MODULE-2

DATA PROTECTION - RAID

Data Protection: RAID

- In 1987, Patterson, Gibson, and Katz at the University of California, Berkeley, published a paper titled "A Case for **Redundant Arrays of Inexpensive Disks (RAID)**."
- **RAID is the use of small-capacity, inexpensive disk drives as an alternative to large-capacity drives common on mainframe computers.**
- Later RAID has been redefined to refer to ***independent*** disks to reflect advances in the storage technology.

2.1 RAID Implementation Methods

- The two methods of RAID implementation are:
    1. Hardware RAID.
    2. Software RAID.

➢ Hardware RAID

- In hardware RAID implementations, a specialized hardware controller is implemented either on the *host* or on the *array*.
- **Controller card RAID** is a *host-based hardware RAID* implementation in which a specialized RAID controller is installed in the host, and disk drives are connected to it.
- Manufacturers also integrate RAID controllers on motherboards.
- A host-based RAID controller is not an efficient solution in a data center environment with a large number of hosts.
- The external RAID controller is an *array-based hardware RAID*.
- It acts as an interface between the host and disks.
- It presents storage volumes to the host, and the host manages these volumes as physical drives.
- The key functions of the RAID controllers are as follows:
    - ✓ Management and control of disk aggregations
    - ✓ Translation of I/O requests between logical disks and physical disks
    - ✓ Data regeneration in the event of disk failures

2.1.2 Software RAID

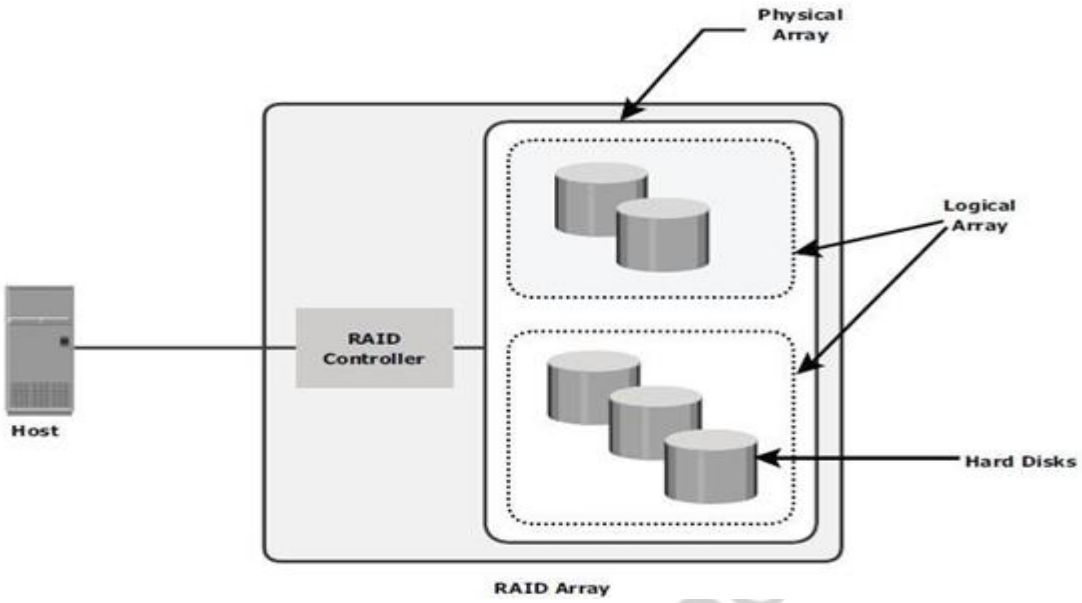
- **Software RAID** uses host-based software to provide RAID functions.

- It is implemented at the operating-system level and does not use a dedicated hardware controller to manage the RAID array.
- Advantages when compared to Hardware RAID:
  - ✓ cost
  - ✓ simplicity benefits
- Limitations:
  - ✓ **Performance**: Software RAID affects overall system performance. This is due to additional CPU cycles required to perform RAID calculations.
  - ✓ **Supported features**: Software RAID does not support all RAID levels.
  - ✓ **Operating system compatibility**: Software RAID is tied to the host operating system; hence, upgrades to software RAID or to the operating system should be validated for compatibility. This leads to inflexibility in the data-processing environment.

RAID Array Components

- □ A **RAID array** is an enclosure that contains a number of HDDs and the supporting hardware and software to implement RAID. HDDs inside a RAID array are usually contained in smaller sub-enclosures.
- □ A subset of disks within a RAID array can be grouped to form logical associations called **Logical Arrays,** also known as a **RAID sector a RAID group**.

  Logical arrays are comprised of **Logical Volumes (LV**). The operating system recognizes the LVs as if they are physical HDDs managed by the RAID controller.



