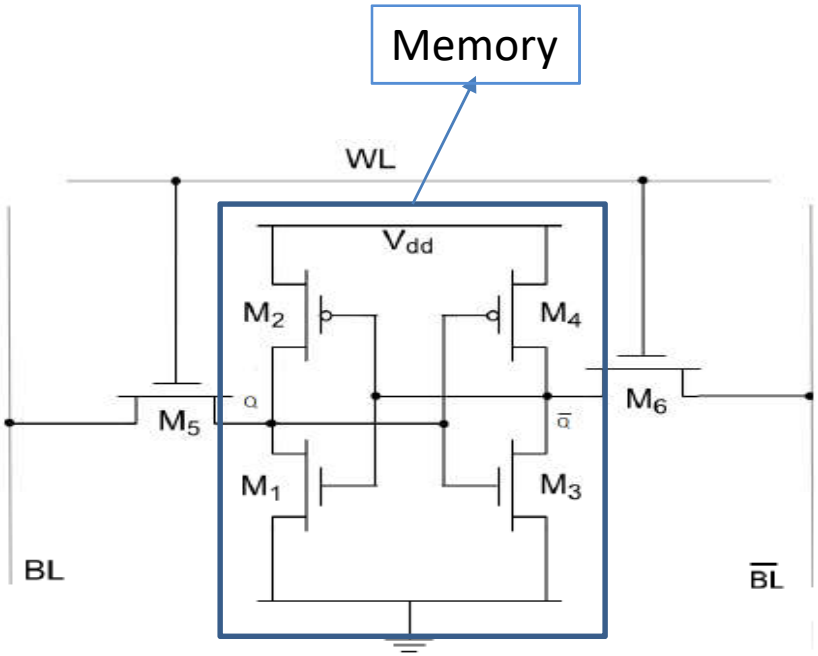
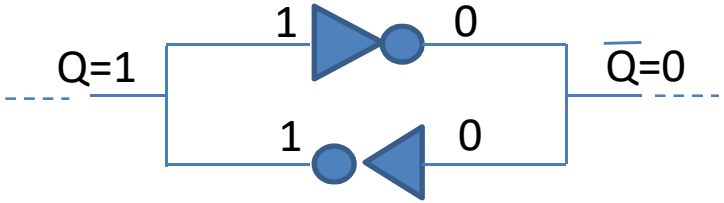


Figure2. A six-transistor CMOS SRAM cell

M5 and M6 are the access transistors

- If the output lines (----) is connected to something, Read or Write is possible in the memory. BL and $\overline{BL}$ are act as these lines.
- To access these lines, M5 and M6 access transistors are used
- If WL = 1, M5 and M6 are on that means BL and $\overline{BL}$ lines are accessible resulting Read and Write are possible
- If WL = 0, access is off and memory is in hold state
- BL and $\overline{BL}$ are act as input lines When something need to Write in to memory
- BL and $\overline{BL}$ are act as output lines When something need to read from memory
- Pre-charged capacitors are used for read and write (not shown in figure)

Simplified circuit (two inverters are connected)



Basic Not gate has been changed to CMOS inverter

Primary Storage
SRAM Operation

- An SRAM cell has three different states:
  - Standby (the circuit is idle)
  - Reading (the data has been requested) or
  - writing (updating the contents)

Primary Storage
SRAM Operation : Standby

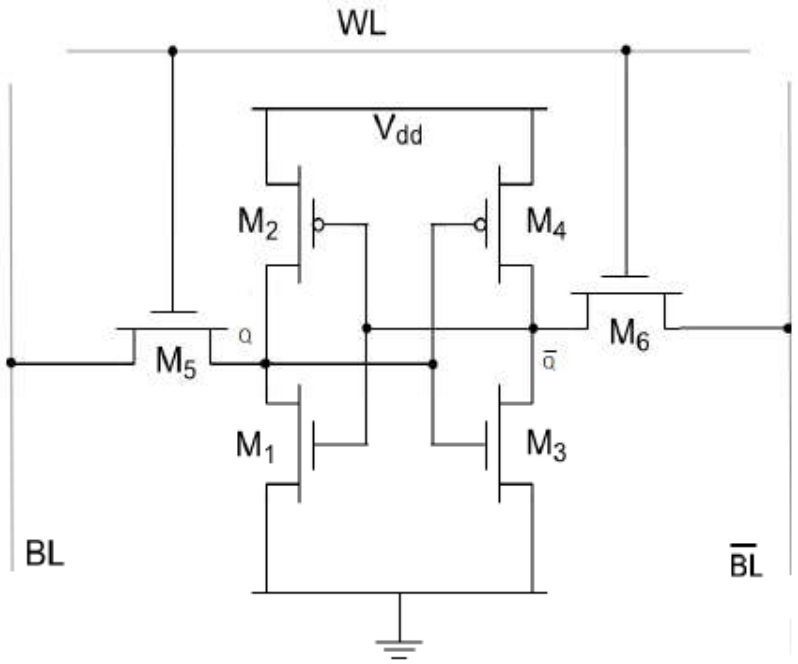


Figure2. A six-transistor CMOS SRAM cell

- If the word line is not asserted, the access transistors M_5 and M_6 disconnect the cell from the bit lines
- The two cross-coupled inverters formed by M_1 – M_4 will continue to reinforce each other as long as they are connected to the supply

Primary Storage

SRAM Operation : Reading

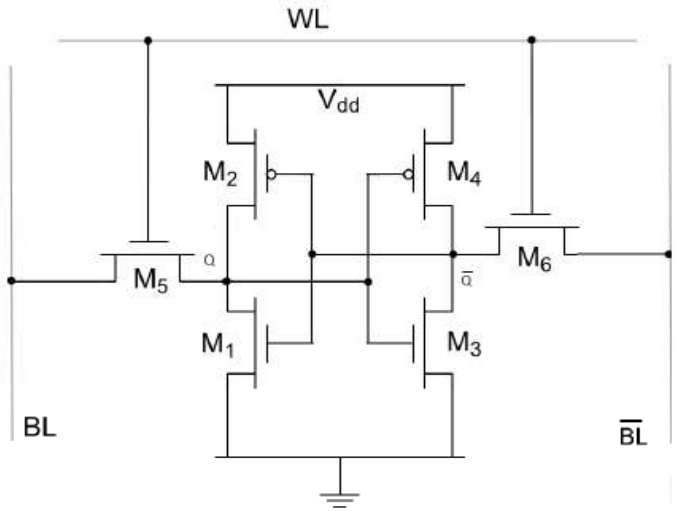


Figure2. A six-transistor CMOS SRAM cell

- During the read time in SRAM, Memory Should hold some value
  - Suppose Memory: Q = 1 and $\overline{Q}$ = 0
- Bit line (BL) and $\overline{BL}$ are going to be used to read
- When the Word Line (WL) = 1, access transistors are on
- While reading, BL and $\overline{BL}$ are the output lines
- Precharged V_{DD}
- Check the voltage difference at the both side:
  - Q=1 & load-voltage in BL=V_{DD}; no voltage difference
  - $\overline{Q}$=0 & load-voltage in $\overline{BL}$=V_{DD}; voltage difference
    - $\overline{BL}$ Voltage is decreased
- Send the found values of *BL* and $\overline{BL}$ to a sense amplifier
  - Sense amplifier will sense which line has the higher voltage and thus determine whether there is *1* or *0* stored
- When the $\overline{BL}$ voltage decreases output value is 1
- Memory read is successful
- When in Memory: Q = 0 and $\overline{Q}$ = 1, **What happens?**

