* RAID concept - all (1 or 2 will be asked)

3.4 RAID Levels

Application performance, data availability requirements, and cost determine the RAID level selection. These RAID levels are defined on the basis of striping, mirroring, and parity techniques. Some RAID levels use a single technique, whereas others use a combination of techniques. Table 3-1 shows the commonly used RAID levels.

Table 3-1: Raid Levels

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

3.4.1 RAID 0

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. Figure 3-5 shows RAID 0 in an array in which data is striped across five disks. 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.

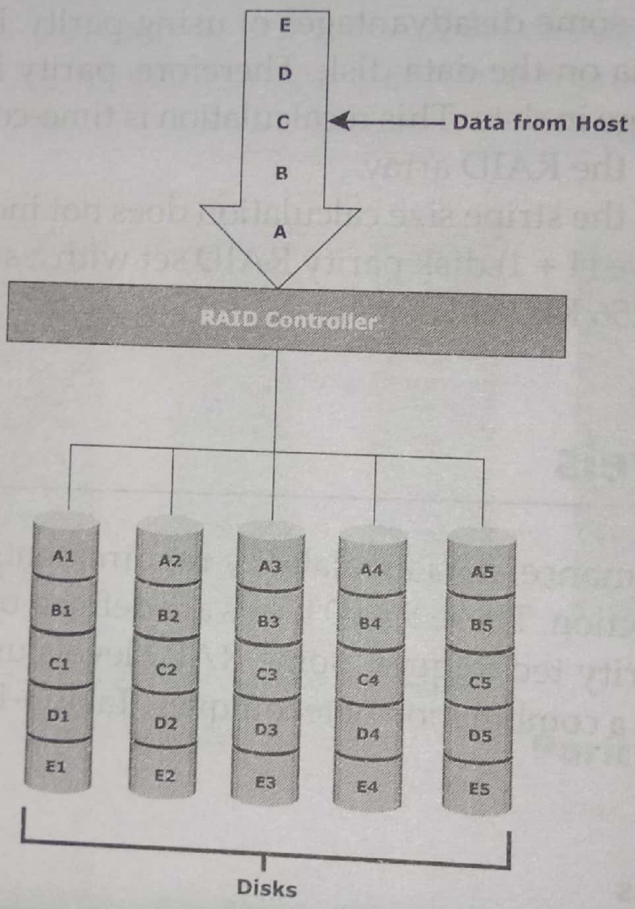


Figure 3-5: RAID 0

3.4.2 RAID 1

RAID 1 is based on the mirroring technique. In this RAID configuration, data is mirrored to provide fault tolerance (see Figure 3-6). 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.