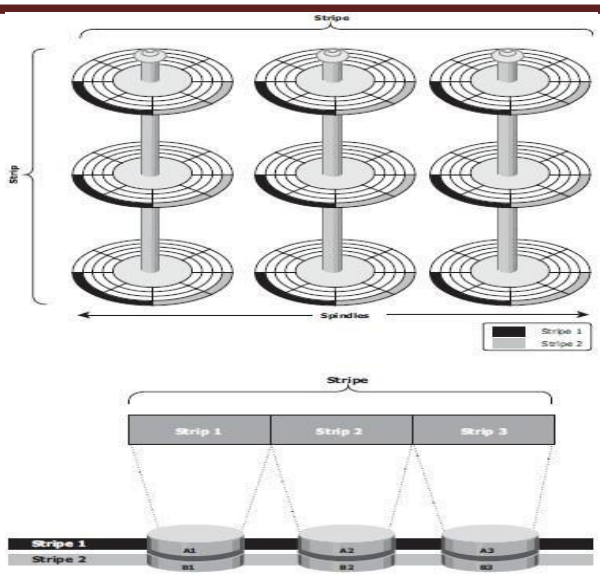
Components of RAID array

2.2 RAID Techniques

- There are three RAID techniques
  1. striping
  2. mirroring
  3. parity

2.2.1 Striping

- **Striping** is a technique to spread data across multiple drives (more than one) to use the drives in parallel.
- All the read-write heads work simultaneously, allowing more data to be processed in a shorter time and increasing performance, compared to reading and writing from a single disk.
- Within each disk in a RAID set, a **predefined number of contiguously addressable** disk blocks are defined as a **strip**.
- The set of aligned strips that spans across all the disks within the RAID set is called a **stripe**.
- Fig 1.11 shows physical and logical representations of a striped RAID set.



- **Strip size** (also called **stripe depth**) describes the number of blocks in a strip and is the maximum amount of data that can be written to or read from a single disk in the set.
- All strips in a stripe have the same number of blocks.
  - ✓ Having a smaller strip size means that data is broken into smaller pieces while spread across the disks.
- **Stripe size** is a multiple of strip size by the number of **data** disks in the RAID set.
  - ✓ Eg: In a 5 disk striped RAID set with a strip size of 64 KB, the stripe size is 320KB (64KB x 5).
- **Stripe width** refers to the number of *data* strips in a stripe.
- Striped RAID does not provide any data protection unless parity or mirroring is used.

2.2.2 Mirroring

- **Mirroring** is a technique whereby the same data is stored on two different disk drives, yielding two copies of the data.
- If one disk drive failure occurs, the data is intact on the surviving disk drive (see Fig 1.12) and the controller continues to service the host's data requests from the surviving disk of a mirrored pair.
- When the failed disk is replaced with a new disk, the controller copies the data from the surviving disk of the mirrored pair.
- This activity is transparent to the host.

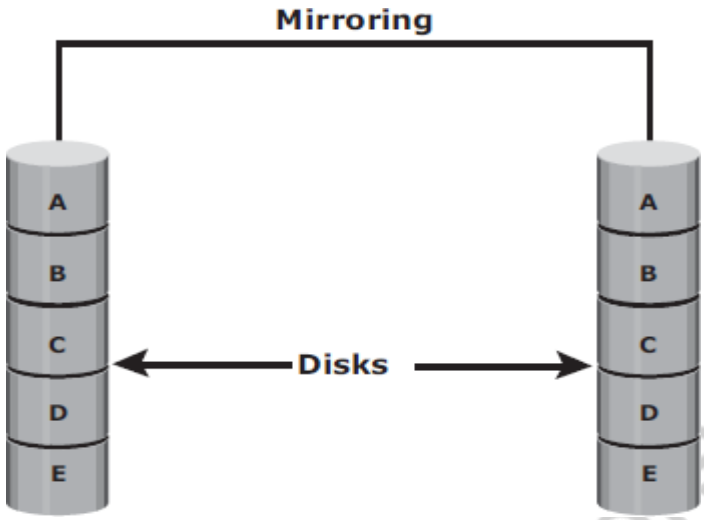


Fig 1.12: Mirrored disks in an array

- Advantages:
  - ✓ complete data redundancy,
  - ✓ mirroring enables fast recovery from disk failure.
  - ✓ data protection
- Mirroring is not a substitute for data backup. Mirroring constantly captures changes in the data, whereas a backup captures point-in-time images of the data.
- Disadvantages:
  - ✓ Mirroring involves duplication of data — the amount of storage capacity needed is twice the amount of data being stored.
  - ✓ Expensive

2.2.3 Parity

- **Parity** is a method to protect striped data from disk drive failure without the cost of mirroring.
- *An additional disk drive is added to hold parity,* a mathematical construct that allows re-creation of the missing data.
- Parity is a **redundancy technique** that ensures protection of data without maintaining a
- Calculation of parity is a function of the RAID controller.
- Parity information can be stored on separate, dedicated disk drives or distributed across all the drives in a RAID set.
- Fig 1.13 shows a parity RAID set.