Primary Storage

SRAM Operation : Write Operation

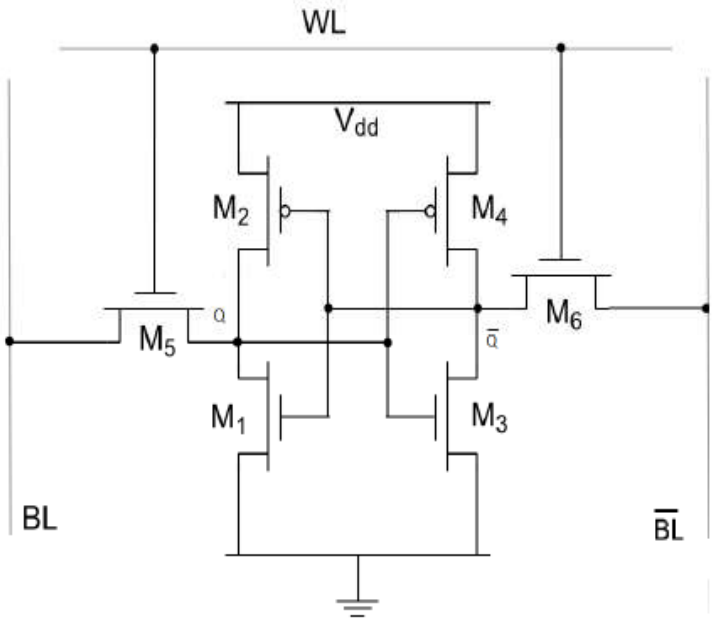
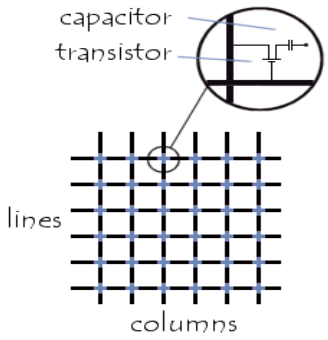


Figure2. A six-transistor CMOS SRAM cell

- Suppose memory value **Q = 0** and $\overline{Q} = 1$
- Bit line (BL) and $\overline{BL}$ are going to be used to write
- When the Word Line (WL) = 1, BL and $\overline{BL}$ are ready to access
- To write into memory, BL and $\overline{BL}$ are input lines, $\overline{BL}$ is force to ground because
  - $\overline{Q}$= 1 and $\overline{BL}$ is ground; Voltage difference
- When $\overline{BL}$ voltage is decreasing, M1 and M2 transistors are going to be affected
- If voltage < threshold voltage of M1
  - M1 is Off
  - M2 is On ; **Q = 1**
- It can be easily seen that Q was 0, but now Q is 1; resulting write operation is successful in memory

Primary Storage
DRAM Operation



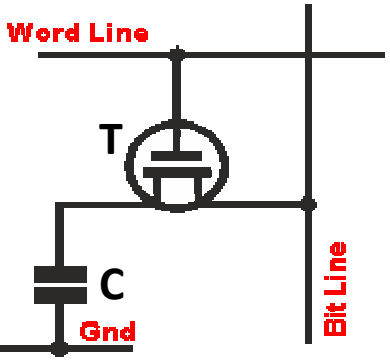


Figure3. DRAM Memory cell

- DRAM memory technology has MOS technology at the heart of the design, fabrication and operation
- DRAM memory cell uses a capacitor to store each bit of data and a transfer device - a MOSFET (Metal Oxide Semiconductor Field Effect Transistor) that acts as a switch
- The level of charge on the memory cell capacitor determines whether that particular bit is a logical "1" or "0"
  - Presence of charge in the capacitor indicates a logic "1" and
  - Absence of charge indicates a logical "0"
- Two lines are connected to each dynamic RAM cell - the Word Line (W/L) and the Bit Line (B/L) connect as shown so that the required cell within a matrix can have data read or written to it

Primary Storage
DRAM Read / Write

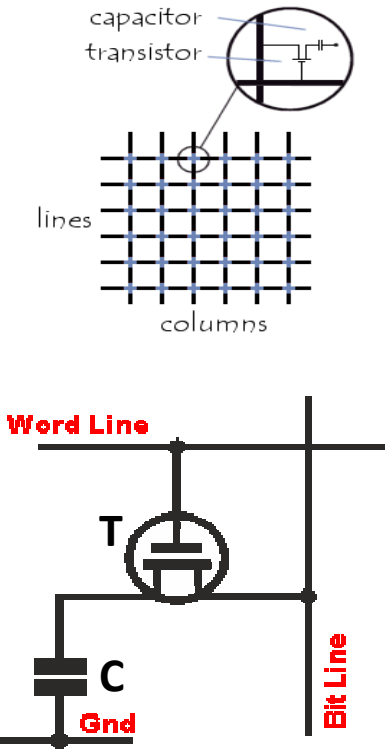


Figure3. DRAM Memory cell

▪ Read Operation:

- When the word line is selected, the transistor turns on and the charge stored on the capacitor is fed out onto a bit line and to a sense amplifier
- The sense amplifier compares the capacitor voltage to a reference value and determines if the cell contains logic 1 or logic 0
- The read out from the cell discharges the capacitor, which must be stored to complete the operation

• Write Operation:

- A voltage signal is applied to the bit line
  - a high voltage represents 1, and
  - a low voltage represents 0
- A signal is then applied to the word line, allowing a charge to be transferred to the capacitor

Secondary Storage

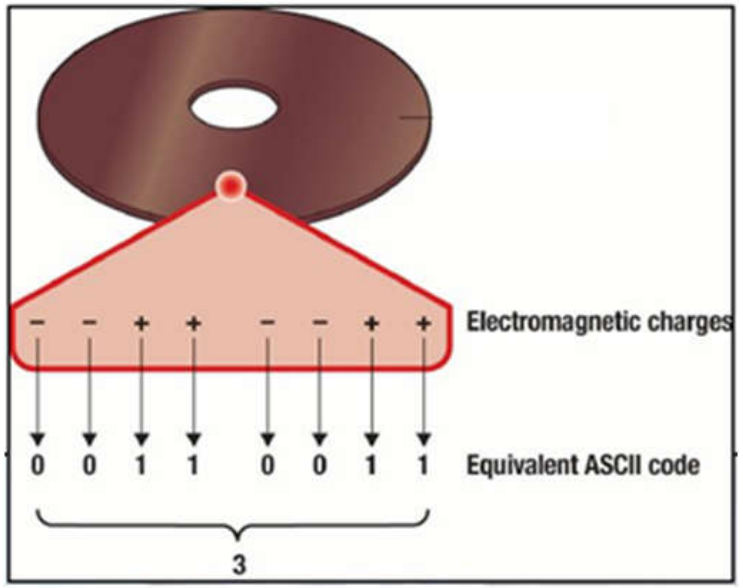
- It is not directly accessible by the CPU
- Computer usually uses its input/output channels to access this type of storage and transfers the desire data using intermediate area in primary storage
- Secondary storage characteristics
  - Media
  - Capacity
  - Storage devices
  - Access speed
- Terminology
  - Reading: is the process of accessing information
  - Writing: is the process of saving information

Secondary Storage
Hard Disk

- Hard Disk Drive (HDD), it is the main and usually largest data storage device in a computer (usually, 160GB to 15TB)
- Hard disk speed is the speed at which content can be read and written on a hard disk.
- A HDD unit comes with a set rotation speed varying from 5400 to 7200 rpm (for desktop and laptop)
- Disk access time is measured in milliseconds

Secondary Storage
Hard Disk (Cont')

- Hard disks save files by altering the magnetic charges of the disk's surface to represent 1s and 0s
- Hard disks retrieve data and programs by reading these charges from the magnetic disk
- Characters are represented by positive (+) and negative (–) charges using the ASCII, EBCDIC, or Unicode binary code



