CSE-323
Computer Architecture

External Memory

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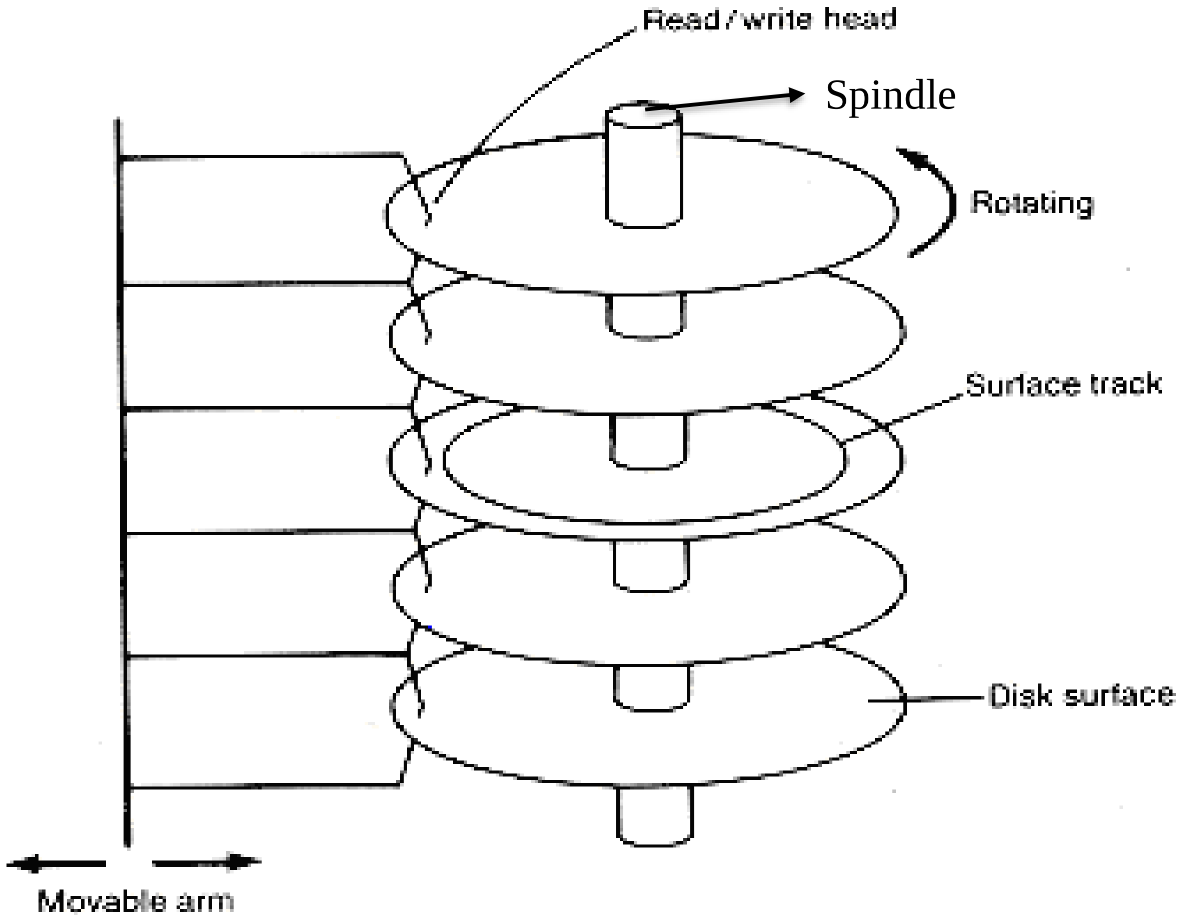
Military Institute of Science and technology

Hard Disk using Magnetic Disks



Magnetic Disk

- A disk is a circular platter constructed of nonmagnetic material, called the substrate, coated with a magnetizable material.
- Traditionally the substrate has been an aluminum or aluminum alloy material.
- Recently glass substrates have been introduced.
- Glass substrate is expensive than aluminum substrate.

Magnetic Disk Layout

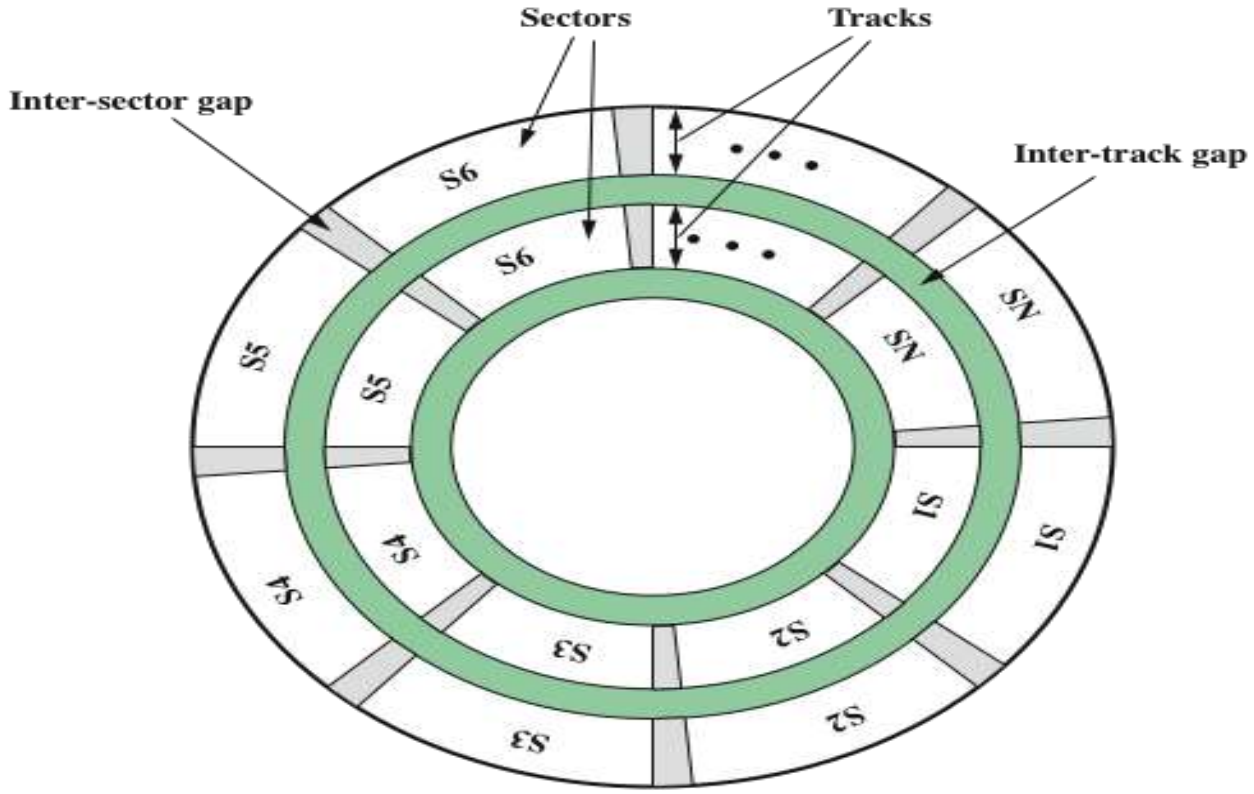


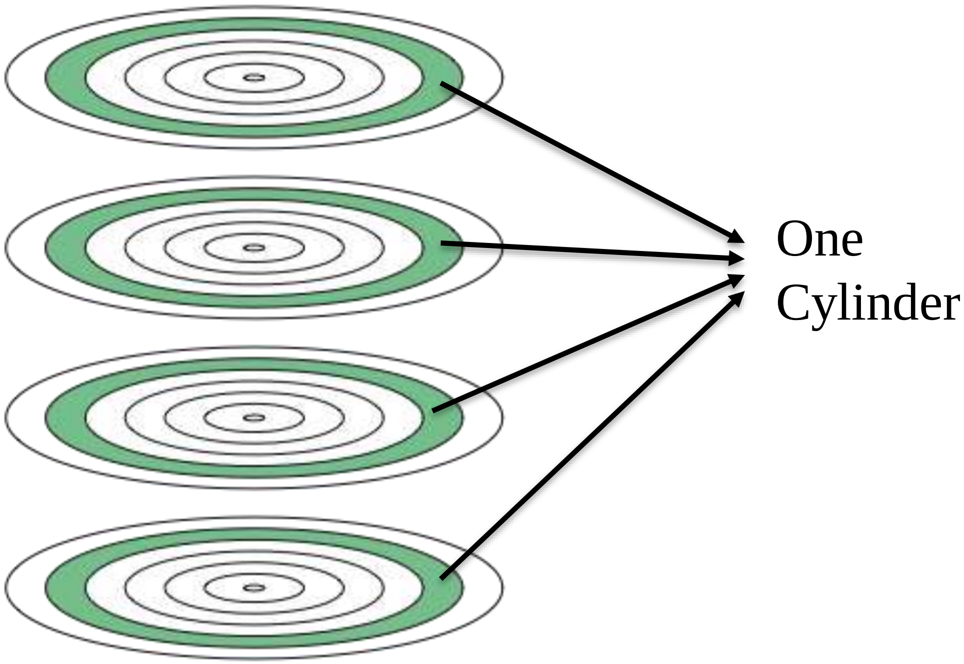
Figure 6.2 Disk Data Layout

Magnetic Disk Layout

- **<u>Track:</u>**
  - A concentric circle of data on the surface of a magnetic disk
- **<u>Inter-track gap:</u>**
  - The gap between two tracks to avoid errors due to misalignment of heads
- **<u>Sector:</u>**
  - A segment of a circular track on a magnetic disk
  - The smallest amount of information that is read from or to a disk (512 – 2048 bytes)
- **<u>Inter-sector gap:</u>**
  - The gap between two sectors to avoid errors due to misalignment of heads

Magnetic Disk Layout

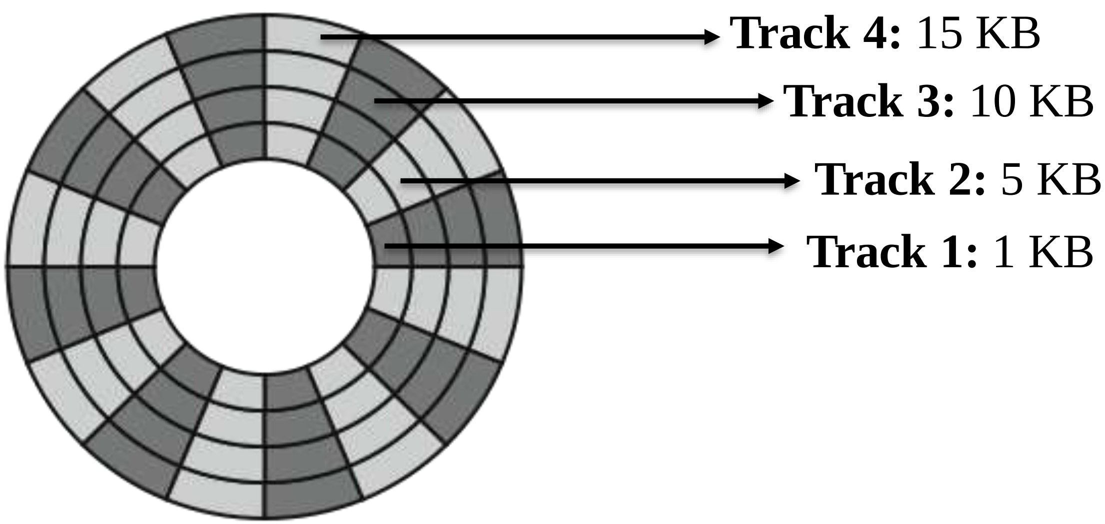
- **Cylinder:**
  - Set of tracks, one from each platter, that are at the same distance from the spindle/center.
  - No. of cylinders in a Hard Disk: Total no. of tracks per platter.