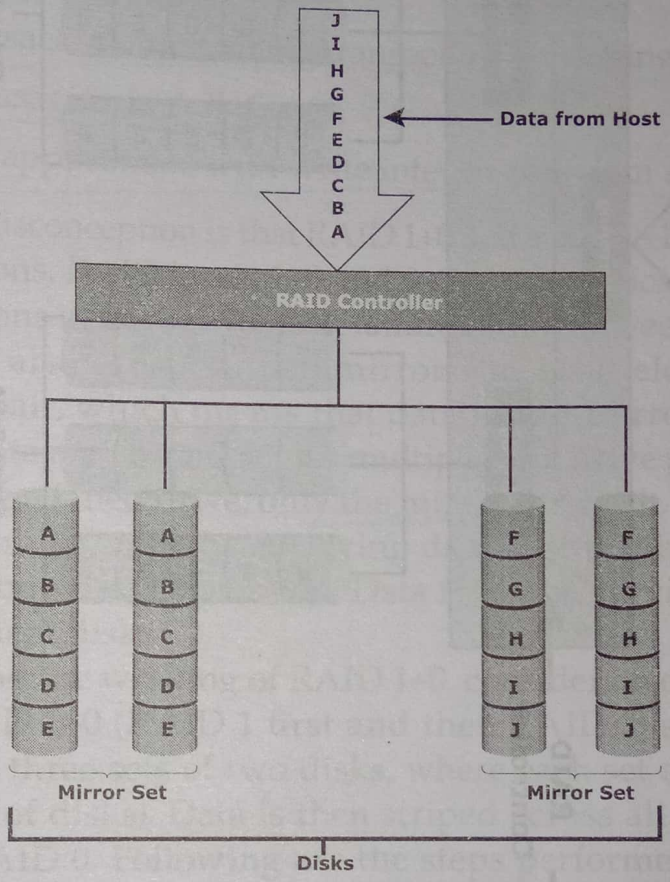


Figure 3-6: RAID 1

3.4.3 Nested RAID

Most data centers require data redundancy and performance from their RAID arrays. RAID 1+0 and RAID 0+1combine 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 Figure 3-7).