Secondary Storage

Internal Hard Disk

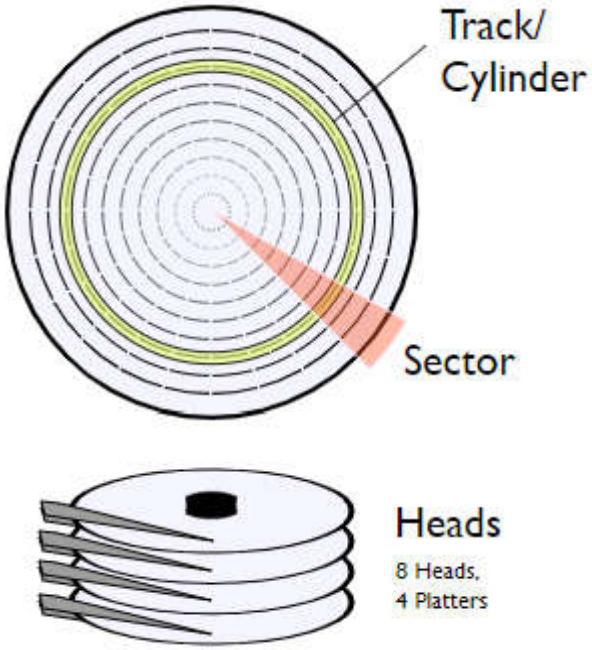
External Hard Disk

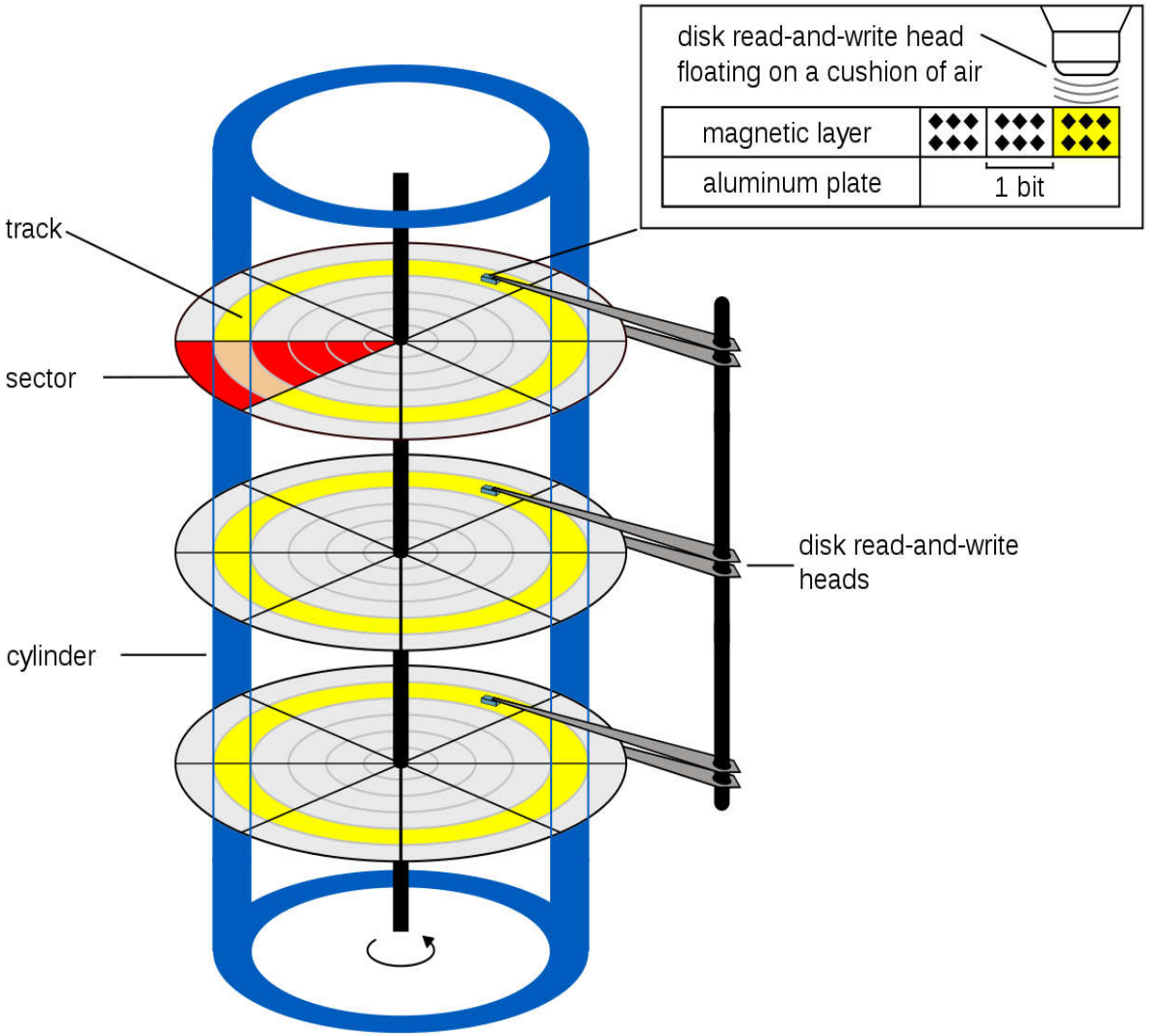
Keywords	Internal Hard Disk	External Hard Disk
Portability	No	Yes
Price	Less expensive	More Expensive
Speed	Fast	Slow
Size	Big	Small
Special Installation	Required	Does not required

Secondary Storage
Hard Disk (Cont')
Components of a Hard Drive

- **Platters** are multiple hard metal surfaces that are stacked one on top of another contained in the hard drive
- **Read/Write Heads** write and read 1s and 0s to and from hard drive surface
  - A **Head Crash** occurs when a read/write head touches the hard drive platter
- **Track** is a concentric circle on a hard drive platter
- **Sectors –** Each track is divided into sectors which contains 512 bytes of data
  - **ZBR (Zone Bit Recording)** efficiently uses the hard drive surface by placing more sectors on the outer tracks than on the inner tracks
  - **Interleaving** is a method of numbering sectors for the most efficient transfer of data between hard drive and controller. Hard drives normally use 1:1 interleave
- **Cylinder** runs through each track of a stack of platters
  - Cylinders are necessary to differentiate files stored on same track and sector of different platters
- When a hard disk is formatted, tracks, sectors, and cylinders are assigned