Types of Disk Layout Methods (Exam)

1. **<u>Variable amount of bits per track</u>:**

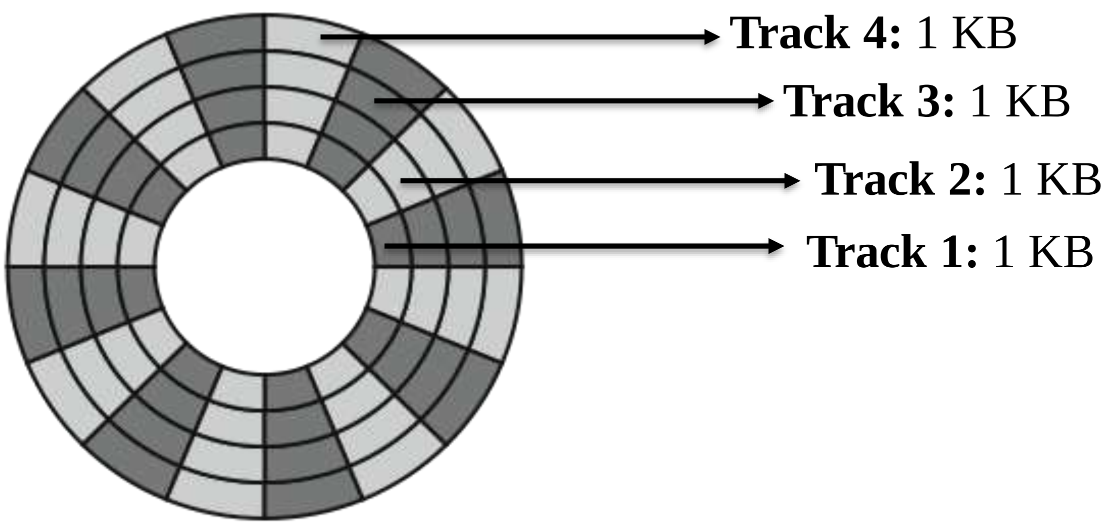
- Tracks farther from the center contain more bits than tracks closer to the center.
- Advantage: Space is used wisely
- Disadvantage: Time to access a specific amount of data varies from one track to another, which leads to complex calculation.



Types of Disk Layout Methods

2. <u>Fixed amount of bits per track/ Constant Angular Velocity</u>:

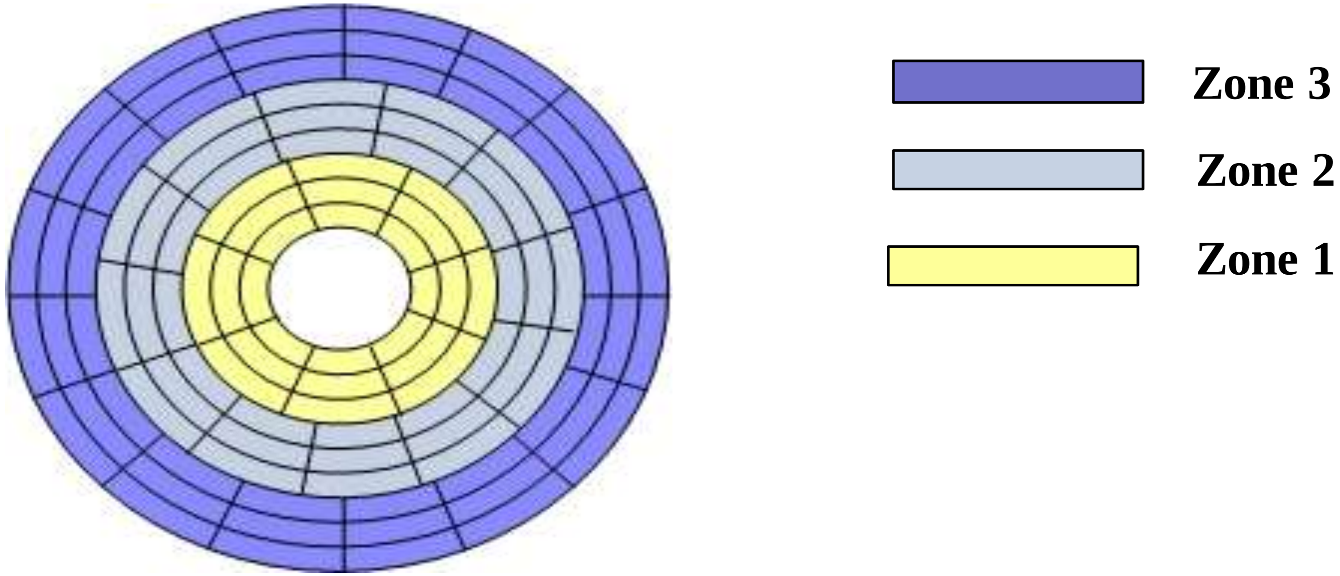
- In each track, the amount of data bits are same.
- Advantage: Time/ velocity required to access a specific amount of data is fixed in each track.
- Disadvantage: Space in outer tracks are wasted.



Types of Disk Layout Methods

3. <u>Multiple Zoned Recording</u>:

- Grouping the tracks into sets called Zones.
- Placing more sectors in the outer tracks than in the inner tracks.
- Advantage: Space on platter are better utilized, allowing for greater overall storage capacity.
- Disadvantage: Require more complex circuitry.



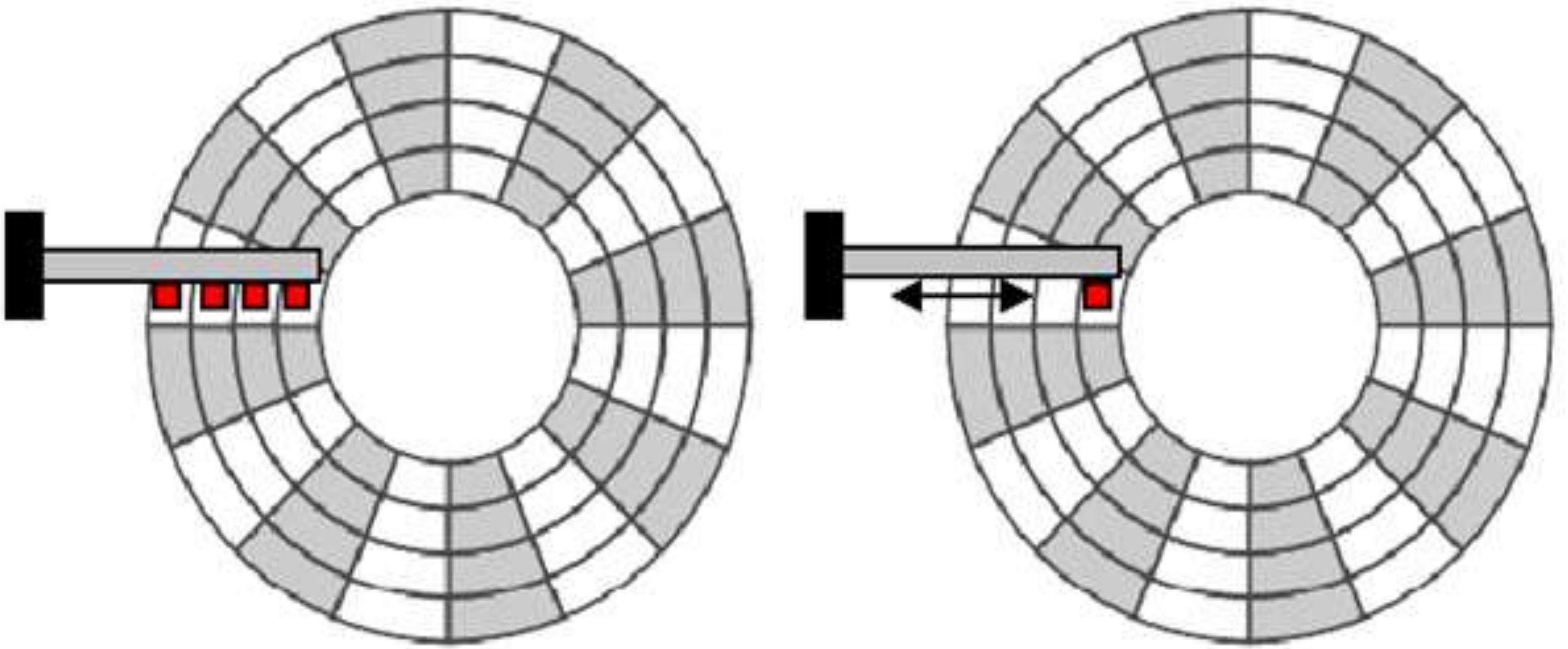
Physical Characteristics of Disk Systems

Head Motion:

- Fixed Head Disk:
  - One read-write head per track.
  - Heads are mounted on a fixed ridged arm.
- Movable Head Disk:
  - One read-write head per platter/ surface.
  - Head is mounted on an flexible arm.
  - The arm can be extended or retracted.

Physical Characteristics of Disk Systems

Head Motion:



(a) Fixed head

(b) Movable head

Physical Characteristics of Disk Systems

Disk Portability

- Non-removable Disk:
  - Permanently mounted in the disk drive
  - The hard disk in a personal computer is a non-removable disk
- Removable Disk:
  - Can be removed and replaced with another disk
  - Advantages:
    - Unlimited amounts of data are available with a limited number of disk systems
    - A disk may be moved from one computer system to another
  - Floppy disks are examples of removable disks

Physical Characteristics of Disk Systems

Sides

- Single Sided Disk:
  - Only one side of each platter is magnetically coated.
- Double Sided Disk:
  - Both sides of each platter is magnetically coated.

Platters

- Single Platter Disk:
  - Only one platter.
- Multiple Platter Disk:
  - More than one platter.