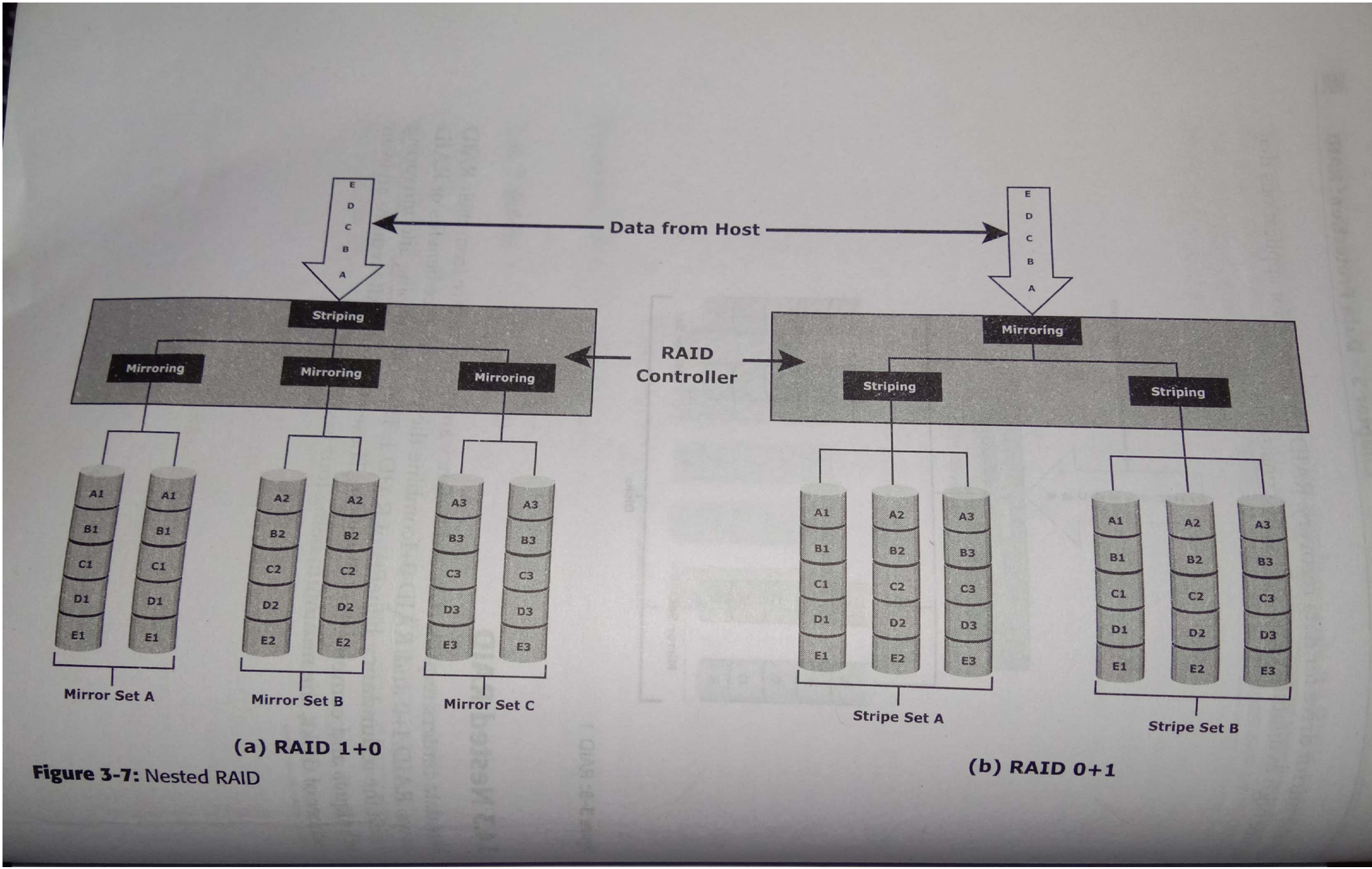


Figure 3-7: Nested RAID

RAID 1+0 is also known as RAID 10 (Ten) or RAID 1/0. Similarly, RAID 0+1 is also known as RAID 01 or RAID 0/1. 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

A common misconception is that RAID 1+0 and RAID 0+1 are the same. Under normal conditions, RAID levels 1+0 and 0+1 offer identical benefits. However, rebuild operations in the case of disk failure differ between the two.

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. In other words, the disk array controller uses the surviving drive in the mirrored pair for data recovery and continuous operation. Data from the surviving disk is copied to the replacement disk.

To understand the working of RAID 1+0, 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 Figure 3-7 [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. Consider the same example of six disks to understand the working of 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 Figure 3-7 [b]):

Drives 1 + 2 + 3 = RAID 0 (Stripe Set A)
Drives 4 + 5 + 6 = RAID 0 (Stripe Set B)

Now, 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.

3.4.4 RAID 3

RAID 3 stripes data for performance and uses parity for fault tolerance. Parity information is stored on a dedicated drive so that the data can be reconstructed if a drive fails in a RAID set. For example, in a set of five disks, four are used for data and one for parity. Therefore, the total disk space required is 1.25 times the size of the data disks. RAID 3 always reads and writes complete stripes of data across all disks because the drives operate in parallel. There are no partial writes that update one out of many strips in a stripe. Figure 3-8 illustrates the RAID 3 implementation.

RAID 3 provides good performance for applications that involve large sequential data access, such as data backup or video streaming.

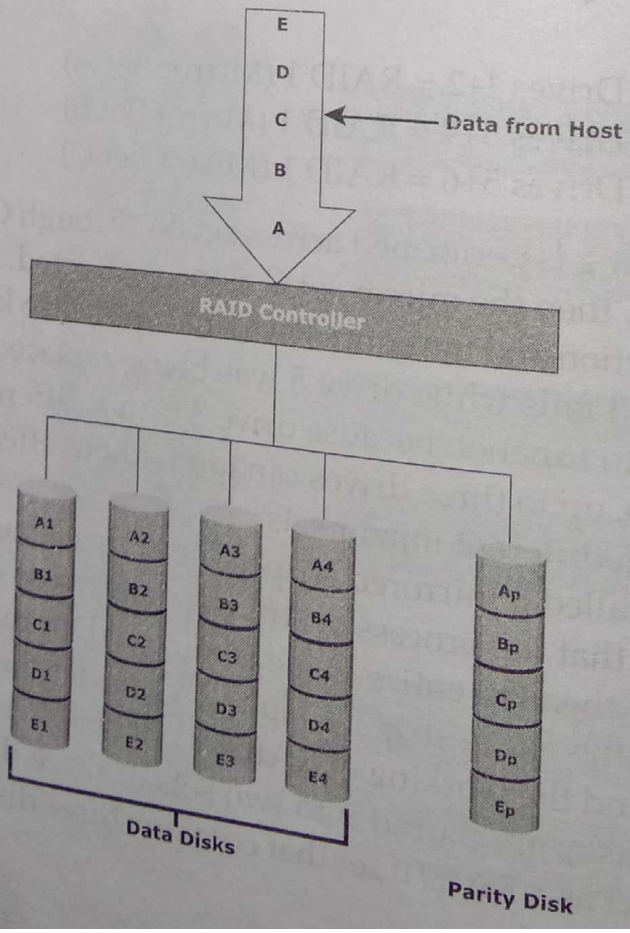


Figure 3-8: RAID 3

3.4.5 RAID 4

Similar to RAID 3, 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.