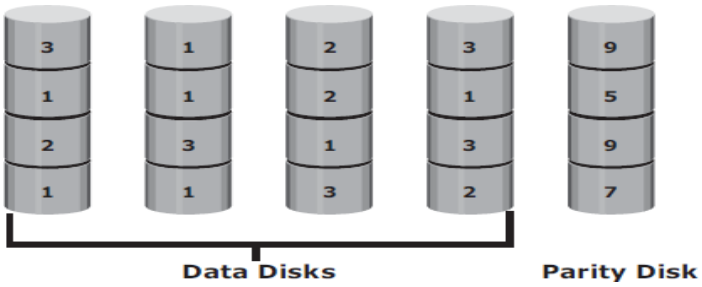


Fig 1.13: Parity RAID

- The first four disks, labeled "*Data Disks*," contain the data. The fifth disk, labeled "*Parity Disk*," stores the parity information, which, in this case, is the sum of the elements in each row.
- Now, if one of the data disks fails, the missing value can be calculated by subtracting the sum of the rest of the elements from the parity value.
- Here, computation of parity is represented as an arithmetic sum of the data. However, parity calculation is a bitwise XOR operation.

XOR Operation:

- A bit-by-bit Exclusive -OR (XOR) operation takes two bit patterns of equal length and performs the logical XOR operation on each pair of corresponding bits.
- The result in each position is 1 if the two bits are different, and 0 if they are the same.
- The truth table of the XOR operation is shown below (A and B denote inputs and C, the output the XOR operation).

Table 1.1: Truth table for XOR Operation

A	B	C
0	0	0
0	1	1
1	0	1
1	1	0

- If any of the data from A, B, or C is lost, it can be reproduced by performing an XOR operation on the remaining available data.
- Eg: if a disk containing all the data from A fails, the data can be regenerated by performing an XOR between B and C.
- Advantages:
  - ✓ Compared to mirroring, parity implementation considerably reduces the **cost**

associated with data protection.

- Disadvantages:
  - ✓ Parity information is generated from data on the data disk. Therefore, parity is recalculated every time there is a change in data.
  - ✓ This recalculation is time-consuming and affects the performance of the RAID array.
- For parity RAID, the stripe size calculation does not include the parity strip.
- Eg: in a five (4 + 1) disk parity RAID set with a strip size of 64 KB, the stripe size will be 256 KB (64 KB x 4).

2.4 RAID Levels

- RAID Level selection is determined by below factors:
  - ✓ Application performance
  - ✓ data availability requirements
  - ✓ cost
- RAID Levels are defined on the basis of:
  - ✓ Striping
  - ✓ Mirroring
  - ✓ Parity techniques
- Some RAID levels use a single technique whereas others use a combination of techniques. Table 1.2 shows the commonly used RAID levels Table 1.2: RAID Levels

2.4.1 RAID 0

LEVELS	BRIEF DESCRIPTION
RAID 0	Striped set with no fault tolerance
RAID 1	Disk mirroring
Nested	Combinations of RAID levels. Example: RAID 1 + RAID 0
RAID 3	Striped set with parallel access and a dedicated parity disk
RAID 4	Striped set with independent disk access and a dedicated parity disk
RAID 5	Striped set with independent disk access and distributed parity
RAID 6	Striped set with independent disk access and dual distributed parity

- **RAID 0** configuration uses *data striping techniques*, where data is striped across all the disks within a RAID set. Therefore it utilizes the full storage capacity of a RAID set.
- To read data, all the strips are put back together by the controller.
- Fig 1.14 shows RAID 0 in an array in which data is striped across five disks.