Physical Characteristics of Disk Systems

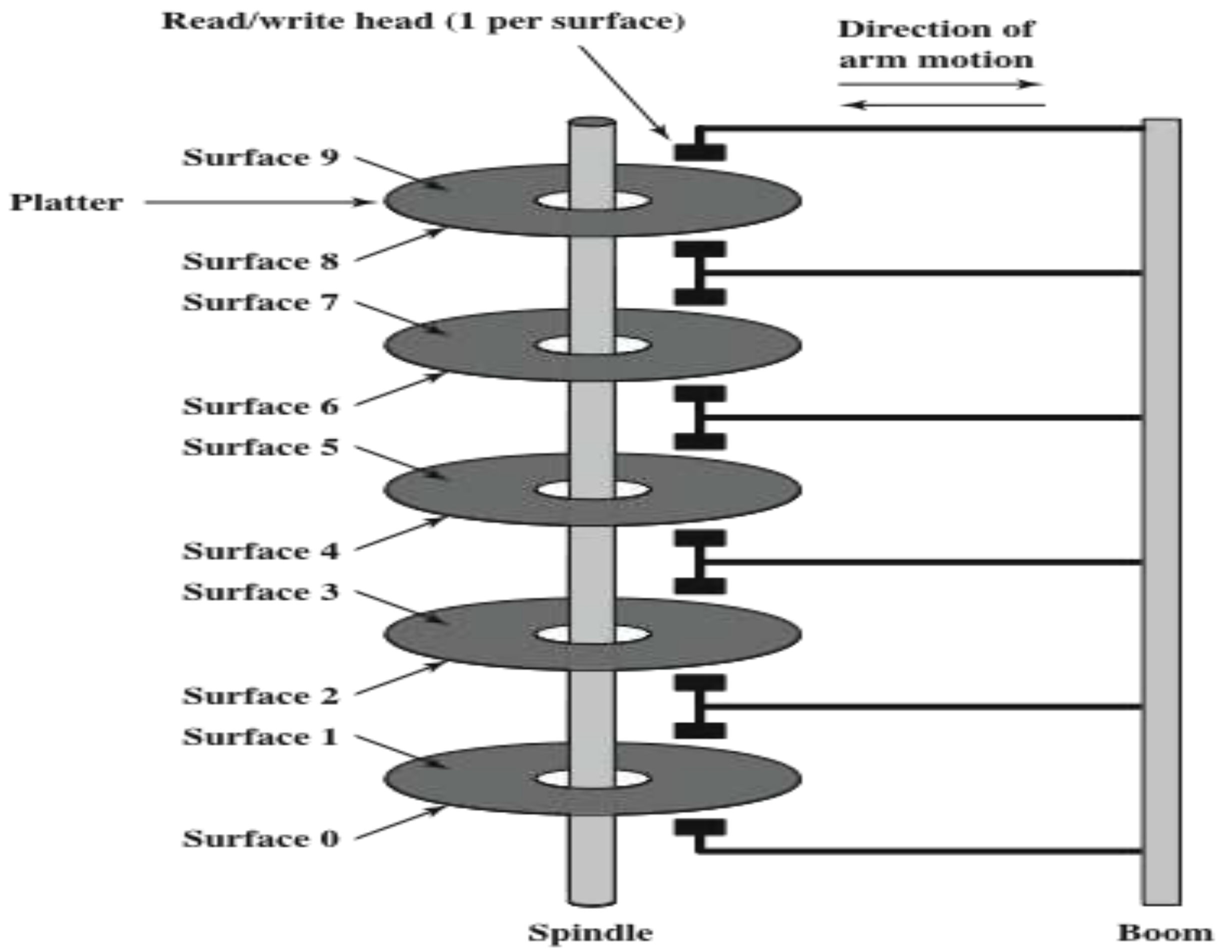


Fig: Double Sided Multiple Platter Disk

Performance Parameters

- **Seek time :** average time it takes to position a head over the correct track. (Zero on fixed head drives)
- **Rotational delay/ latency:** It is the delay waiting for the rotation of the disk to bring the required disk sector under the read-write head .
- **Access time :** seek time + rotational delay
- **Transfer time :** time to read or write one sector once it has reached the head

Performance Parameters (Average Rotational Delay)

- We know that, Speed = $\frac{Distance}{time}$
- So, Rotational Speed, r = $\frac{Rotation\ or\ Revolution}{time}$
- Generally, disk rotation speed is measured in RPM, which stands for **rotation per minute**.
- **Best Case of Rotational Delay:** If the data are stored in the consecutive sectors, the little bit of rotation which is required can be ignored. So in best case, let us suppose 0 rotation is required.
- **Worst Case of Rotational Delay :** If the data are stored randomly, in the worst possible case it may happen that full 1 rotation is required to get the data.
- So, on average we can assume that the disk spins halfway.
- So, **Average Rotational Delay** = $\mathbf{\frac{1}{2r}}$

Performance Parameters (Transfer Time)

- Transfer Rate = $\dfrac{data\ to\ be\ transfered}{Transfer\ time}$
- Transfer rate = per minute how much data I can transfer

  = capacity of a track * No. of rotations/ minute

  = capacity of a track * Rotational Speed

  = capacity of a track * r
- So, **Transfer time** = $\dfrac{\boldsymbol{data\ to\ be\ tranfered}}{\boldsymbol{Transfer\ rate}}$

$$= \frac{\boldsymbol{data\ to\ be\ tranfered}}{\boldsymbol{capacity\ of\ a\ track * r}}$$

$$= \frac{\boldsymbol{number\ of\ bytes\ to\ be\ tranfered}}{\boldsymbol{number\ of\ bytes\ on\ a\ track * r}}$$

Performance Parameters

- Rotational Speed, r = $\frac{Revolutions}{time}$
- Average Rotational delay = $\frac{1}{2r}$
- Transfer time, $T = \frac{b}{rN}$ where,

  b = number of bytes to be transferred

  N = number of bytes on a track

  r = rotation speed, in revolutions per second

- The total average access time can be expressed as,

  Average Seek time + Average Rotational delay + Transfer time

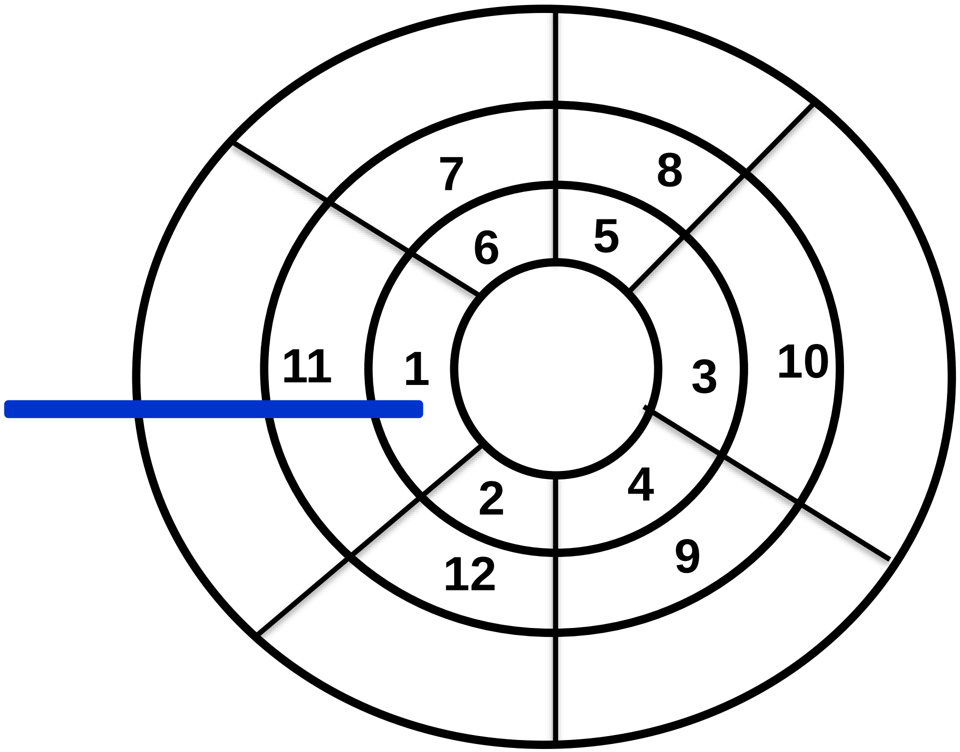
  $\therefore$ Ta = Ts + $\frac{1}{2r} + \frac{b}{rN}$

Performance Parameters

Practice Problem:

Consider a disk with an advertised average seek time of 4 ms, rotation speed of 15,000 rpm, and 512-byte sectors with 500 sectors per track. Suppose that we wish to read a file consisting of 2500 sectors for a total of 1.28 Mbytes. Calculate the average access time for both Sequential access and Random access

Performance Parameters



Sequential Organization

Performance Parameters

Solution:

For **sequential** access,

Let, the file occupies all of the sectors on 2500/500 = 5 adjacent tracks.

Now, the time to read the first track is as follows:

Average seek = 4 ms

Rotational speed, r = 15000 rpm = 15000/60 rps = 250 rps

Average rotational delay = 1/2r = 1/(2*250 rps) = 2ms

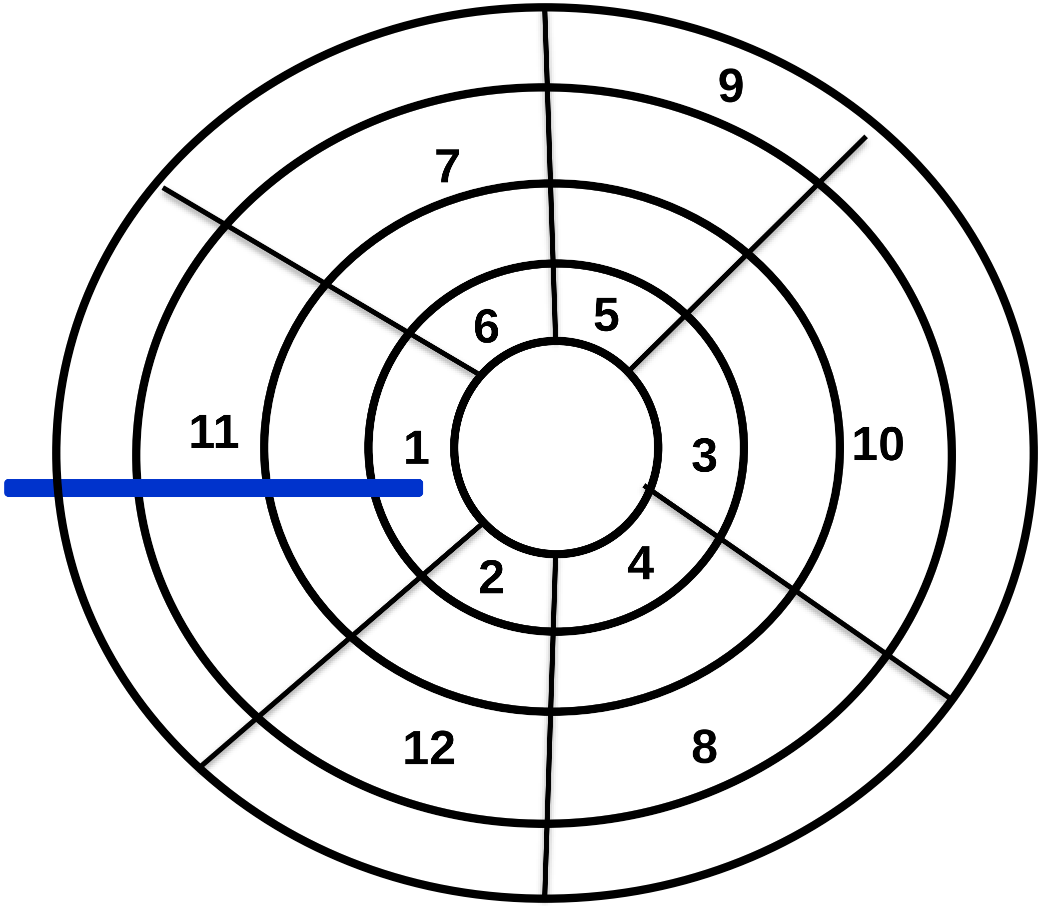
Transfer time for 1 sector = $\frac{b}{rN} = \frac{512}{250*512*500}$ = .008ms

Transfer time for 1 track or 500 sectors = 500* 0.008 ms = 4 ms

Avg. access time for 1^{st} track= 4 + 2 + 4 = 10 ms

Suppose that the remaining tracks can now be read with essentially no seek time. That is, the I/O operation can keep up with the flow from the disk. Then, at most, we need to deal with rotational delay for each succeeding track. Thus each successive track is read in 2 + 4 = 6 ms. To read the entire file, Total time = 10 + (4 * 6) = 34 ms = **0.034 seconds**

Performance Parameters



Random Organization

Performance Parameters

Solution:

For **random** access,

Here, accesses to the sectors are distributed randomly over the disk. For each sector, we have,

Average seek = 4 ms

Rotational speed, r = 15000 rpm = 15000/60 rps = 250 rps

Average rotational delay = 1/2r = 1/(2*250 rps) = 2ms

Transfer time for 1 sector = $\frac{b}{rN} = \frac{512}{250 * 512 * 500}$ = .008ms