Unlike RAID 3, data disks in RAID 4 can be accessed independently so that specific data elements can be read or written on a single disk without reading or writing an entire stripe. RAID 4 provides good read throughput and reasonable write throughput.

3.4.6 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 to overcome the write bottleneck of a dedicated parity disk. Figure 3-9 illustrates the RAID 5 implementation.

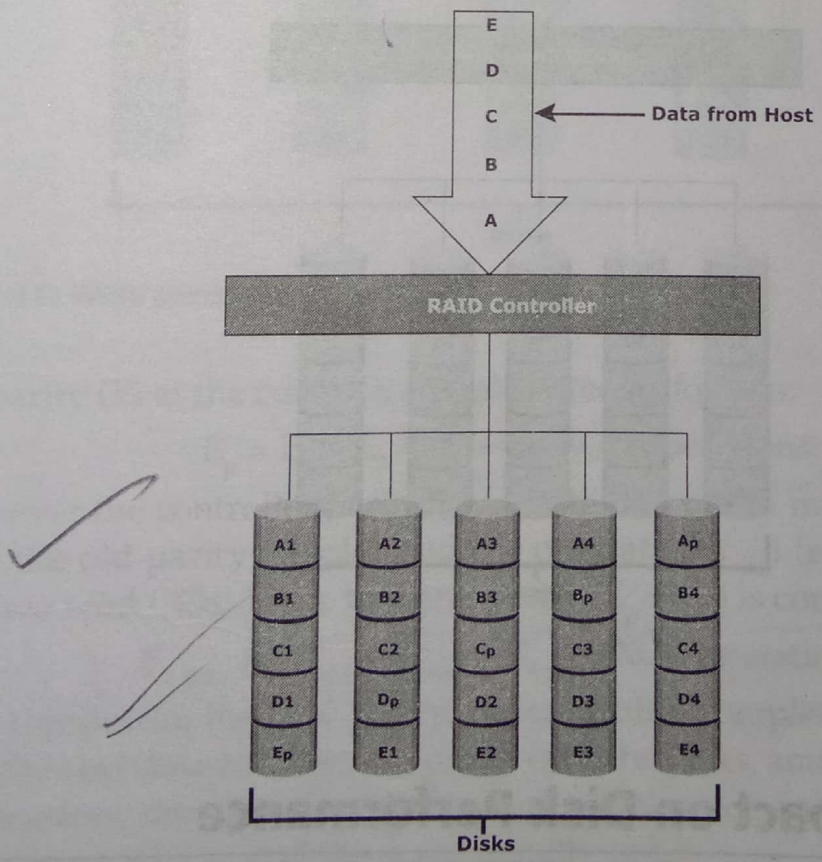


Figure 3-9: RAID 5

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.

3.4.7 RAID 6

RAID 6 works the same way as RAID 5, except that RAID 6 includes a second parity element to enable survival if two disk failures occur in a RAID set (see Figure 3-10). Therefore, a RAID 6 implementation requires at least four disks. RAID 6 distributes the parity across all the disks. The write penalty (explained later in this chapter) 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.