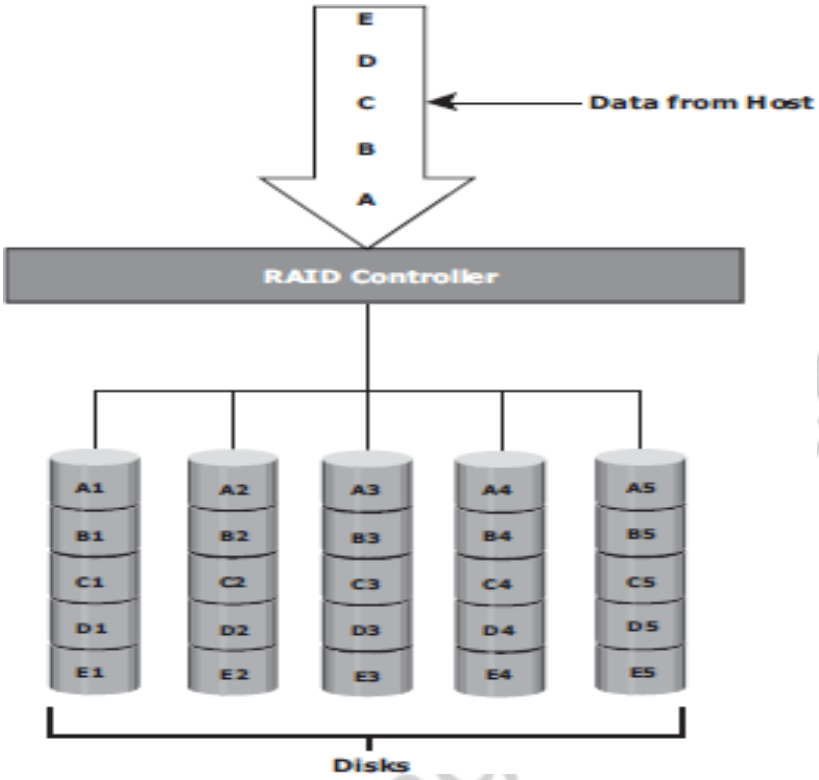


Fig 1.14: RAID 0

- When the number of drives in the RAID set increases, performance improves because more data can be read or written simultaneously.
- RAID 0 is a good option for applications that need high I/O throughput.
- However, if these applications require high availability during drive failures, RAID 0 does not provide data protection and availability.

2.4.2RAID 1

- **RAID 1** is based on the *mirroring* technique.
- In this RAID configuration, data is mirrored to provide *fault tolerance* (see Fig 1.15). A
- RAID 1 set consists of two disk drives and every write is written to both disks.
- The mirroring is transparent to the host.
- During disk failure, the impact on data recovery in RAID 1 is the least among all RAID implementations. This is because the RAID controller uses the mirror drive for data recovery.
- RAID 1 is suitable for applications that require high availability and cost is no constraint.

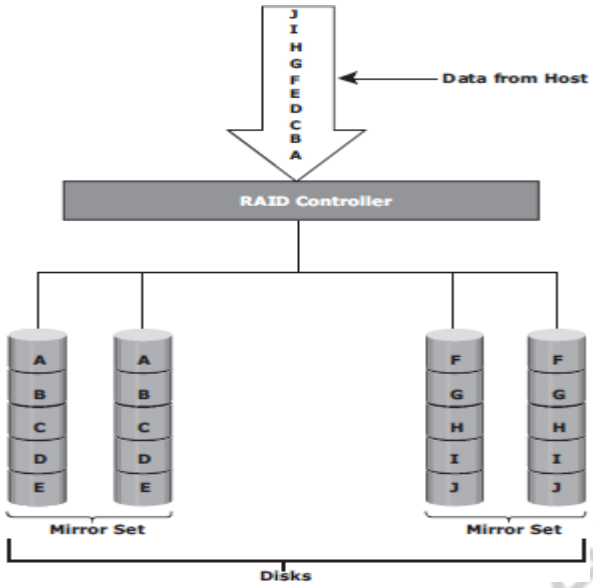


Fig 1.15: RAID 1

2.4.3 Nested RAID

- Most data centers require data redundancy and performance from their RAID arrays.
- RAID 1+0 and RAID 0+1 combine the performance benefits of RAID 0 with the redundancy benefits of RAID 1.
- They use striping and mirroring techniques and combine their benefits.
- These types of RAID require an even number of disks, the minimum being four (see Fig 1.16).