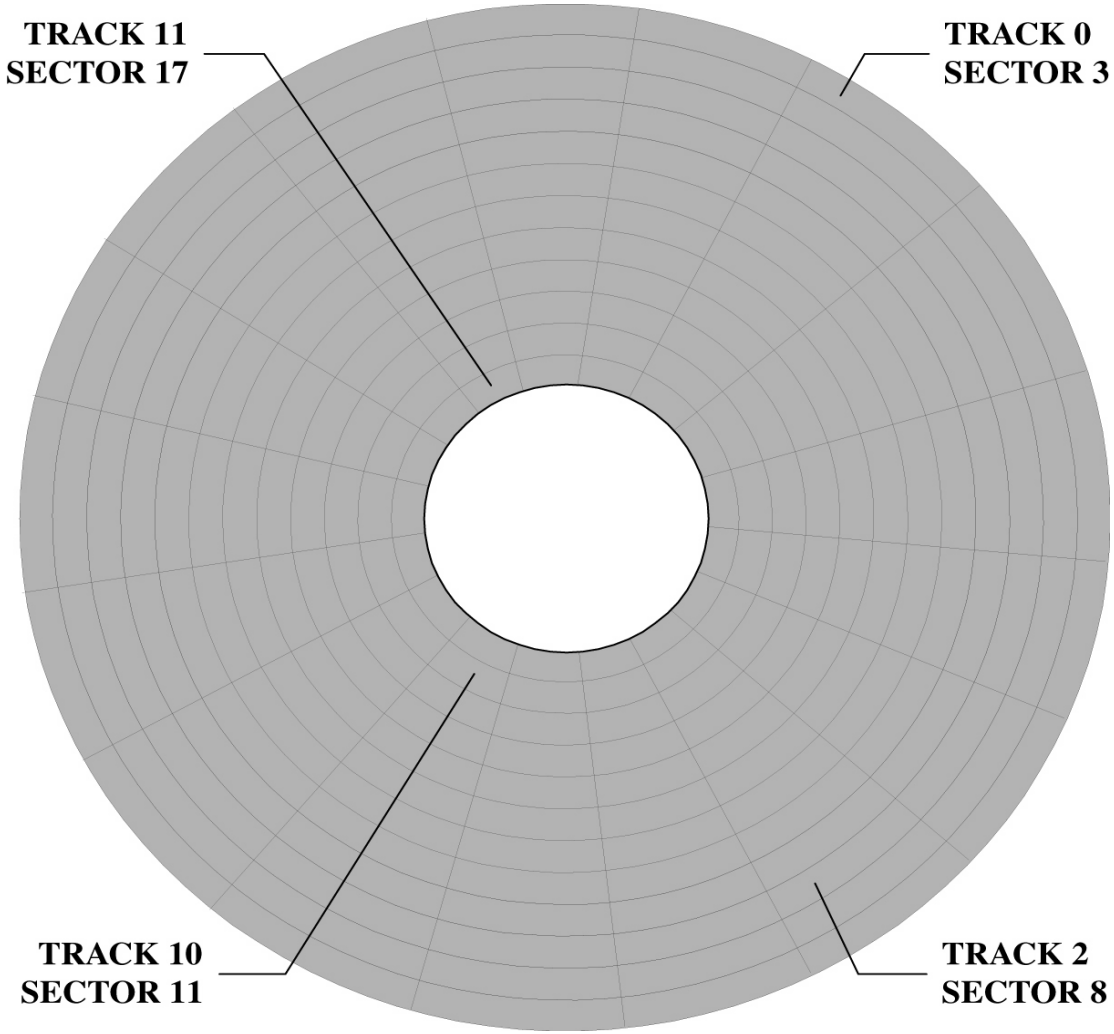
Secondary Storage
Hard Disk (Cont')



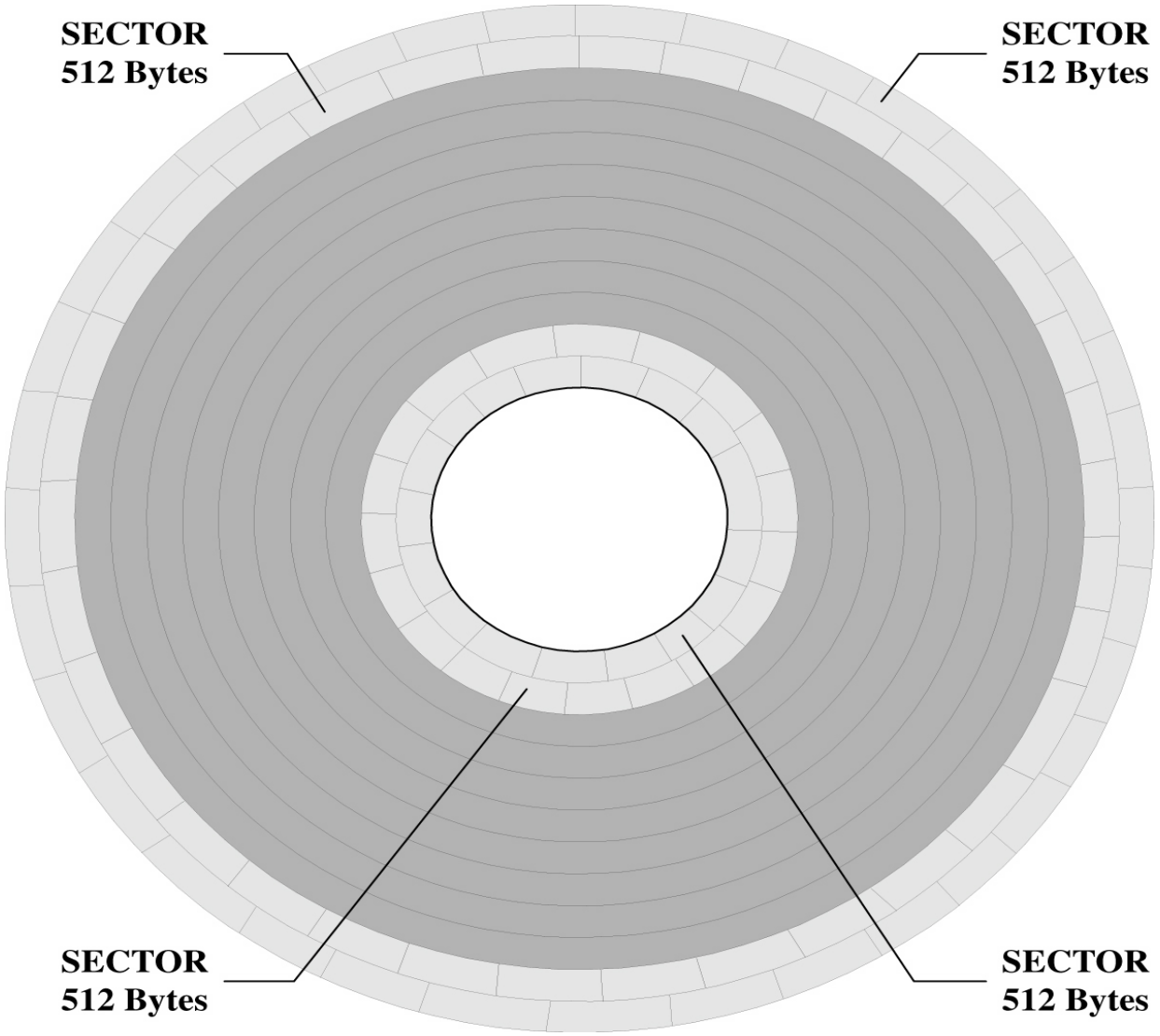


Hard Drive Geometry

Secondary Storage
Hard Disk (Cont')