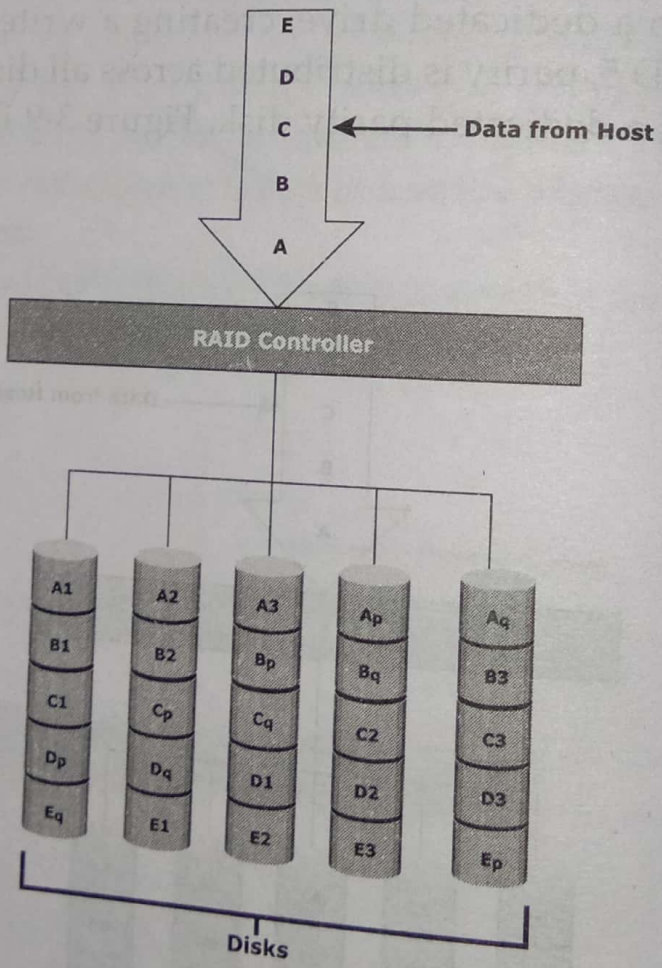


Figure 3-10: RAID 6

* Data center characteristics and component

1.3 Data Center Infrastructure

Organizations maintain data centers to provide centralized data-processing capabilities across the enterprise. Data centers house and manage large amounts of data. The data center infrastructure includes hardware components, such as computers, storage systems, network devices, and power backups; and software components, such as applications, operating systems, and management software. It also includes environmental controls, such as air conditioning, fire suppression, and ventilation.

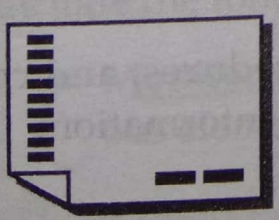
Large organizations often maintain more than one data center to distribute data processing workloads and provide backup if a disaster occurs.

1.3.1 Core Elements of a Data Center

Five core elements are essential for the functionality of a data center:

- **Application:** A computer program that provides the logic for computing operations
- **Database management system (DBMS):** Provides a structured way to store data in logically organized tables that are interrelated
- **Host or compute:** A computing platform (hardware, firmware, and software) that runs applications and databases
- **Network:** A data path that facilitates communication among various networked devices
- **Storage:** A device that stores data persistently for subsequent use

These core elements are typically viewed and managed as separate entities, but all the elements must work together to address data-processing requirements.



In this book, host, compute, and server are used interchangeably to represent the element that runs applications.

Figure 1-5 shows an example of an online order transaction system that involves the five core elements of a data center and illustrates their functionality in a business process.