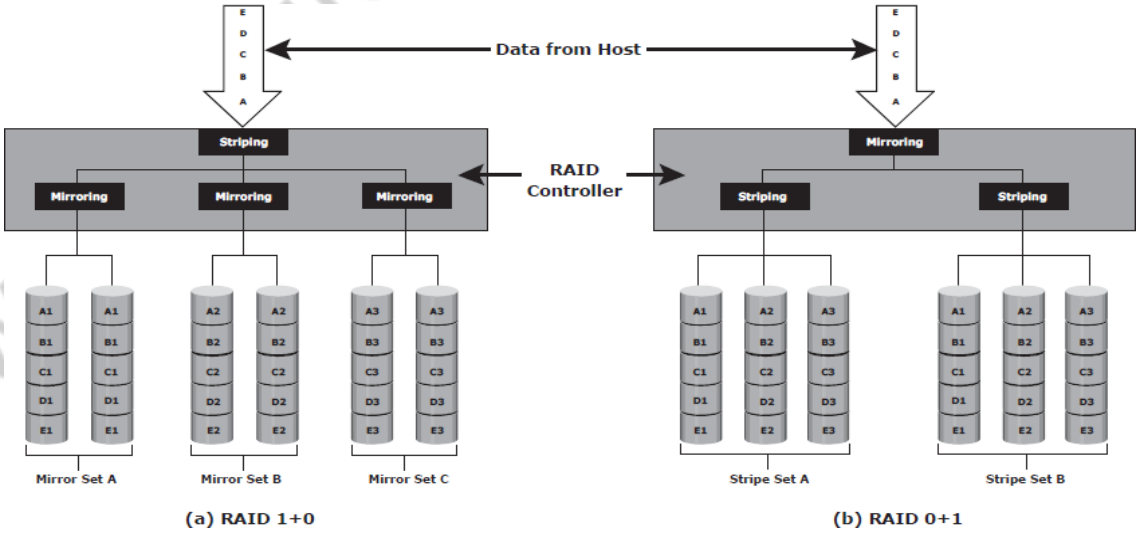


Fig 1.16: Nested RAID

RAID 1+0:

- RAID 1+0 is also known as RAID 10 (Ten) or RAID 1/0.
- RAID 1+0 performs well for workloads with small, random, write-intensive I/Os.
- Some applications that benefit from RAID 1+0 include the following:
  - ✓ High transaction rate Online Transaction Processing (OLTP)
  - ✓ Large messaging installations
  - ✓ Database applications with write intensive random access workloads
- **RAID 1+0** is also called striped mirror.
- The basic element of RAID 1+0 is a mirrored pair, which means that data is first mirrored and then both copies of the data are striped across multiple disk drive pairs in a RAID set.
- When replacing a failed drive, only the mirror is rebuilt. The disk array controller uses the surviving drive in the mirrored pair for data recovery and continuous operation.

Working of RAID 1+0:

- Eg: consider an example of six disks forming a RAID 1+0 (RAID 1 first and then RAID 0) set.
- These six disks are paired into three sets of two disks, where each set acts as a RAID 1 set (mirrored pair of disks). Data is then striped across all the three mirrored sets to form RAID 0.
- Following are the steps performed in RAID 1+0 (see Fig 1.16 [a]):
  - ✓ Drives 1+2 = RAID 1 (Mirror Set A)
  - ✓ Drives 3+4 = RAID 1 (Mirror Set B)
  - ✓ Drives 5+6 = RAID 1 (Mirror Set C)
- Now, RAID 0 striping is performed across sets A through C.
- In this configuration, if drive 5 fails, then the mirror set C alone is affected. It still has drive 6 and continues to function and the entire RAID 1+0 array also keeps functioning.
- Now, suppose drive 3 fails while drive 5 was being replaced. In this case the array still continues to function because drive 3 is in a different mirror set.
- So, in this configuration, up to three drives can fail without affecting the array, as long as they are all in different mirror sets.
- **RAID 0+1** is also called a mirrored stripe.

- The basic element of RAID 0+1 is a stripe. This means that the process of striping data across disk drives is performed initially, and then the entire stripe is mirrored.
- In this configuration if one drive fails, then the entire stripe is faulted.

Working of RAID 0+1:

- Eg: Consider the same example of six disks forming a RAID 0+1 (that is, RAID 0 first and then RAID 1).
- Here, six disks are paired into two sets of three disks each.
- Each of these sets, in turn, act as a RAID 0 set that contains three disks and then these two sets are mirrored to form RAID 1.
- Following are the steps performed in RAID 0+1 (see Fig 1.16 [b]):
  - ✓ Drives 1 + 2 + 3 = RAID 0 (Stripe Set A)
  - ✓ Drives 4 + 5 + 6 = RAID 0 (Stripe Set B)
- These two stripe sets are mirrored.
- If one of the drives, say drive 3, fails, the entire stripe set A fails.
- A rebuild operation copies the entire stripe, copying the data from each disk in the healthy stripe to an equivalent disk in the failed stripe.
- This causes increased and unnecessary I/O load on the surviving disks and makes the RAID set more vulnerable to a second disk failure.

2.4.5 RAID 3

- RAID 3 stripes data for high performance and uses parity for improved fault tolerance.
- Parity information is stored on a dedicated drive so that data can be reconstructed if a drive fails. For example, of five disks, four are used for data and one is used for parity.
- RAID 3 always reads and writes complete stripes of data across all disks, as the drives operate in parallel. There are no partial writes that update one out of many strips in a stripe.
- RAID 3 provides good bandwidth for the transfer of large volumes of data. RAID 3 is used in applications that involve large sequential data access, such as video streaming.
- Fig 1.17 shows the RAID 3 implementation