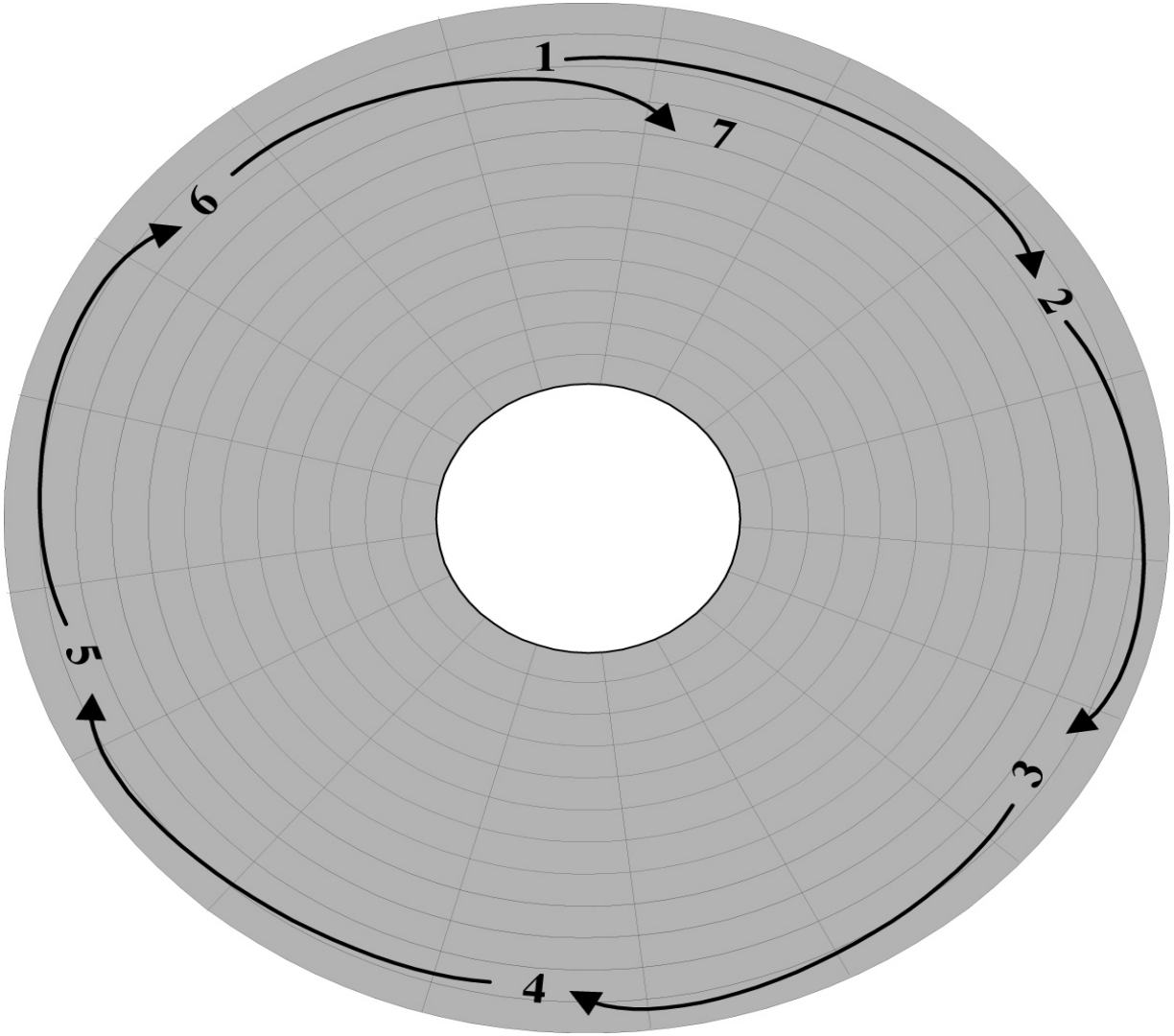


Secondary Storage
Hard Disk (Cont')



Zone Bit Recording Sectors

Secondary Storage
Hard Disk (Cont')

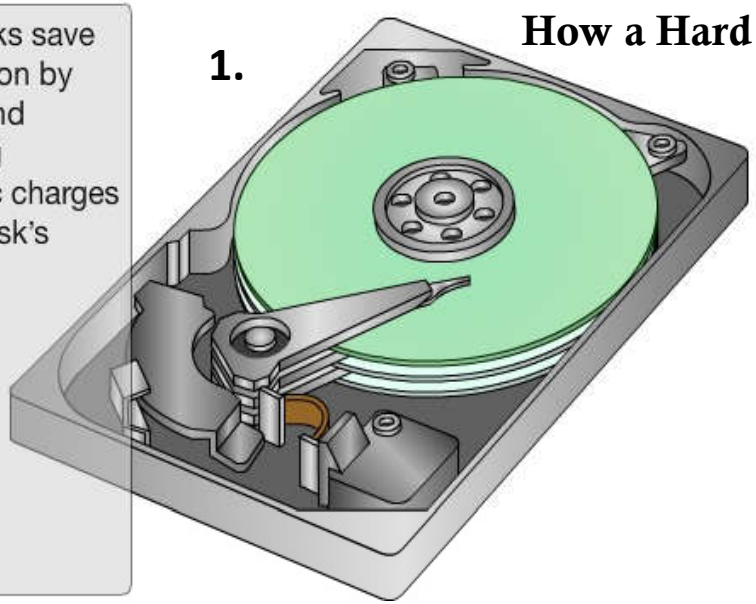


3:1 Interleaving

Secondary Storage
Hard Disk (Cont')
How a Hard Disk Work?

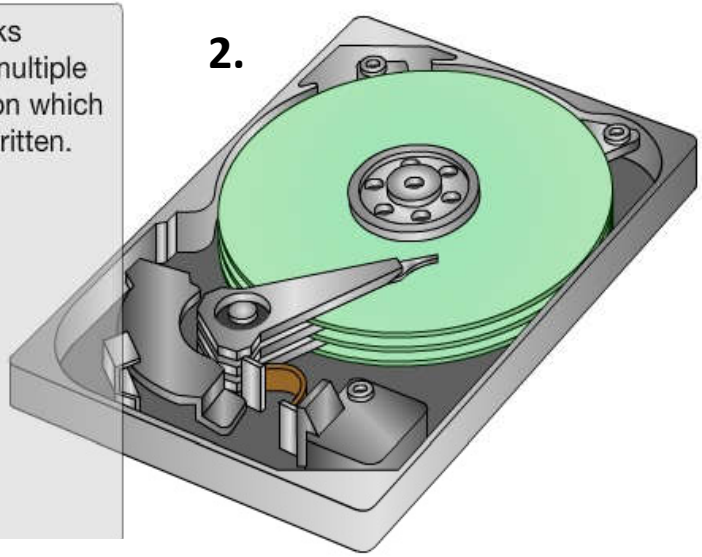
Hard disks save information by saving and retrieving magnetic charges on the disk's surface.

1.



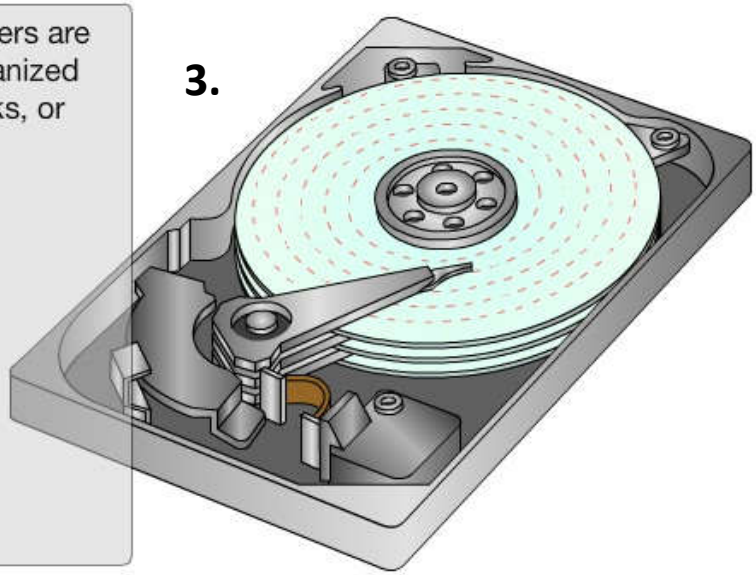
Hard disks contain multiple platters on which data is written.

2.



The platters are then organized into tracks, or rings.

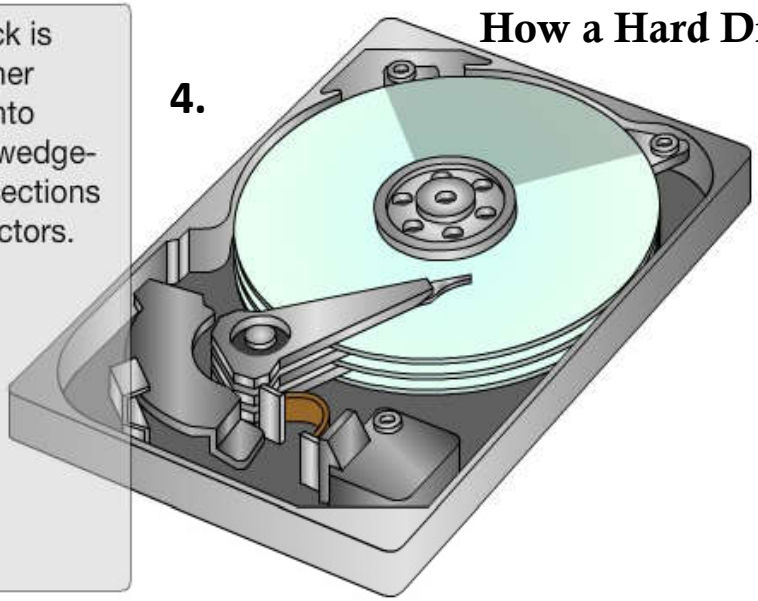
3.