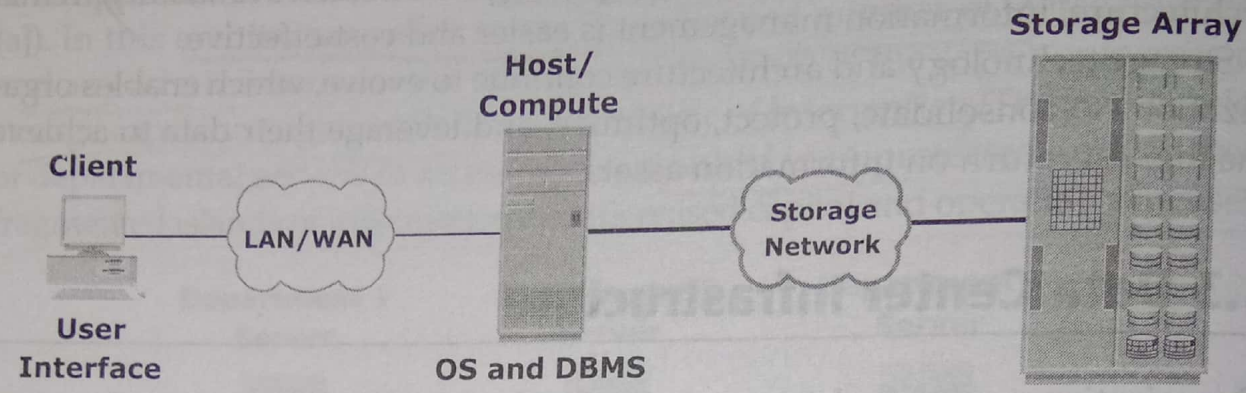


Figure 1-5: Example of an online order transaction system

A customer places an order through a client machine connected over a LAN/WAN to a host running an order-processing application. The client accesses the DBMS on the host through the application to provide order-related information, such as the customer name, address, payment method, products ordered, and quantity ordered.

The DBMS uses the host operating system to write this data to the physical disks in the storage array. The storage networks provide the communication link between the host and the storage array and transports the request to read or write data between them. The storage array, after receiving the read or write request from the host, performs the necessary operations to store the data on physical disks.

1.3.2 Key Characteristics of a Data Center

Uninterrupted operation of data centers is critical to the survival and success of a business. Organizations must have a reliable infrastructure that ensures that data is accessible at all times. Although the characteristics shown in Figure 1-6 are applicable to all elements of the data center infrastructure, the focus here is on storage systems. This book covers the various technologies and solutions to meet these requirements.

- **Availability:** A data center should ensure the availability of information when required. Unavailability of information could cost millions of dollars per hour to businesses, such as financial services, telecommunications, and e-commerce.
- **Security:** Data centers must establish policies, procedures, and core element integration to prevent unauthorized access to information.

- **Scalability:** Business growth often requires deploying more servers, new applications, and additional databases. Data center resources should scale based on requirements, without interrupting business operations.
- **Performance:** All the elements of the data center should provide optimal performance based on the required service levels.
- **Data integrity:** Data integrity refers to mechanisms, such as error correction codes or parity bits, which ensure that data is stored and retrieved exactly as it was received.
- **Capacity:** Data center operations require adequate resources to store and process large amounts of data, efficiently. When capacity requirements increase, the data center must provide additional capacity without interrupting availability or with minimal disruption. Capacity may be managed by reallocating the existing resources or by adding new resources.
- **Manageability:** A data center should provide easy and integrated management of all its elements. Manageability can be achieved through automation and reduction of human (manual) intervention in common tasks.