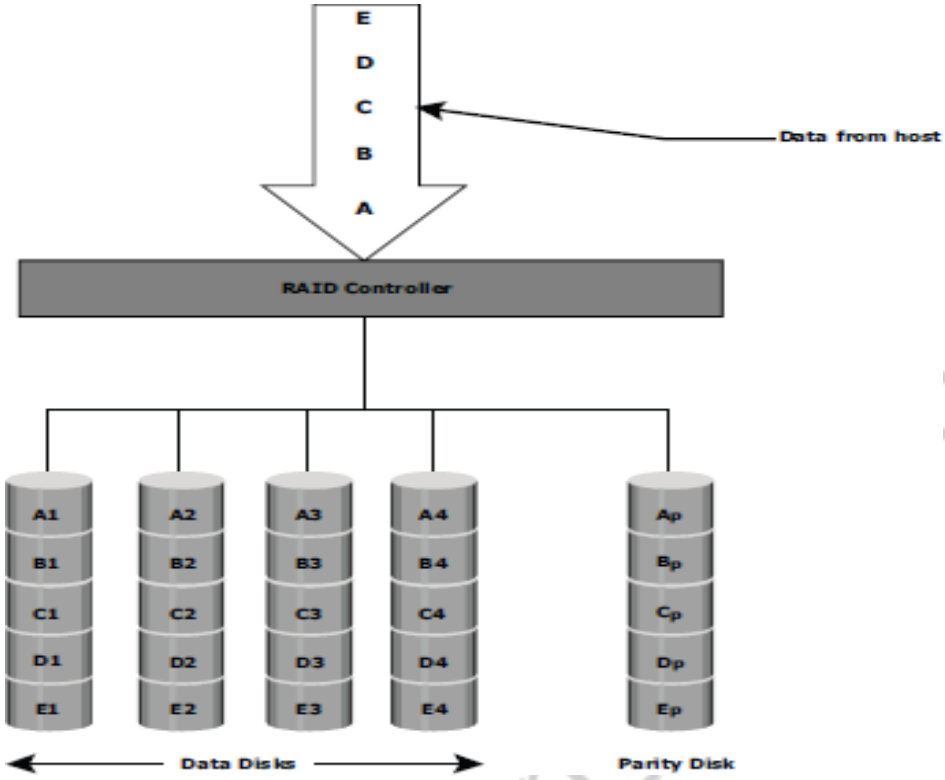


Fig 1.17: RAID 3

2.4.6 RAID 4

- RAID 4 stripes data for high performance and uses parity for improved fault tolerance. Data is striped across all disks except the parity disk in the array.
- Parity information is stored on a dedicated disk so that the data can be rebuilt if a drive fails. Striping is done at the block level.
- Unlike RAID 3, data disks in RAID 4 can be accessed independently so that specific data elements can be read or written on single disk without read or write of an entire stripe. RAID 4 provides good read throughput and reasonable write throughput.

2.4.7 RAID 5

- RAID 5 is a versatile RAID implementation.
- It is similar to RAID 4 because it uses striping. The drives (strips) are also independently accessible.
- The difference between RAID 4 and RAID 5 is the parity location. In RAID 4, parity is written to a dedicated drive, creating a write bottleneck for the parity disk
- In RAID 5, parity is distributed across all disks. The distribution of parity in RAID 5

overcomes the Write bottleneck. Below Figure illustrates the RAID 5 implementation.

- Fig 1.18 illustrates the RAID 5 implementation.
- RAID 5 is good for random, read-intensive I/O applications and preferred for messaging, data mining, medium-performance media serving, and relational database management system (RDBMS) implementations, in which database administrators (DBAs) optimize data access.