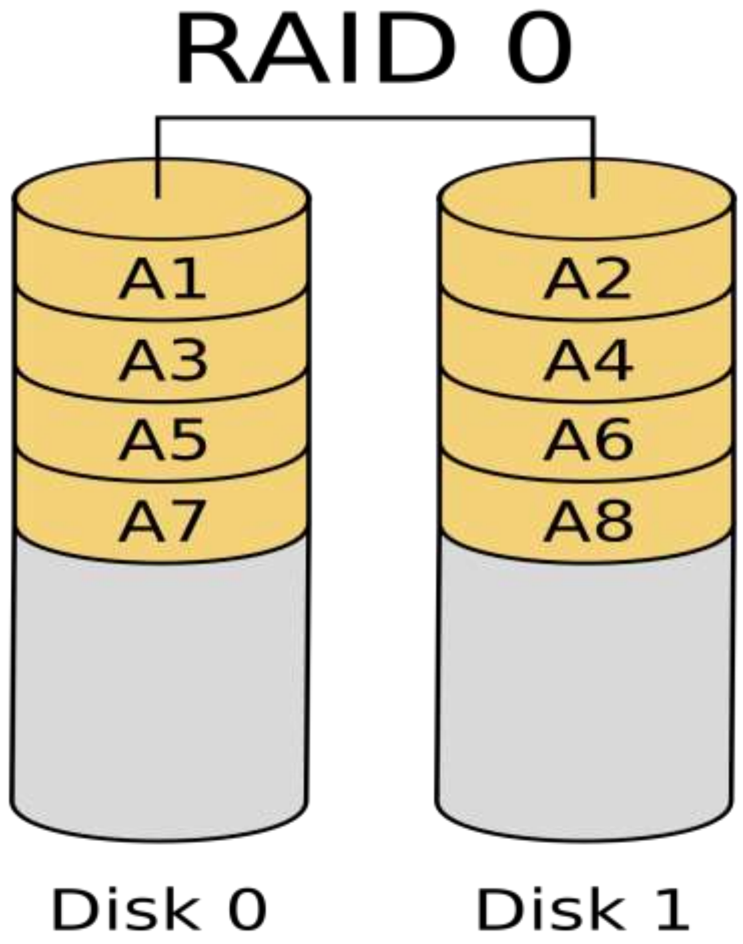
Avg access time for 1 sector 4 + 2 + .008 = 6.008 ms

Total time to read all data = 2500 * 6.008 = 15,020 ms = **15.02 seconds**

RAID

- RAID is a technology that is used to increase the performance and/or reliability of data storage.
- The abbreviation stands for either **Redundant Array of Inexpensive Disks** or **Redundant Array of Independent Drives**.
- A RAID system consists of two or more drives working in parallel. These can be hard disks, but there is a trend to also use the technology for SSD (Solid State Drives).
- There are different RAID levels, each optimized for a specific situation.

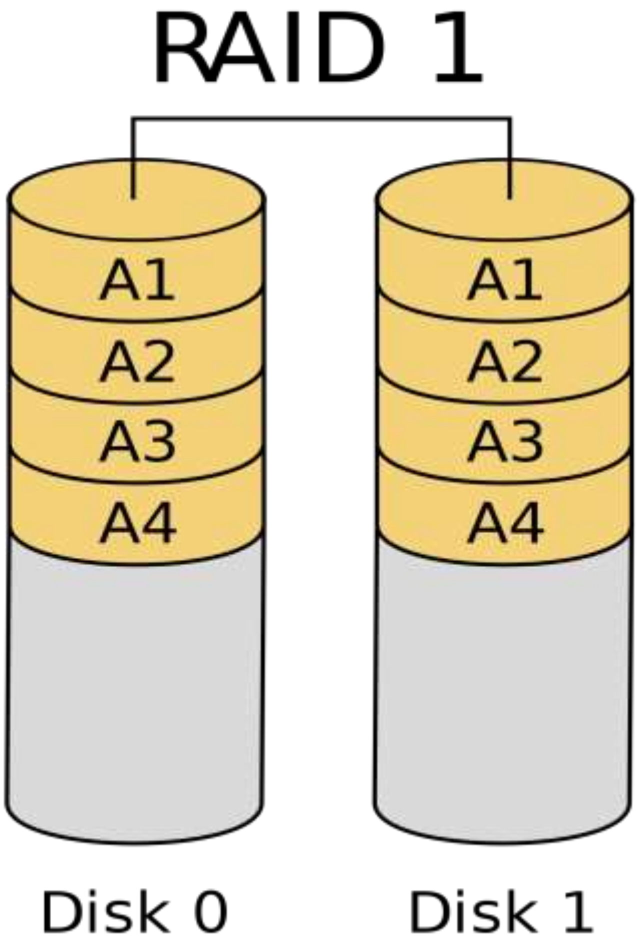
RAID – 0 (Striping)



RAID – 0 (Striping)

- RAID 0 splits data (stripes) evenly across two or more disks, without parity information, redundancy, or fault tolerance.
- You need at least 2 drives for a RAID 1 array.
- <u>Advantages:</u>
  - By using multiple disks (at least 2) at the same time, this offers great performance, both in read and write operations. There is no overhead caused by parity controls.
  - The technology is easy to implement.
- Disadvantages:
  - RAID 0 not fault-tolerant. If one drive fails, all data in the RAID 0 array are lost.

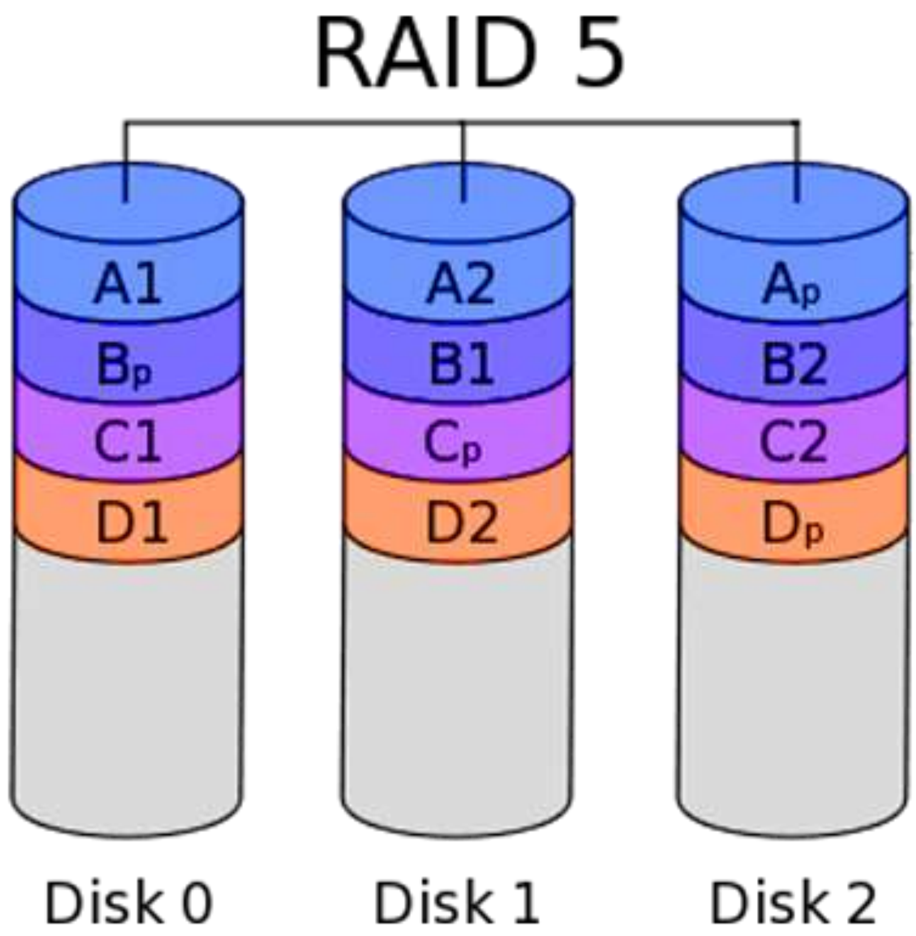
RAID – 1 (Mirroring)



RAID – 1 (Mirroring)

- Data are stored twice by writing them to both the data drive (or set of data drives) and a mirror drive (or set of drives).
- If a drive fails, the controller uses either the data drive or the mirror drive for data recovery and continues operation.
- You need at least 2 drives for a RAID 1 array.
- Advantages:
  - RAID 1 offers excellent read speed and a write-speed that is comparable to that of a single drive.
  - In case a drive fails, data do not have to be rebuild, they just have to be copied to the replacement drive.
  - RAID 1 is a very simple technology.
- Disadvantages:
  - The main disadvantage is that the effective storage capacity is only half of the total drive capacity because all data get written twice.

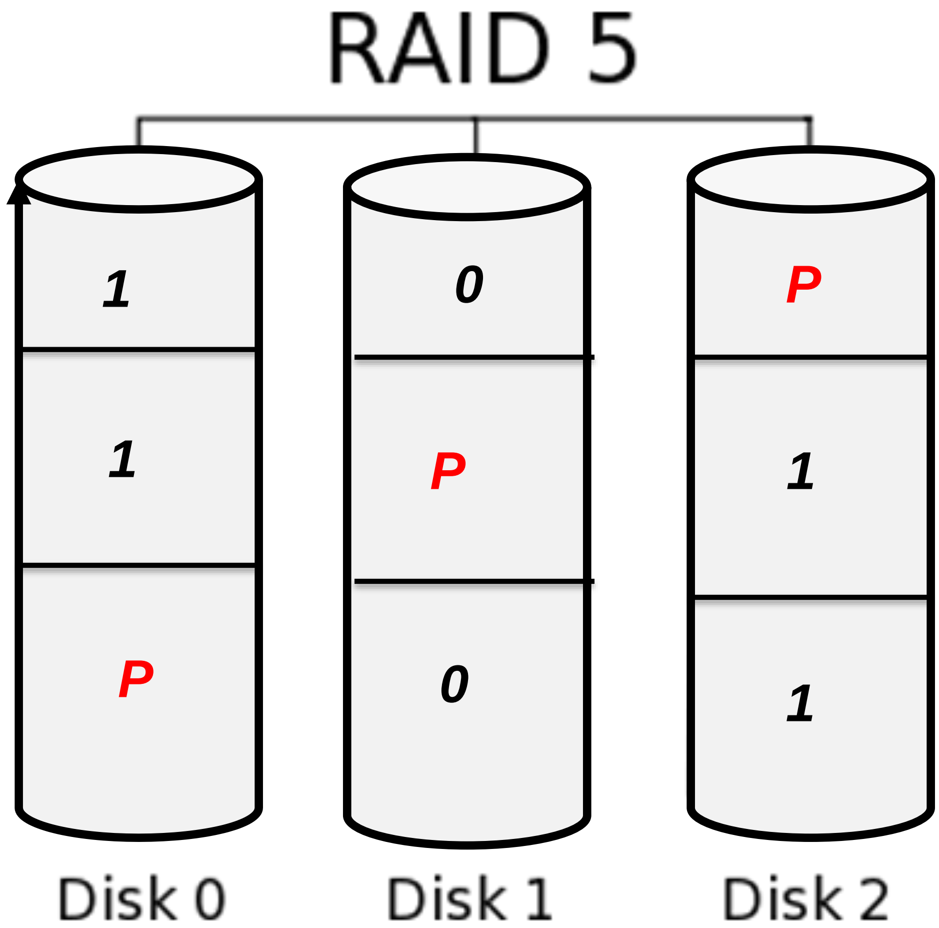
RAID – 5 (striping with parity)



RAID – 5 (striping with parity)