Secondary Storage
Hard Disk (Cont')
How a Hard Disk Work? (Cont')

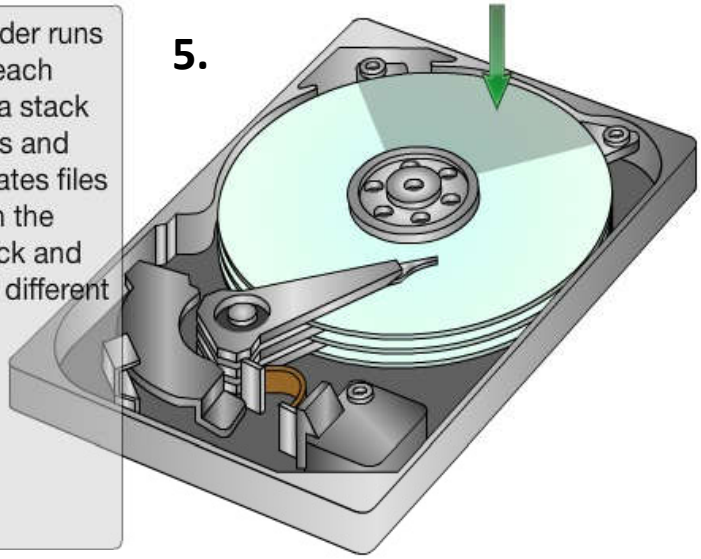
Each track is then further divided into invisible wedge-shaped sections called sectors.

4.



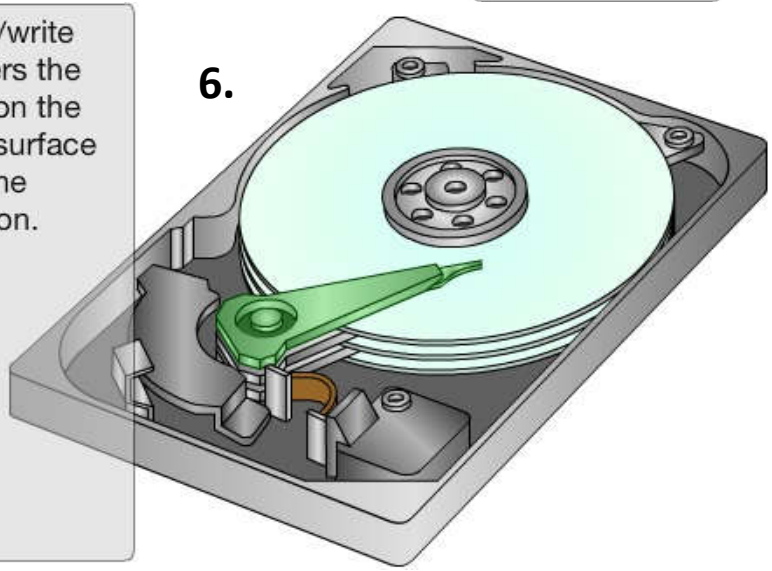
The cylinder runs through each track on a stack of platters and differentiates files stored on the same track and sector of different platters.

5.



The read/write head alters the charges on the platter's surface to save the information.

6.



Secondary Storage
Hard Disk (Cont')

- Hard disks are sensitive instruments
- Their read/write heads ride on a cushion of air about 0.000001 inch thick.
  - It is so thin that a smoke particle, fingerprint, dust, or human hair could cause what is known as a head crash

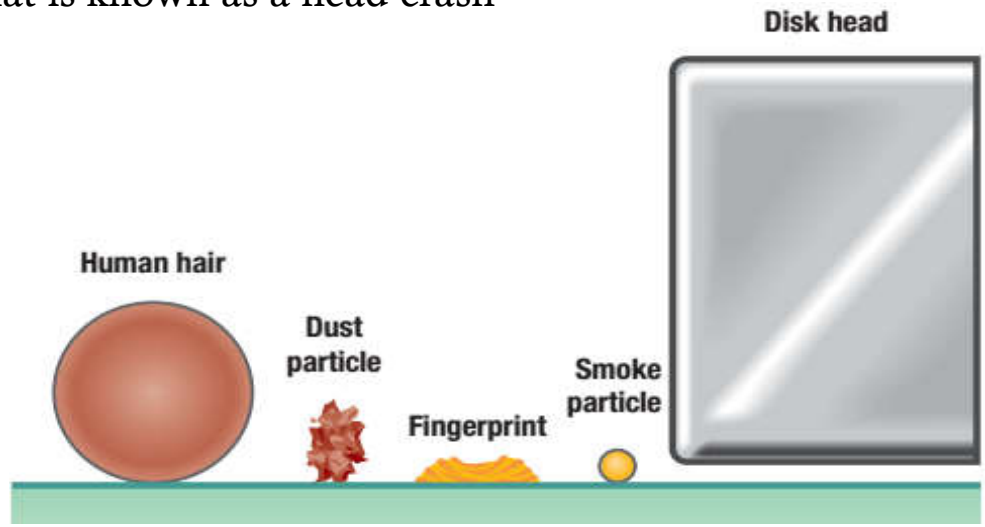


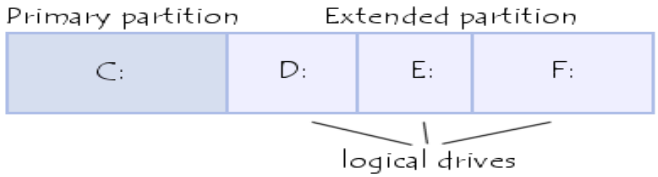
Figure3. Materials that can cause a head crash

- A head crash occurs when a read/write head makes contact with the hard disk's surface or with particles on its surface
- A head crash is a disaster for a hard disk

Secondary Storage
Hard Disk (Cont')

Hard-drive Partitioning

- **Partitioning** divides a hard drive so that the computer system sees more than one drive



- **Types of Partitions:**
  - The **Primary Partition** is the first detected drive on the hard drive
  - The **Extended Partition** is a hard drive division
  - **Logical drives** divides the extended partition into separate units which appear as separate drive letters
- **The boot sector called MBR (Master Boot Record)** is the first sector of a hard drive (Cylinder 0, head 0, sector 1)
  - it contains the main partition and the code, called the Boot Loader, which when loaded in to the memory, will allow the system to boot up
  - After it is loaded into memory, this program will determine from which system partition to boot, and will start the program (called the **bootstrap**), which will start up operating system present on that partition

Secondary Storage
Hard Disk (Cont')
Hard-drive Partitioning (Cont')

How Drive Letters Are Assigned:

- The order in which the partitions are assigned drive letters depends on three factors:
  - The number of hard drives
  - The type of partitions on the hard drives
  - The operating system
- The first floppy drive detected is assigned drive letter A:
- The second floppy drive detected is assigned drive letter B:
- The first hard drive primary partition detected receives drive letter C:
- Drive letters assigned after letter C: are dependent upon the operating system installed

Secondary Storage
Hard Disk (Cont')
Hard-drive Partitioning (Cont')