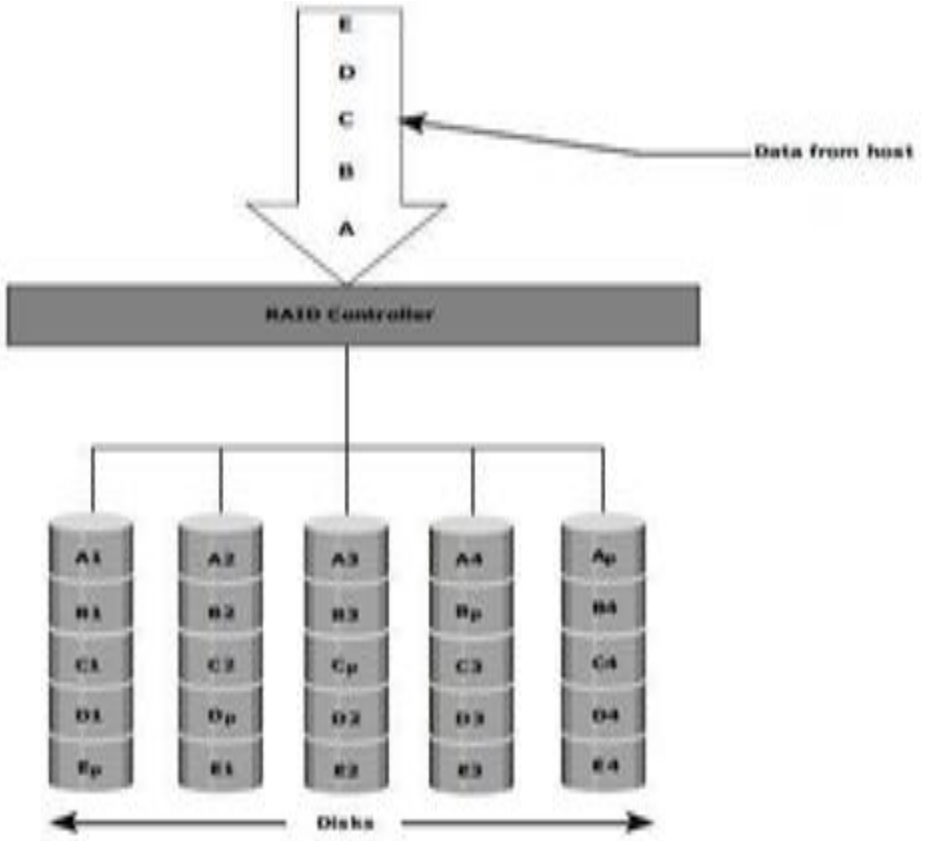
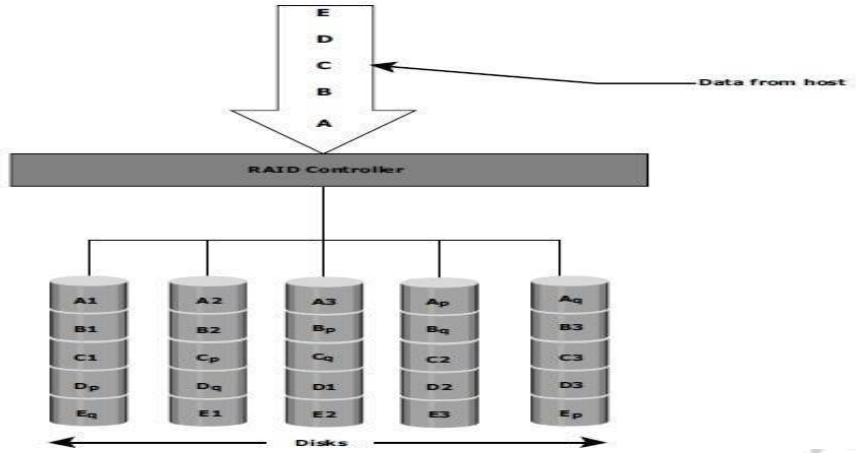


Fig 1.18: RAID 5

2.4.8 RAID 6

- RAID 6 includes a second parity element to enable survival in the event of the failure of two disks in a RAID group. Therefore, a RAID 6 implementation requires at least four disks.
- RAID 6 distributes the parity across all the disks. The write penalty in RAID 6 is more than that in RAID 5; therefore, RAID 5 writes perform better than RAID 6. The rebuild operation in RAID 6 may take longer than that in RAID 5 due to the presence of two parity sets.
- Fig 1.19 illustrates the RAID 6 implementation

Fig 1.19: RAID 6



RAID Comparison

RAID	Min Disks	Storage Efficiency %	Cost	Read Performance	Write Performance
0	2	100	Low	Very good for both random and sequential read	Very good
1	2	50	High	Good Better than a single disk	Good Slower than a single disk, as every write must be committed to two disks
3	3	(n-1)*100/n where n= number of disks	Moderate	Good for random reads and very good for sequential reads	Poor to fair for small random writes Good for large, sequential writes
5	3	(n-1)*100/n where n= number of disks	Moderate	Very good for random reads Good for sequential reads	Fair for random write Slower due to parity overhead Fair to good for sequential writes
6	4	(n-2)*100/n where n= number of disks	Moderate but more than RAID 5	Very good for random reads Good for sequential reads	Good for small, random writes (has write penalty)
1+0 and 0+1	4	50	High	Very good	Good