Total Data

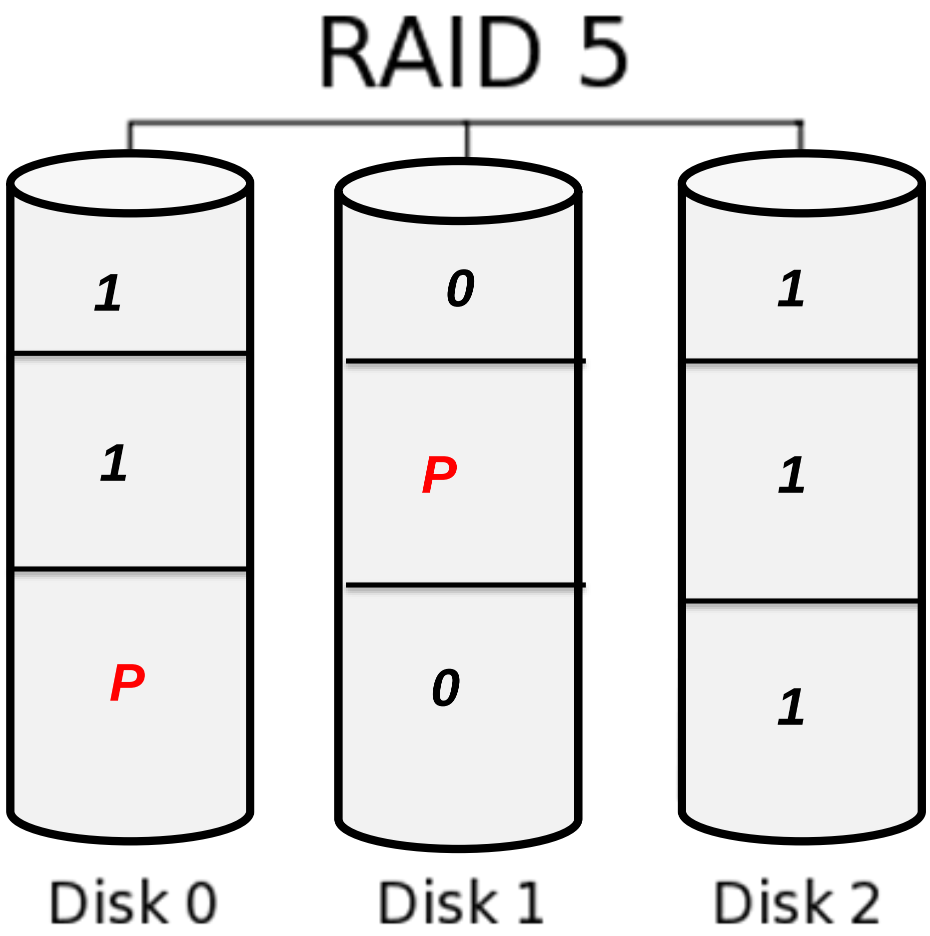
1
0
1
1
0
1



RAID – 5 (striping with parity)

Total Data

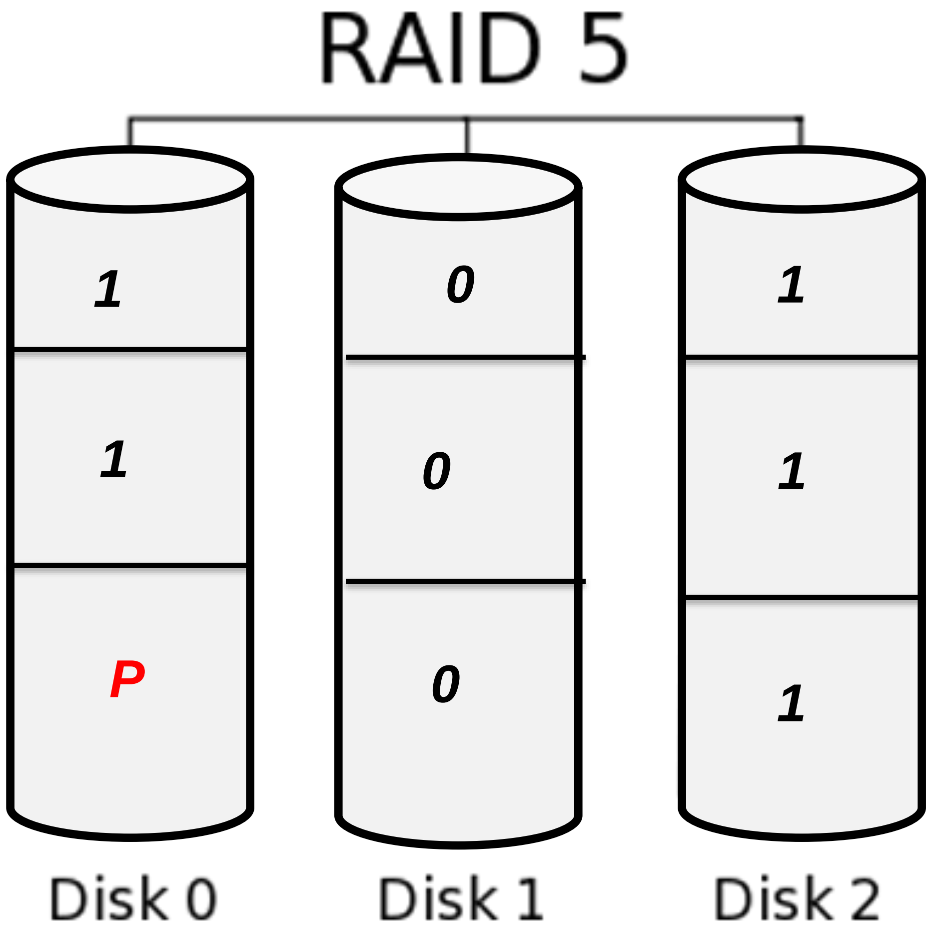
1
0
1
1
0
1



RAID – 5 (striping with parity)

Total Data

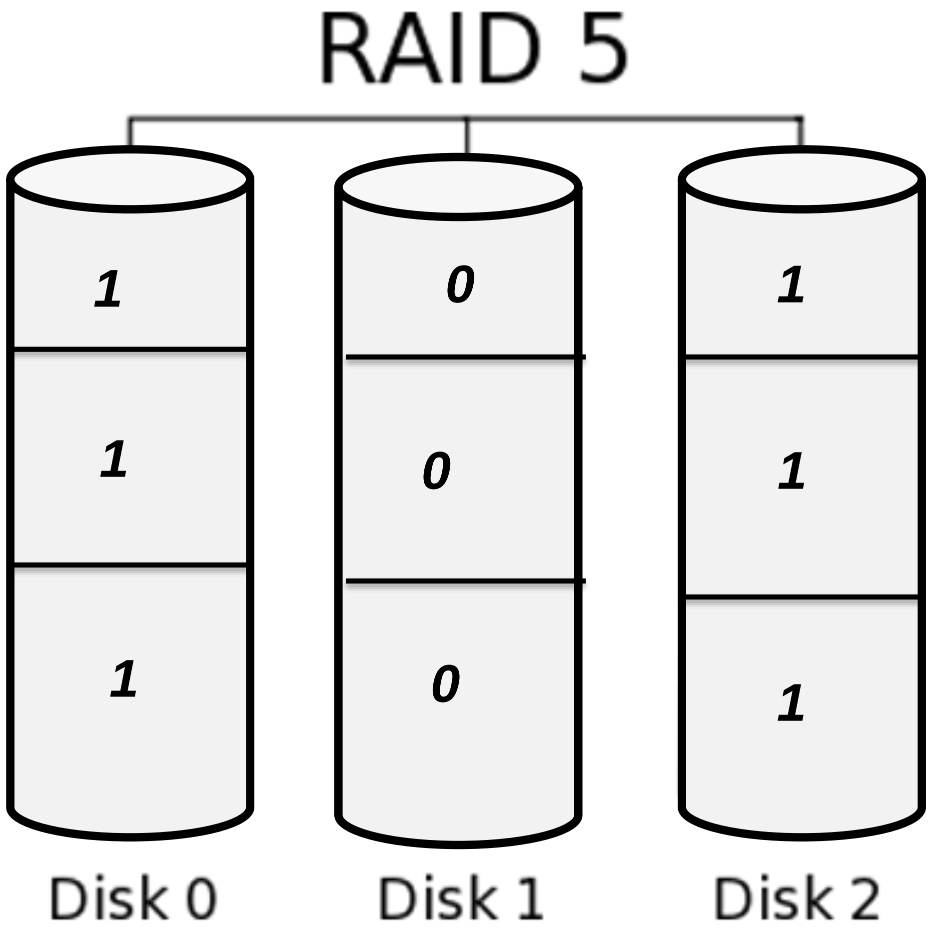
1
0
1
1
0
1



RAID – 5 (striping with parity)

Total Data

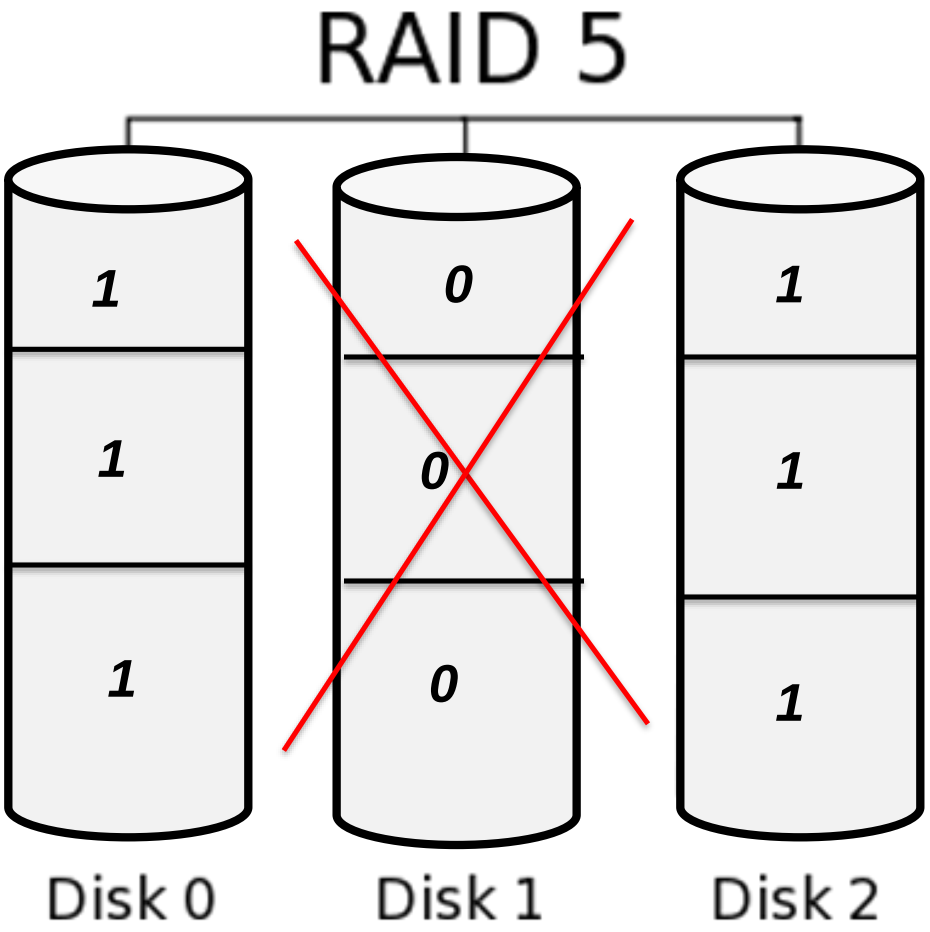
1
0
1
1
0
1



RAID – 5 (striping with parity)