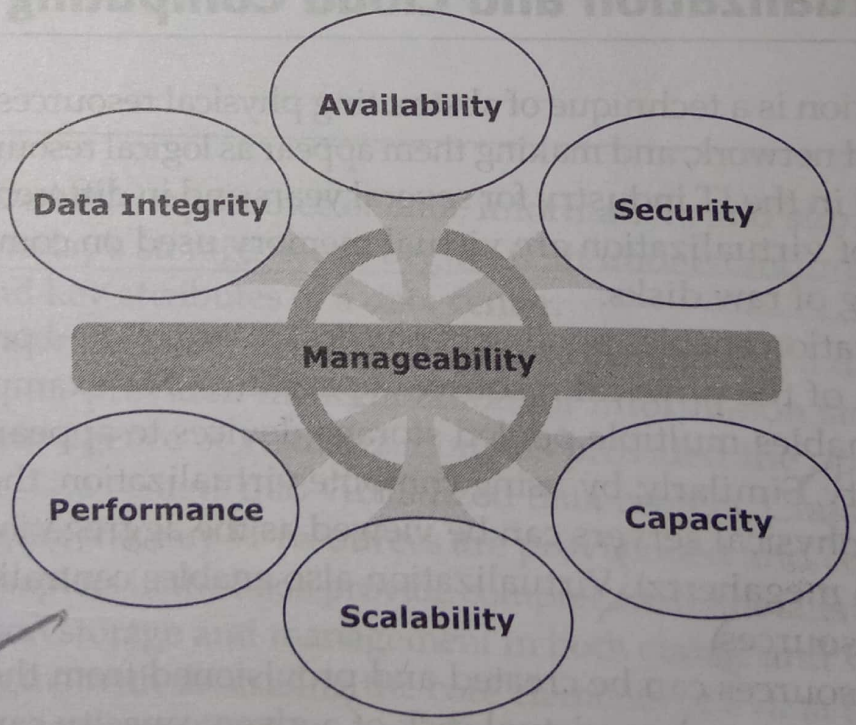


Figure 1-6: Key characteristics of a data center

* Connectivity.

2.4 Connectivity

Connectivity refers to the interconnection between hosts or between a host and peripheral devices, such as printers or storage devices. The discussion here focuses only on the connectivity between the host and the storage device. Connectivity and communication between host and storage are enabled using physical components and interface protocols.

2.4.1 Physical Components of Connectivity

The *physical components* of connectivity are the hardware elements that connect the host to storage. Three physical components of connectivity between the host and storage are the host interface device, port, and cable (Figure 2-4).

A *host interface device* or *host adapter* connects a host to other hosts and storage devices. Examples of host interface devices are host bus adapter (HBA) and network interface card (NIC). *Host bus adaptor* is an *application-specific integrated circuit* (ASIC) board that performs I/O interface functions between the host and storage, relieving the CPU from additional I/O processing workload. A host typically contains multiple HBAs.

A *port* is a specialized outlet that enables connectivity between the host and external devices. An HBA may contain one or more ports to connect the host

to the storage device. *Cables* connect hosts to internal or external devices using copper or fiber optic media.