2.5 RAID Impact on Disk Performance

- When choosing a RAID type, it is imperative to consider its impact on disk performance and application IOPS.
- In both mirrored (RAID 1) and parity RAID (RAID 5) configurations, every write operation translates into more I/O overhead for the disks which is referred to as **write penalty**.
- In a RAID 1 implementation, every write operation must be performed on two disks configured as a mirrored pair. **The write penalty is 2.**
- In a RAID 5 implementation, a write operation may manifest as four I/O operations. When performing small I/Os to a disk configured with RAID 5, the controller has to read, calculate, and write a parity segment for every data write operation.
- Fig 1.20 illustrates a single write operation on RAID 5 that contains a group of five disks.
- Four of these disks are used for data and one is used for parity.
- The **parity (E_p)** at the controller is calculated as follows:

$$E_p = E_1 + E_2 + E_3 + E_4 \text{ (XOR operations)}$$

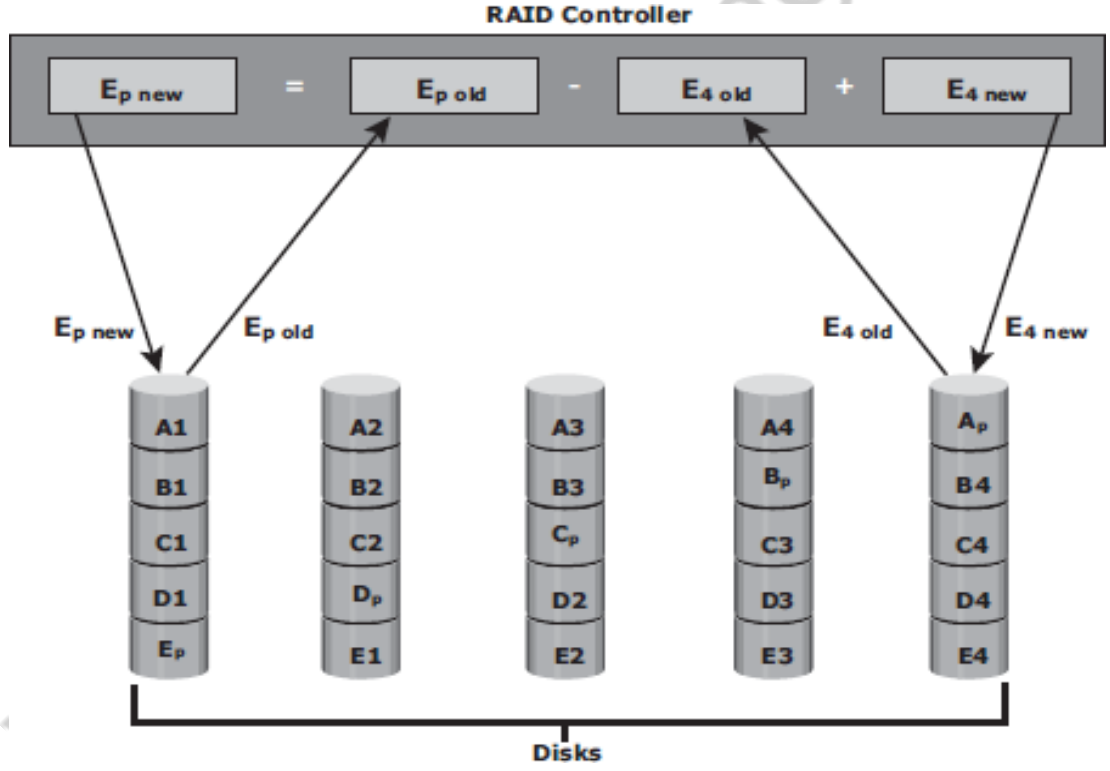


Fig 1.20: Write Penalty in RAID 5

- Whenever the controller performs a write I/O, parity must be computed by reading the old

parity (E_p old) and the old data (E_4 old) from the disk, which means two read I/Os.

- The new parity (E_p new) is computed as follows:

$$E_p \text{ new} = E_p \text{ old} - E4 \text{ old} + E4 \text{ new (XOR operations)}$$

- After computing the new parity, the controller completes the write I/O by doing two write I/Os for the new data and the new parity onto the disks..
- Therefore, the controller performs two disk reads and two disk writes for every write operation, and **the write penalty is 4**.
- In RAID 6, which maintains dual parity, a disk write requires **three read operations**: two parity and one data.
- After calculating both new parities, the controller performs **three write operations**: two parity and an I/O.
- Therefore, in a RAID 6 implementation, the controller performs six I/O operations for each write I/O, and the **write penalty is 6**.

Hot Spares

- A **hot spare** refers to a spare HDD in a RAID array that temporarily replaces a failed HDDof a RAID set.
- A hot spare takes the identity of the failed HDD in the array.
- One of the following methods of data recovery is performed depending on the RAID implementation.
  1. If parity RAID is used, then the data is rebuilt onto the hot spare from the parity and thedata on the surviving HDDs in the RAID set.
  2. If mirroring is used, then the data from the surviving mirror is used to copy the data.

- When the failed HDD is replaced with a new HDD, one of the following takes place:
  1. The hot spare replaces the new HDD permanently. This means that it is no longer a hot spare, and a new hot spare must be configured on the array.
  2. When a new HDD is added to the system, data from the hot spare is copied to it. The hot spare returns to its idle state, ready to replace the next failed drive.