Total Data

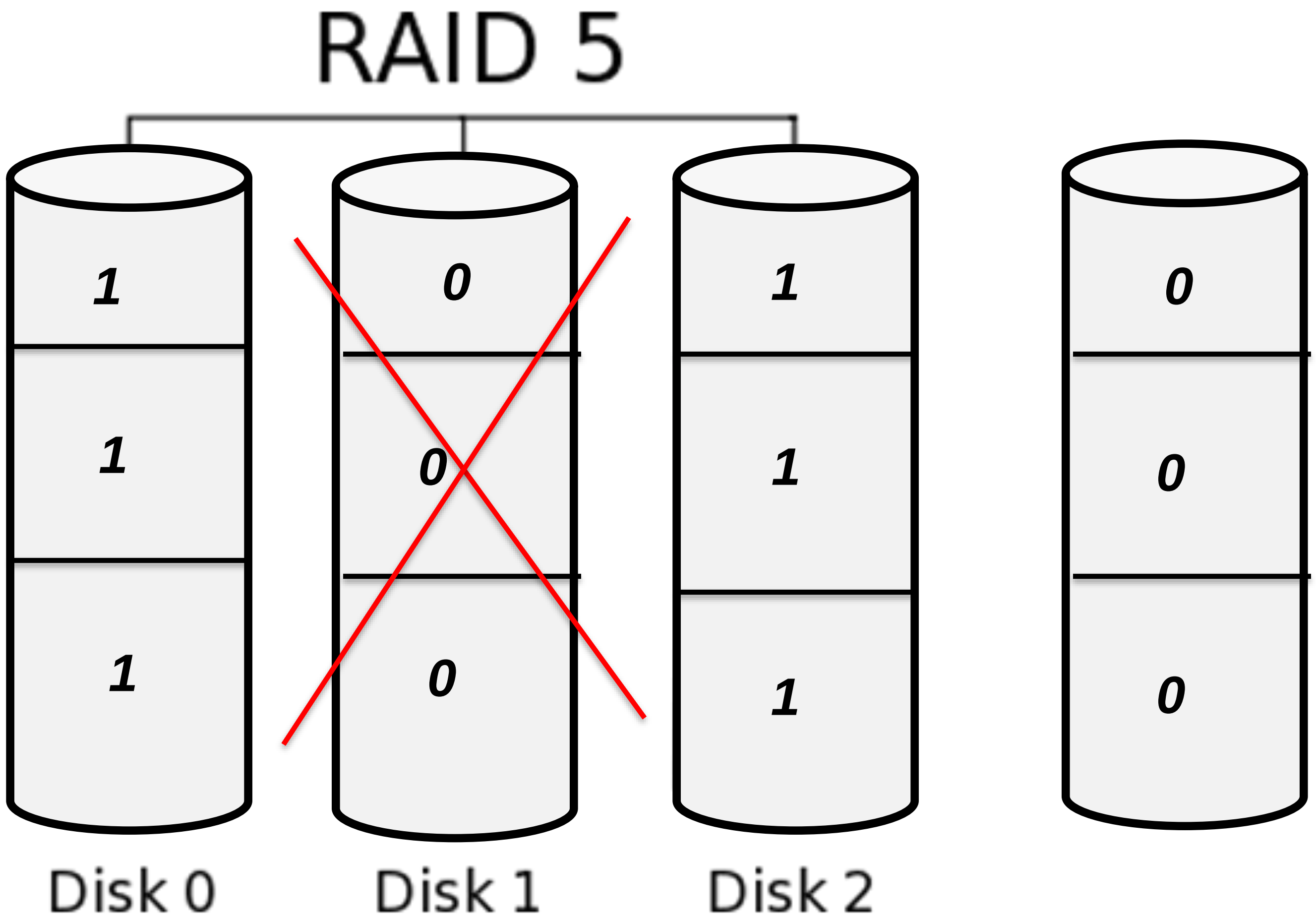
1
0
1
1
0
1



RAID – 5 (striping with parity)

Total Data

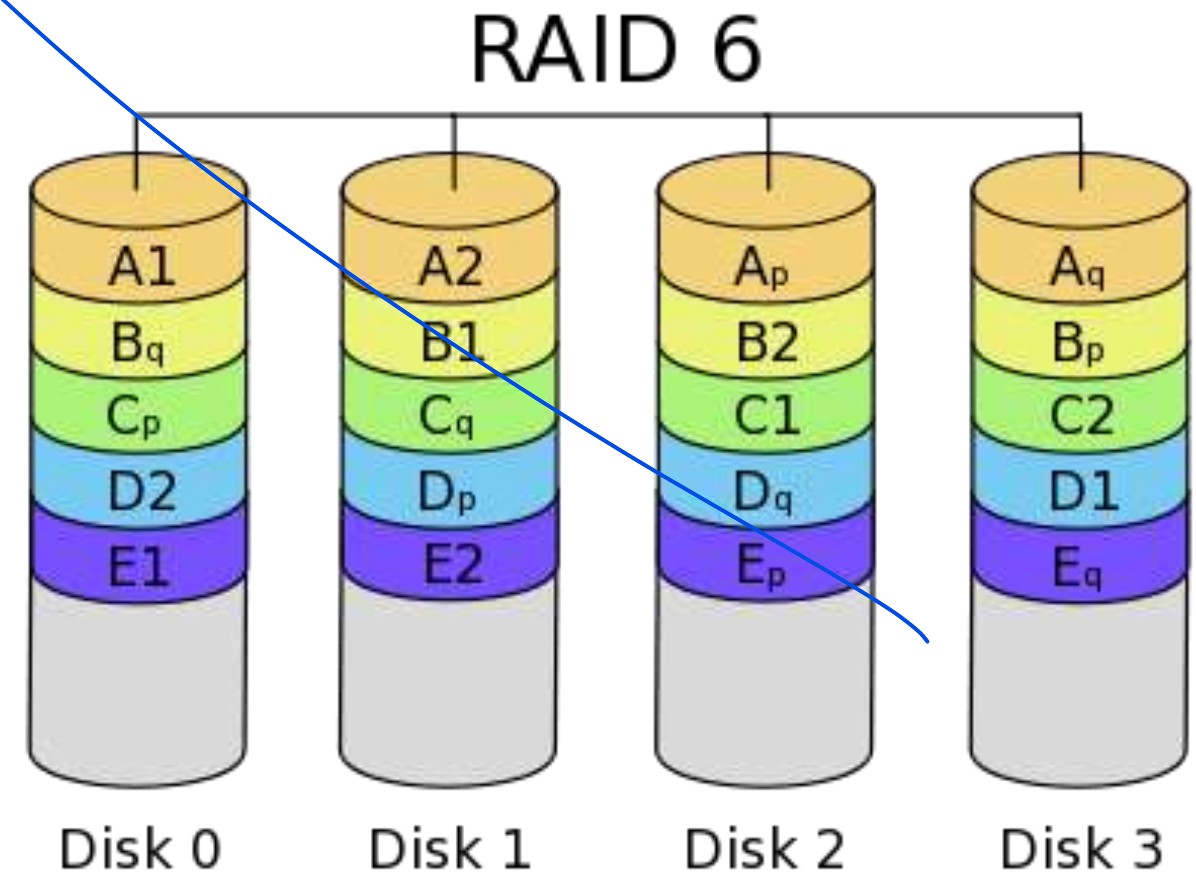
1
0
1
1
0
1



RAID – 5 (striping with parity)

- Data blocks are striped across the drives and on one drive a parity checksum of all the block data is written
- The parity data are not written to a fixed drive, they are spread across all drives
- Using the parity data, the computer can recalculate the data of one of the other data blocks, should those data no longer be available.
- <u>Advantages:</u>
  - RAID 5 array can withstand a single drive failure without losing data or access to data.
- <u>Disadvantages:</u>
  - Drive failures have an effect on throughput, although this is still acceptable.
  - This is complex technology. If one of the disks in an array using 4TB disks fails and is replaced, restoring the data (the rebuild time) may take a day or longer.

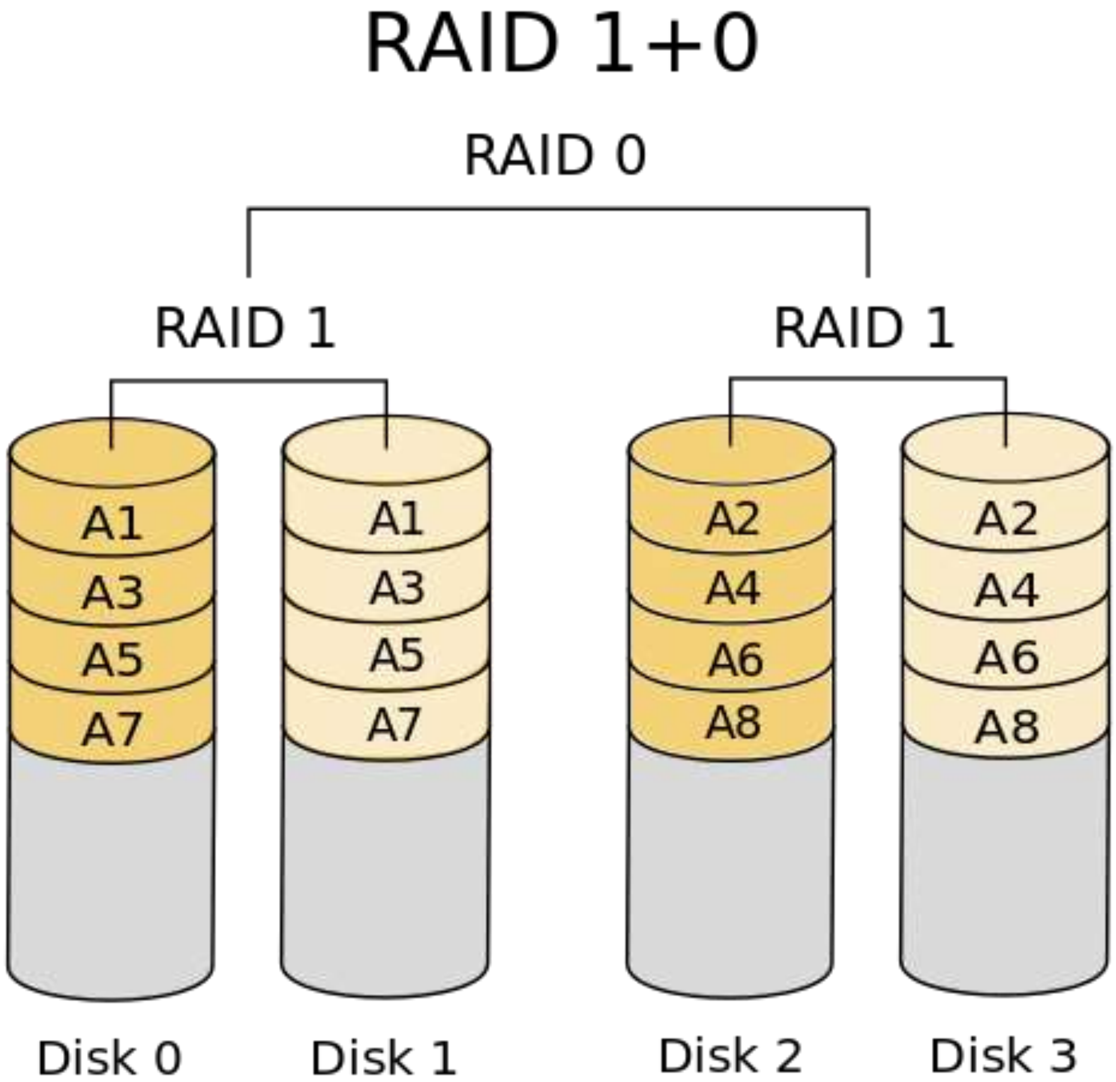
RAID – 6 (striping with double parity)



RAID – 6 (striping with double parity)

- RAID 6 is like RAID 5, but the parity data are written to two drives.
- It requires at least 4 drives
- It can withstand 2 drives dying simultaneously
- Advantages:
  - If two drives fail, you still have access to all data, even while the failed drives are being replaced. So RAID 6 is more secure than RAID 5.
- Disadvantages:
  - Drive failures have an effect on throughput, although this is still acceptable.
  - This is complex technology. Rebuilding an array in which one drive failed can take a long time.