- A **File System** defines how data is stored on a drive.
  - **FAT (File Allocation Table)** is a method of organizing a computer's file system
  - **FAT16** file system is supported by DOS, Windows 9x, NT, 2000, and XP
  - **FAT32** file system used by Windows 95 Service Release 2, Windows 98, Windows 2000, XP and so on that supports hard drives up to 2TB in size
  - **NTFS (NT File System)** file system used with Windows NT, Window XP, 7, 8, 9, 10
  - **Linux Ex2, Ex3, Ex4 and beyond** for Linux

Secondary Storage
Hard Disk (Cont')
Preventive Maintenance for Hard Drives

- Preventive Maintenance will prolong the life of HDD
  - **CHKDSK** is a program that locates clusters disassociated from data files
    - **Lost Clusters** are sectors on a disk that the file allocation table cannot associate with any file or directory
  - **SCANDISK** is a software program used to detect and repair lost clusters
  - **Disk Cleanup** utility helps free up hard drive space by emptying the Recycle Bin, removing temporary files, etc.
  - **Defragmentation** is the process of placing files in contiguous sectors. This allows for faster hard disk access of files

Secondary Storage

Hard Disk (Cont')

Performance Enhancements

- **Disk caching**
  - Provides a temporary high- speed holding area between a secondary storage device and the CPU
    - ➢ Improves performance by anticipating data needs and reducing time to access data from secondary storage
- **Redundant Arrays of Inexpensive Disks (RAID)**
  - Several inexpensive hard-disk drives are connected together
    - ➢ Improves performance by providing expanded storage, fast access, and high reliability
- **File compression and decompression**
  - ➢ Files compressed before storing and then decompressed before being used again
    - ➢ Improves performance through efficient storage

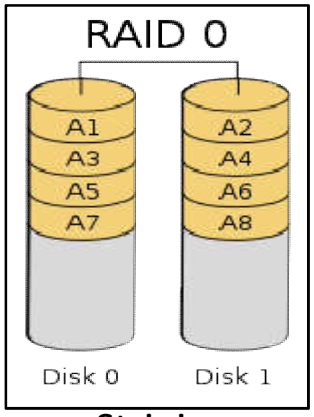
Secondary Storage

Hard Disk (Cont')

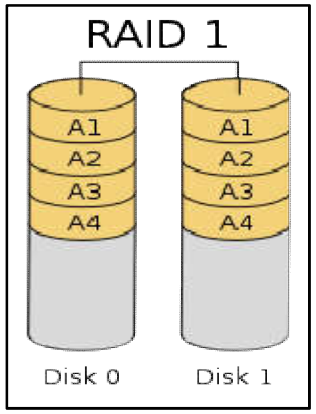
Redundant Arrays of Inexpensive Disks (RAID)

- Storage is an important part of fault tolerance
- A disk failure results in data loss that is not desired in any organization and therefore, data loss prevention is required
- RAID can be one of the best ways to prevent data loss
  - The data is copied on multiple disk
  - Different RAID Levels: **RAID 0 (Striping)**, **RAID 1 (Mirroring)**, RAID 2 (Bit-level striping with Hamming code for error correction), RAID 3 (Byte-level striping with dedicated parity), RAID 4 (Block-level striping with dedicated parity), **RAID 5 (Block-level striping with distributed parity)**, **RAID 6 (Block-level striping with double distributed parity)**, **RAID 10 (Striping + Mirroring),** and so on

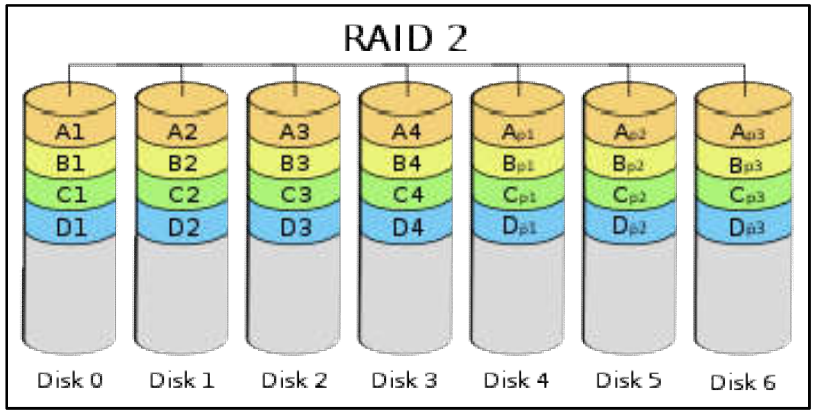
Different levels of RAID



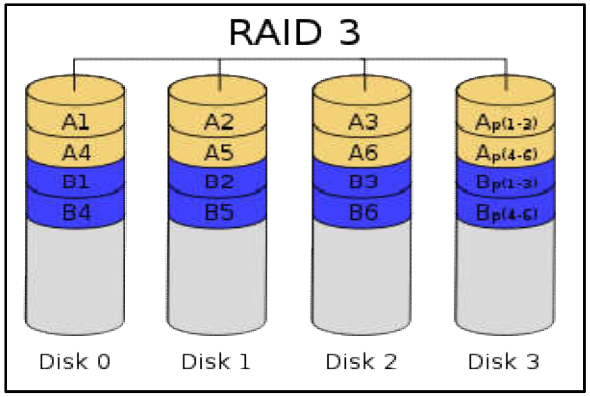
Striping



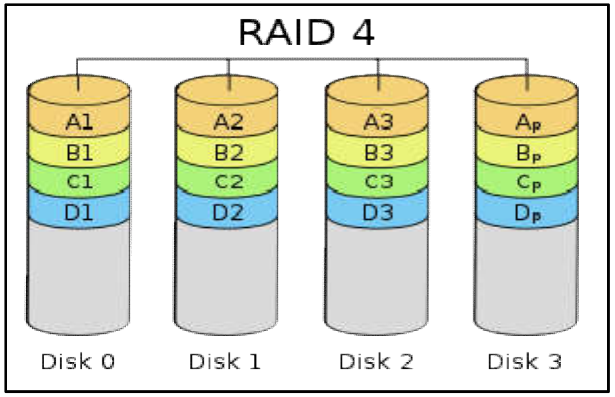
Mirroring



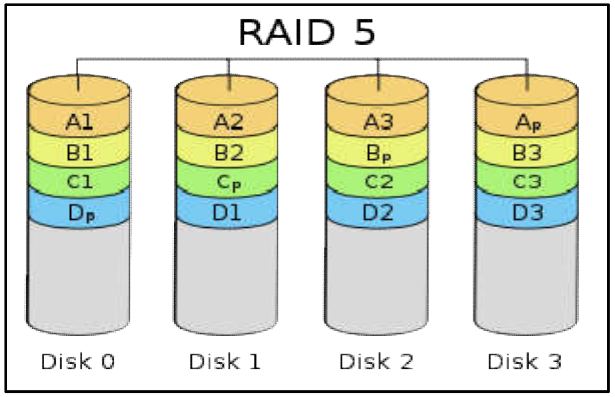
Bit-level striping



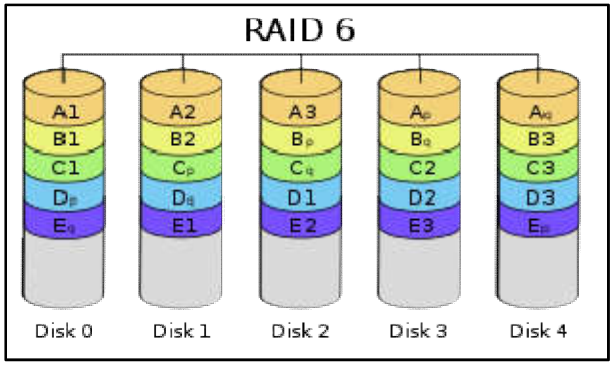
Byte-level striping with dedicated parity