RAID – 10 (combining RAID 1 & 0)



RAID – 10 (striping with double parity)

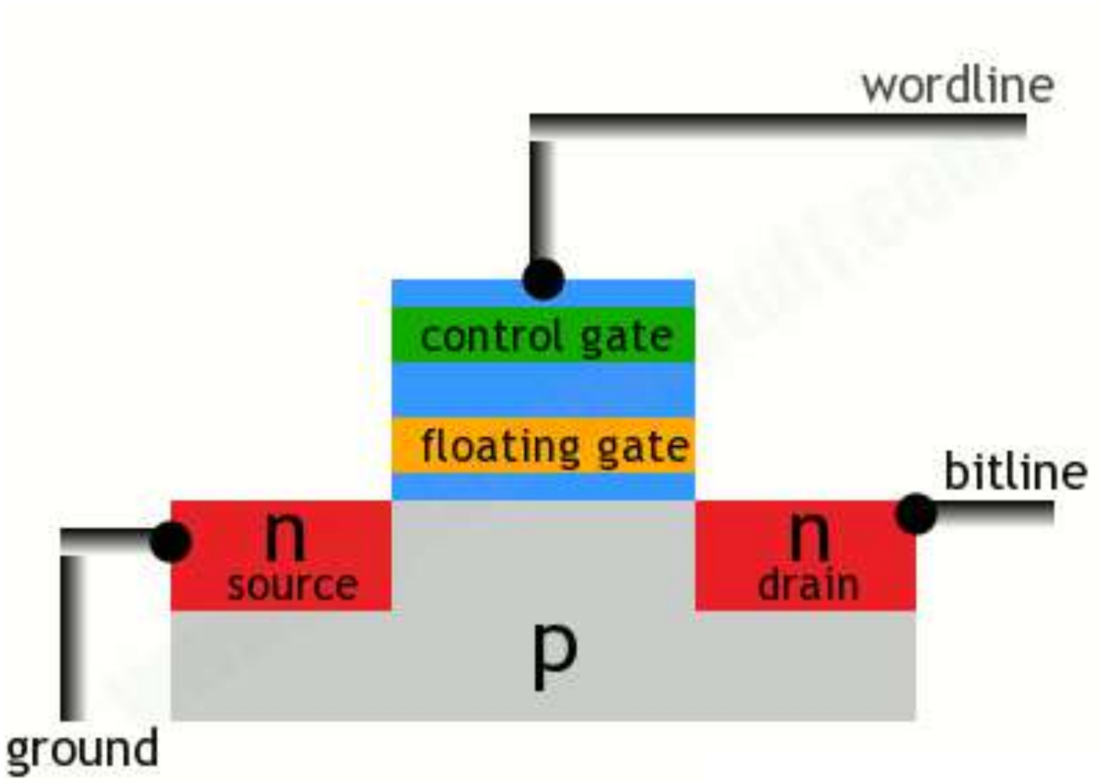
- It is done by combining the advantages (and disadvantages) of RAID 0 and RAID 1 in one single system.
- It provides security by mirroring all data on secondary drives while using striping across each set of drives to speed up data transfers.
- <u>Advantages:</u>
  - If something goes wrong with one of the disks in a RAID 10 configuration, the rebuild time is very fast since all that is needed is copying all the data from the surviving mirror to a new drive.
- <u>Disadvantages</u>:
  - Half of the storage capacity goes to mirroring

Flash Drive

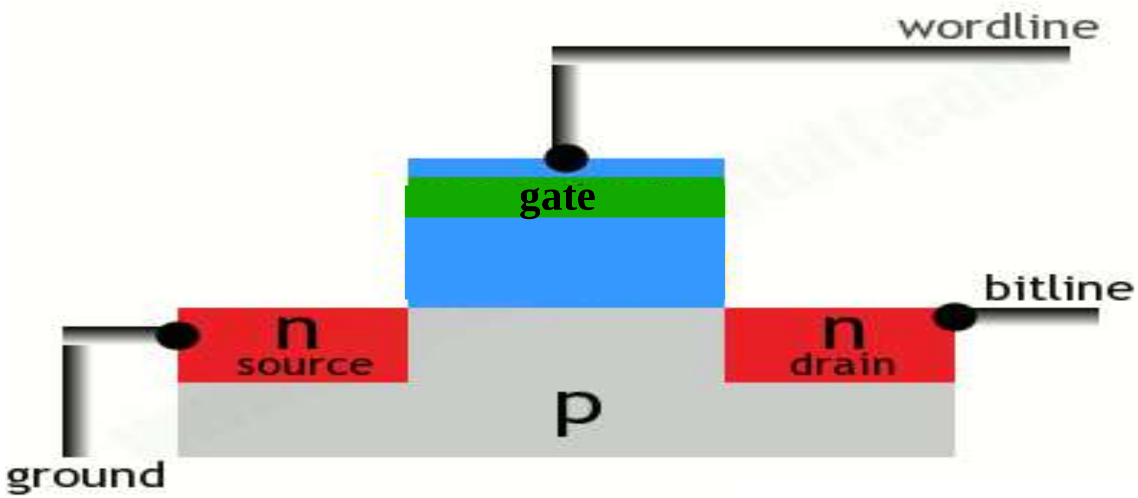
- Why do we need flash drive?
  - Ordinary computer chips "forget" everything (lose their entire contents) when the power is switched off. So we need a non-volatile memory.
  - Large personal computers get around this by having powerful magnetic memories called hard disks. These are non-volatile.
  - The size of hard disks are large. For smaller, more portable devices, such as smart phones, digital cameras, and MP3 players, smaller and more portable memories are needed. This is when we need **Flash Drives**.

How Flash Drive Works?

- Each Flash Memory Cell is made of a special type of transistor called Floating Gate Transistor.

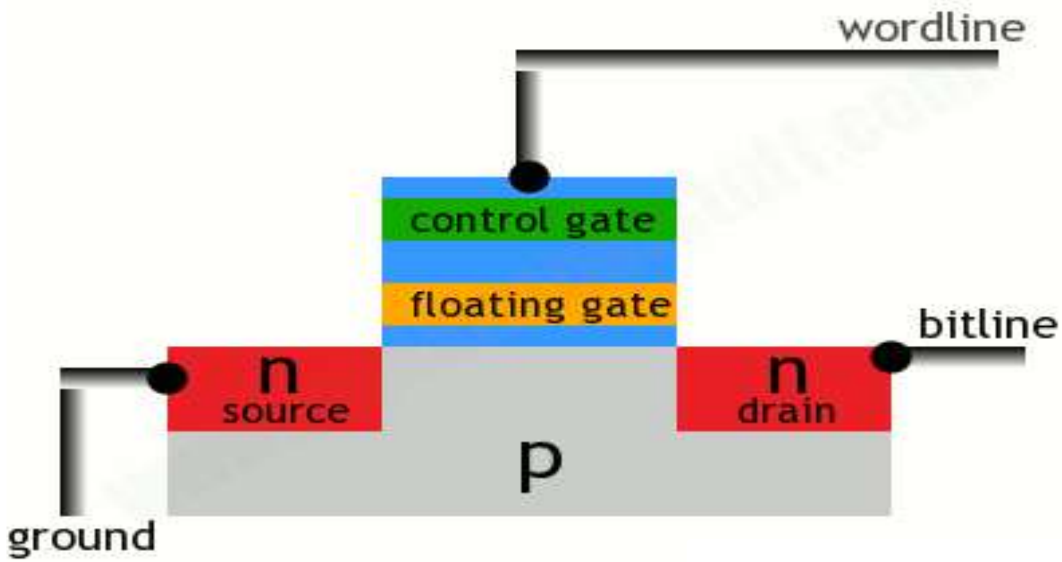


Problems with Ordinary Transistor



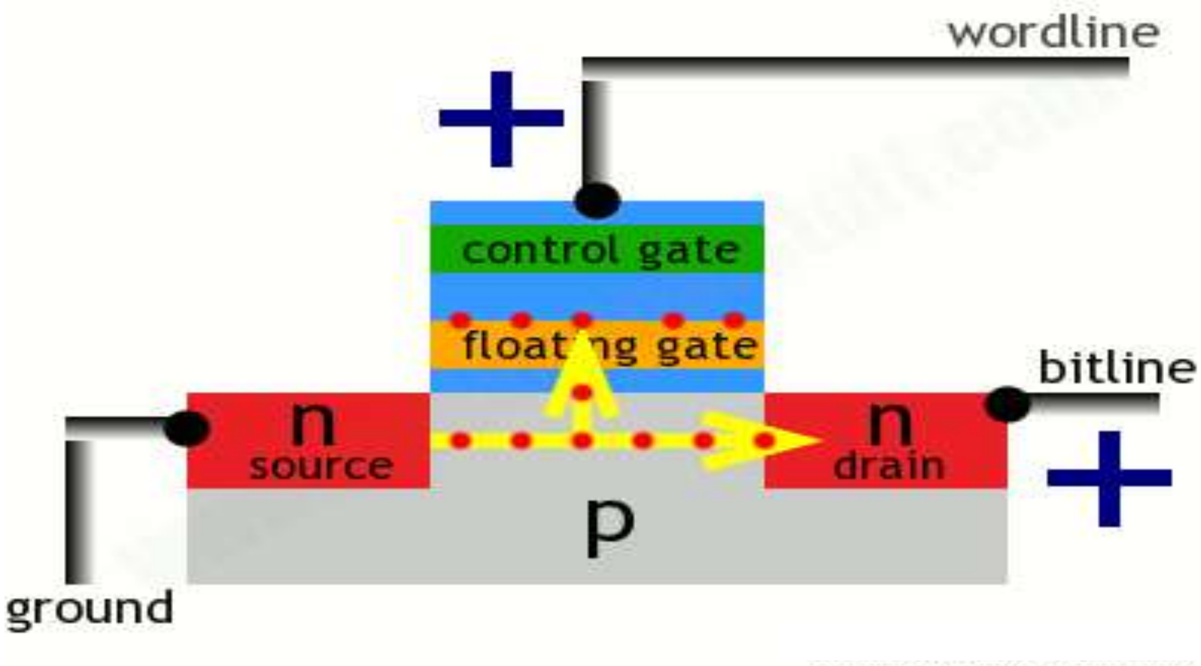
- When the gate is closed, no electricity can flow and the transistor is off. In this state, the transistor stores a zero.
- When the gate is opened, electricity flows, the transistor is on, and it stores a one.
- But when the power is turned off, the transistor switches off too. When you switch the power back on, the transistor is still off, and since you can't know whether it was on or off before the power was removed, you can see why we say it "forgets" any information it stores.
- So clearly it is a **volatile memory**

Solution with Floating Gate Transistor



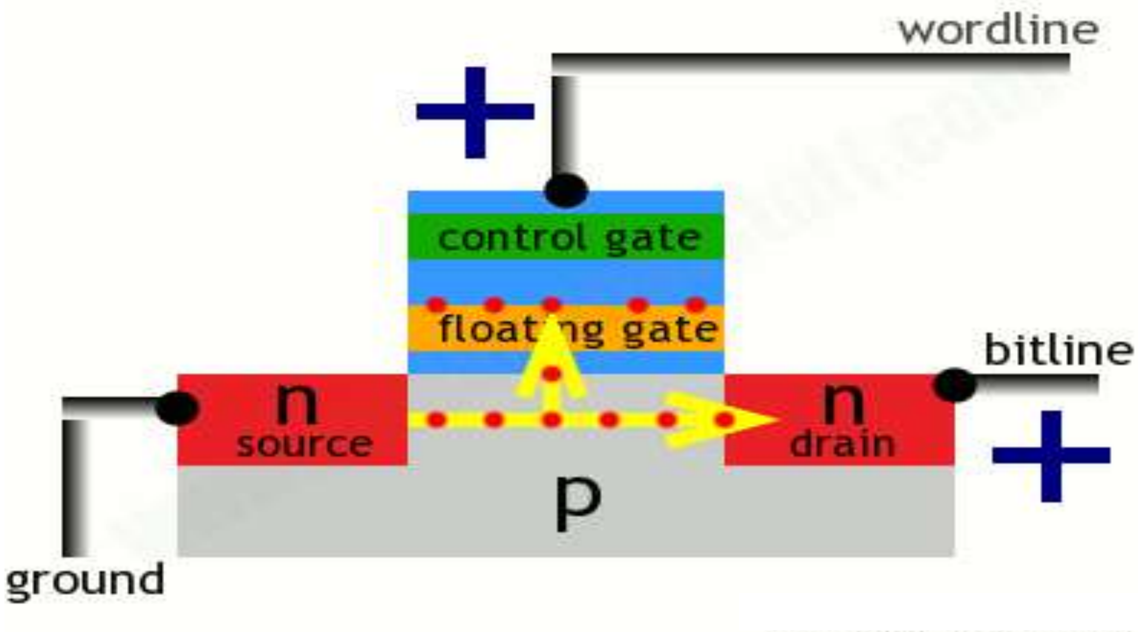
- It's an n-p-n sandwich with two gates on top, one called a control gate and one called a floating gate.
- The two gates are separated by oxide layers through which current cannot normally pass.
- In this state, the transistor is **switched off** — and effectively storing a zero.

Solution with Floating Gate Transistor



- Both the source and the drain regions are rich in electrons (because they're made of n-type silicon), but electrons cannot flow from source to drain because of the p-type material between them.
- To turn it on, we apply a positive voltage to the wordline and bitline and electrons get pulled in a rush from source to drain

Solution with Floating Gate Transistor



- A few also manage to wriggle through the oxide layer by a process called tunneling and get stuck on the floating gate. These he electrons will stay there indefinitely, even when the positive voltages are removed and whether there is power supplied to the circuit or not.
- The electrons can be flushed out by putting a negative voltage on the wordline—which repels the electrons back the way they came, clearing the floating gate and making the transistor store a zero again.

Advantages of Flash Memory

- It saves data when power is OFF. It is non-volatile and hence preserve state without any power.
- High transferring speed, hence it has faster read and write compare to traditional hard disk drives.
- Small size, portability
- Low power consumption than traditional hard disk drives
- Accidentally dropping a flash stick will likely have no effect on the information contained on it.
- It does not have any moving parts larger than electrons.
- Work more quietly than physical hard drive
- Adding or deleting files in flash memory is quick and tidy.

Solid State Drive (SSD)

- Does Flash Memory and SSD means the same thing?
  - The answer is : NO!!
- To understand the relation between them, think that “flash is like eggs and an SSD is like an omelet”.
  - Just like an omelet is made mostly of eggs, an SSD is made mostly of flash.
  - You can also do lots of things with eggs besides making omelets. In the same way, you can do lots of things with flash besides making SSDs.
  - It might also be possible to make an omelet without eggs, if you used an egg substitute. Just like this, it's definitely possible to make an SSD without flash.

Solid State Drive (SSD)

- There are 2 types of Flash Memory:
  - NOR Flash Memory
  - NAND Flash Memory
- NAND Flash is used for SSD
  - In NOR flash, the cells are wired in parallel.
  - In NAND flash, the cells are wired in serial.
  - NAND flash is less expensive, and it can read and write data much more rapidly. This makes NAND flash an ideal storage technology for using in solid-state drives.
- In computers, SSD can be used as a replacement of HDD, as it serves the same purpose as HDD.
- But like HDD, they have no moving parts, that’s why they are called “solid state”.

Solid State Drive (SSD)

- SSDs can only write to empty pages in a block.
- Page and Block:
  - In SSD, NAND flash is organized in a grid. The entire grid layout is referred to as a block, while the individual rows that make up the grid are called a page.
  - Common page sizes are 2K, 4K, 8K, or 16K, with 128 to 256 pages per block. Block size therefore typically varies between 256KB and 4MB.

Advantages of SSD over HDD

SSDs have the following advantages over HDDs:

- **Durability:** Less susceptible to physical shock and vibration.
- **Longer lifespan:** SSDs are not susceptible to mechanical wear. Mechanical wear is the continuing loss of material from the surface of a solid body due to mechanical action
- **Lower power consumption**: SSDs use as little as 2.1 watts of power per drive, considerably less than comparable-size HDDs.
- **Quieter and cooler running capabilities:** Less floor space required, lower energy costs, and a greener enterprise.
- **Lower access times and latency rates:** Over 10 times faster than the spinning disks in an HDD.
- **High-performance input/output operations per second (IOPS):** Significantly increases performance of I/O subsystems.

Limitations of SSD

- One of the functional limitations of SSD is while they can read and write data very quickly to an empty drive, erasing data is much slower. This is because:
  - SSDs read data at the page level (meaning from individual rows within the NAND memory grid) and can write at the page level but they can only erase data at the block level.
- Another limitation lies while updating an existing page. To do so what we need to do is:
  - Copy the contents of the entire block into memory
  - Erase the block
  - After that write the updated data and also the contents of memory
- Flash memory becomes unusable after a certain number of writes
- For these reasons SSDs can become slower as they age

CD-ROM

- CD-ROM is an optical disk and the full form of CD-ROM is Compact Disk- Read Only Memory.
- As the name suggests, one can read the CD many times but can not write. The writing part is done during manufacture process.
- Previously, floppy disks were used instead of CD-ROMs. 1 CD-ROM = 700 Floppy disks. So definitely, it's a better version.

How CD-ROM works

- A CD-ROM has three layers: base layer, reflective layer and protective layer.
- The base layer is made of a polycarbonate substrate called transparent substrate.
- On the base, there is a metal (generally, aluminum) reflective data layer.
- On the reflecting layer, there is a protective coating called protective layer.
- The information to be stored is digitized, that is, the data can be represented by binary numbers, which are made up of '1' and '0' digits. This information is stored on the metal layer. The data is represented using pits (1) and space between pits is called land (0). Here pits means a rough surface and land means a smooth surface.
- While reading, the difference of the reflections between pits and land determines whether the data is 1 or 0.

How CD-ROM works

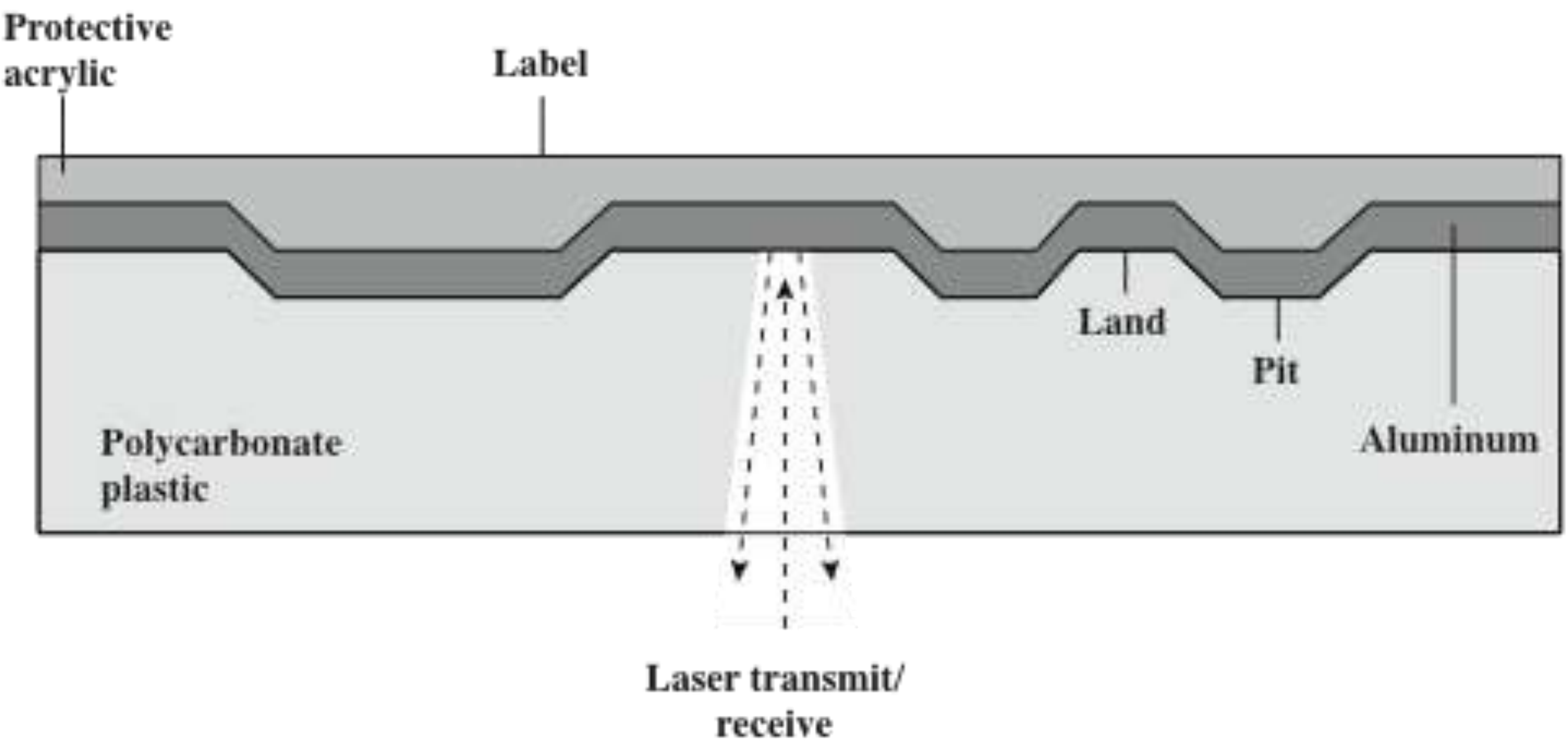


Figure 6.12 CD Operation

Advantages and Disadvantages of CD-ROM

Advantages:

- Data can not be erased, so data loss is not normally possible
- Easy to carry around.
- Cheap to produce.
- Can be read by a DVD drive also.
- Easily removable.

Disadvantages:

- User can not write data of own.
- Can get scratched easily, this effects the data when the laser reads it.
- Slower to access than a hard disk.

CD-R and CD-RW

CD-R:

- The full form of CD-R is Compact Disk Recordable.
- A CD-R is a blank CD that can be written to by a CD burner.
- That means, you can burn it individually in your computer CD drive at home or in office.
- Once written, it can not be changed.

CD-RW:

- The full form of CD-RW is Compact Disk Re-writable.
- Just like CD-R, it is also a blank CD that can be written to by a CD burner.
- But unlike a CD-R, a CD-RW can be written to multiple times.
- The data burned on a CD-RW cannot be changed, but it can be erased. Therefore, you have to completely erase a CD-RW every time you want to change the files or add new data.

Comparison between CD-R and CD-RW

At first glance, it would seem hard to identify one from the other without the distinctive writing on the top side. The main difference between these two are:

- **Reusability:** CD-R can only be written to once, although you don't have to write to the entire disc at once. Once it is full, you can only read data from it. On the other hand, a CD-RW is rewritable. This means, that you can erase the information stored on it and write new data whenever you want.
- **Compatibility:** CD-R is compatibility with older CD-ROMS. Because of the difference in material with the CD-RW, some older drives and players may fail to recognize and read the data stored in a CD-RW. Newer models can read both CD-R and CD-RW, but for those with older hardware, a CD-R is the safer bet.
- **Cost:** The more versatile CD-RW disc is pricier than a CD-R disc.

Digital Versatile Disk(DVD)

- A DVD is very similar to a CD, but it has a much **larger data capacity**. A standard DVD holds about seven times more data than a CD does.
- DVDs can store more data than CDs for a few reasons:
  - **Higher-density data storage:** Single-sided, single-layer DVDs can store about seven times more data than CDs. A large part of this increase comes from the pits and tracks being smaller on DVDs.
  - **Multi-layer storage:** To increase the storage capacity even more, a DVD can have up to four layers, two on each side.
  - **Less overhead, more area:** On a CD, there is a lot of extra information encoded on the disc to allow for error correction -- this information is really just a repetition of information that is already on the disc. The error correction scheme that a CD uses is quite old and inefficient compared to the method used on DVDs. The DVD format doesn't waste as much space on error correction, enabling it to store much more real information.


THANK YOU