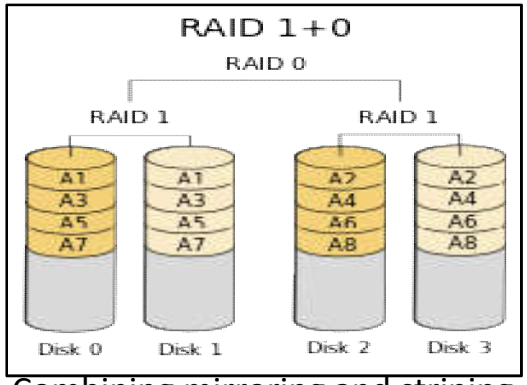
Block-level striping with dedicated parity



Block-level striping with distributed parity



Block-level striping with double distributed parity

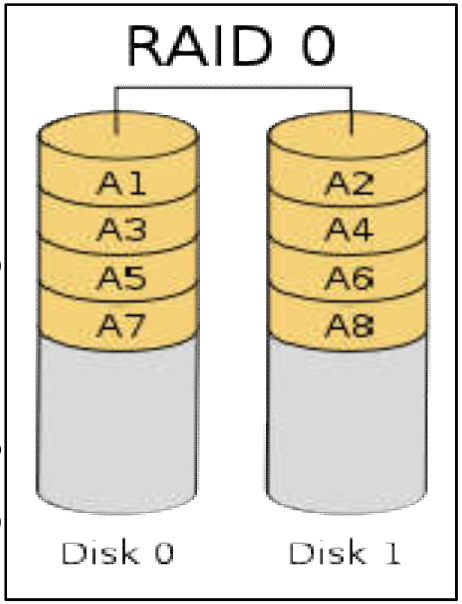


Combining mirroring and striping

Commonly used RAID Levels are RAID 0, 1, 5, 6, 10

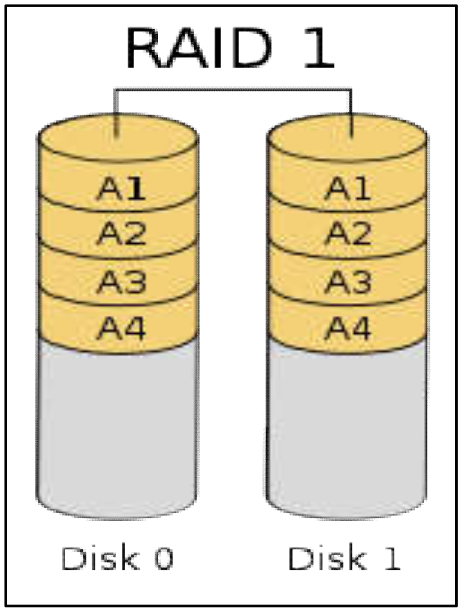
Secondary Storage
Hard Disk (Cont')
Redundant Arrays of Inexpensive Disks (RAID)

- RAID 0
  - It splits data among two or more disks.
  - Provides good performance.
  - Lack of data redundancy means there is no fail over support with this configuration.
  - In the diagram to the right, the odd blocks are written to disk 0 and the even blocks to disk 1 such that A1, A2, A3, A4, … would be the order of blocks read if read sequentially from the beginning.
  - Used in read only Network File System (NFS) systems and gaming systems.



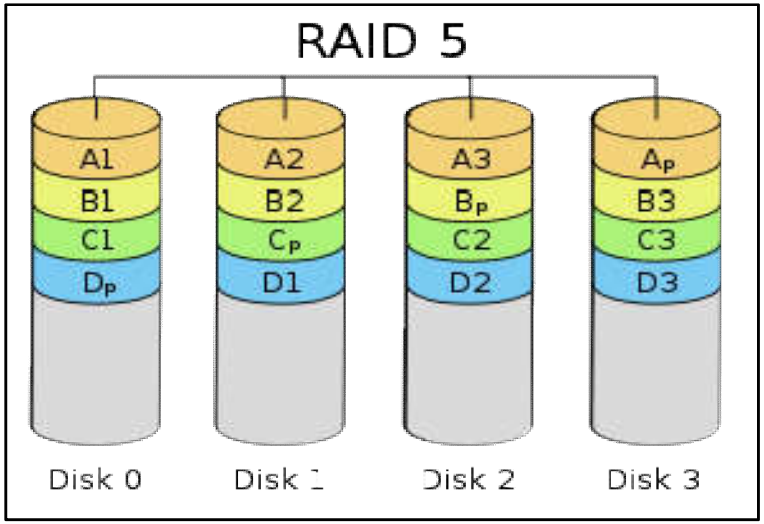
Secondary Storage
Hard Disk (Cont')
Redundant Arrays of Inexpensive Disks (RAID)

- RAID 1
  - RAID1 is 'data mirroring'.
  - Two copies of the data are held on two physical disks, and the data is always identical.
  - Twice as many disks are required to store the same data when compared to RAID 0.
  - Array continues to operate so long as at least one drive is functioning.



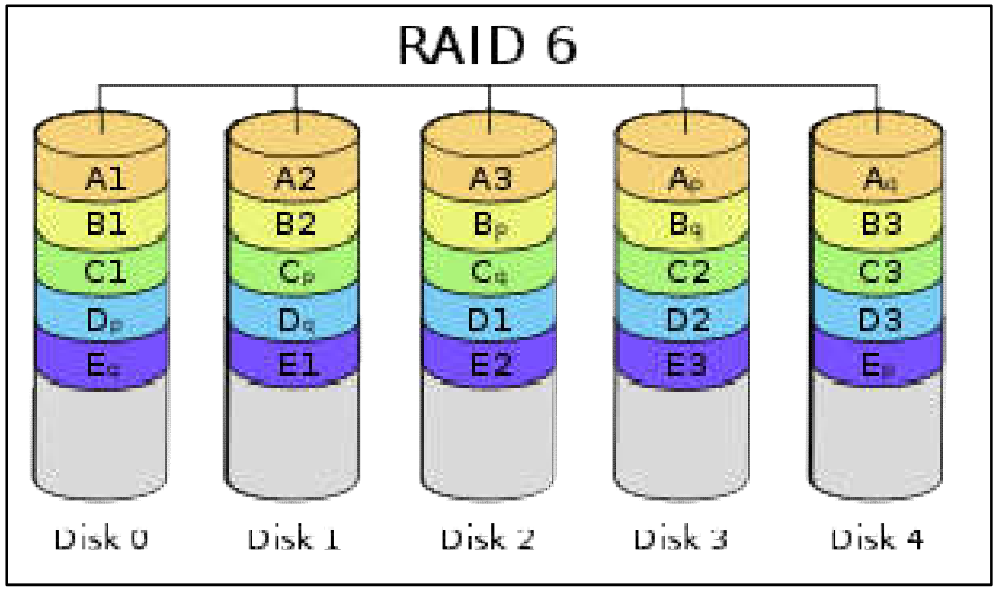
Secondary Storage
Hard Disk (Cont')
Redundant Arrays of Inexpensive Disks (RAID)

- RAID 5
  - RAID 5 is an ideal combination of good performance, good fault tolerance and high capacity and storage efficiency.
  - An arrangement of parity and CRC to help rebuilding drive data in case of disk failures.
  - "Distributed Parity" is the key word here.



Secondary Storage
Hard Disk (Cont')
Redundant Arrays of Inexpensive Disks (RAID)

- RAID 6
  - It is seen as the best way to guarantee data integrity as it uses double parity.
  - It has a drawback though of longer write time.



Secondary Storage
Hard Disk (Cont')
Redundant Arrays of Inexpensive Disks (RAID)

- RAID 10
  - Combines RAID 1 and RAID 0.
  - Which means having the pleasure of both - good performance and good failover handling.
  - Also called 'Nested RAID'.
  - Benefits from the fault tolerance of RAID 1 and The Speed of RAID 0