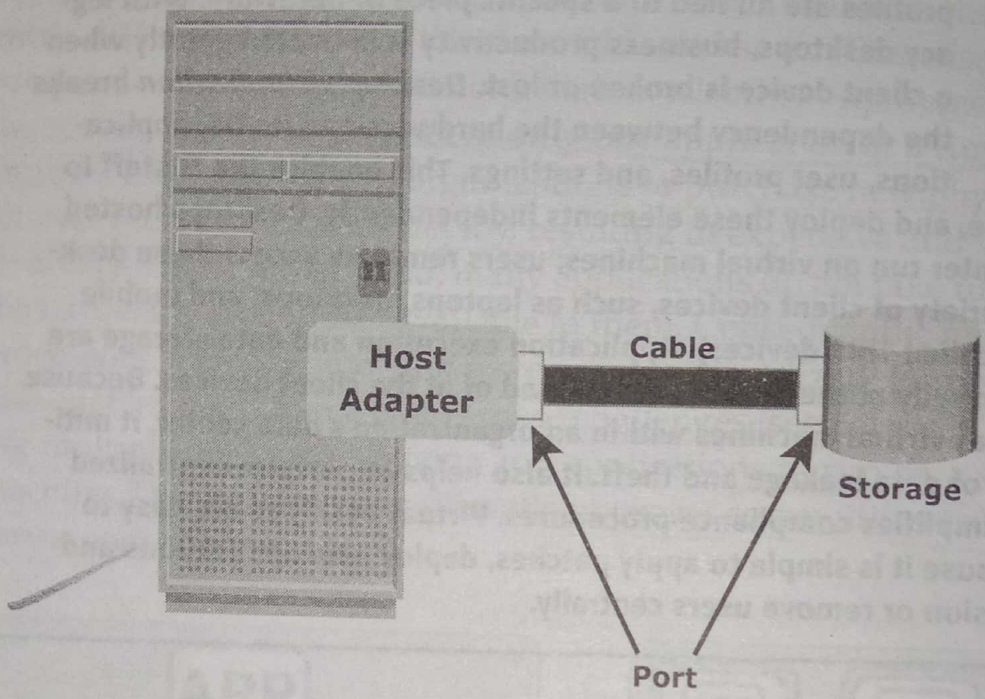


Figure 2-4: Physical components of connectivity

2.4.2 Interface Protocols

A *protocol* enables communication between the host and storage. Protocols are implemented using interface devices (or controllers) at both source and destination. The popular interface protocols used for host to storage communications are *Integrated Device Electronics/Advanced Technology Attachment* (IDE/ATA), *Small Computer System Interface* (SCSI), *Fibre Channel* (FC) and *Internet Protocol* (IP).

IDE/ATA and Serial ATA

IDE/ATA is a popular interface protocol standard used for connecting storage devices, such as disk drives and CD-ROM drives. This protocol supports parallel transmission and therefore is also known as Parallel ATA (PATA) or simply ATA. IDE/ATA has a variety of standards and names. The Ultra DMA/133 version of ATA supports a throughput of 133 MB per second. In a master-slave configuration, an ATA interface supports two storage devices per connector. However, if the performance of the drive is important, sharing a port between two devices is not recommended.

The serial version of this protocol supports single bit serial transmission and is known as Serial ATA (SATA). High performance and low cost SATA has largely replaced PATA in newer systems. SATA revision 3.0 provides a data transfer rate up to 6 Gb/s.

SCSI and Serial SCSI

SCSI has emerged as a preferred connectivity protocol in high-end computers. This protocol supports parallel transmission and offers improved performance, scalability, and compatibility compared to ATA. However, the high cost associated with SCSI limits its popularity among home or personal desktop users. Over the years, SCSI has been enhanced and now includes a wide variety of related technologies and standards. SCSI supports up to 16 devices on a single bus and provides data transfer rates up to 640 MB/s (for the Ultra-640 version). Serial attached SCSI (SAS) is a point-to-point serial protocol that provides an alternative to parallel SCSI. A newer version of serial SCSI (SAS 2.0) supports a data transfer rate up to 6 Gb/s. This book's Appendix B provides more details on the SCSI architecture and interface.

Fibre Channel

Fibre Channel is a widely used protocol for high-speed communication to the storage device. The Fibre Channel interface provides gigabit network speed. It provides a serial data transmission that operates over copper wire and optical fiber. The latest version of the FC interface (16FC) allows transmission of data up to 16 Gb/s. The FC protocol and its features are covered in more detail in Chapter 5.

Internet Protocol (IP)

IP is a network protocol that has been traditionally used for host-to-host traffic. With the emergence of new technologies, an IP network has become a viable option for host-to-storage communication. IP offers several advantages in terms of cost and maturity and enables organizations to leverage their existing IP-based network. iSCSI and FCIP protocols are common examples that leverage IP for host-to-storage communication. These protocols are detailed in Chapter 6.

4 Cache operation

4.1.2 Cache

Cache is semiconductor memory where data is placed temporarily to reduce the time required to service I/O requests from the host.

Cache improves storage system performance by isolating hosts from the mechanical delays associated with rotating disks or hard disk drives (HDD). Rotating disks are the slowest component of an intelligent storage system. Data access on rotating disks usually takes several millisecond because of seek time and rotational latency. Accessing data from cache is fast and typically takes less than a millisecond. On intelligent arrays, write data is first placed in cache and then written to disk.

Structure of Cache

Cache is organized into pages, which is the smallest unit of cache allocation. The size of a cache page is configured according to the application I/O size. Cache consists of the *data store* and *tag RAM*. The data store holds the data whereas the tag RAM tracks the location of the data in the data store (see Figure 4-2) and in the disk.

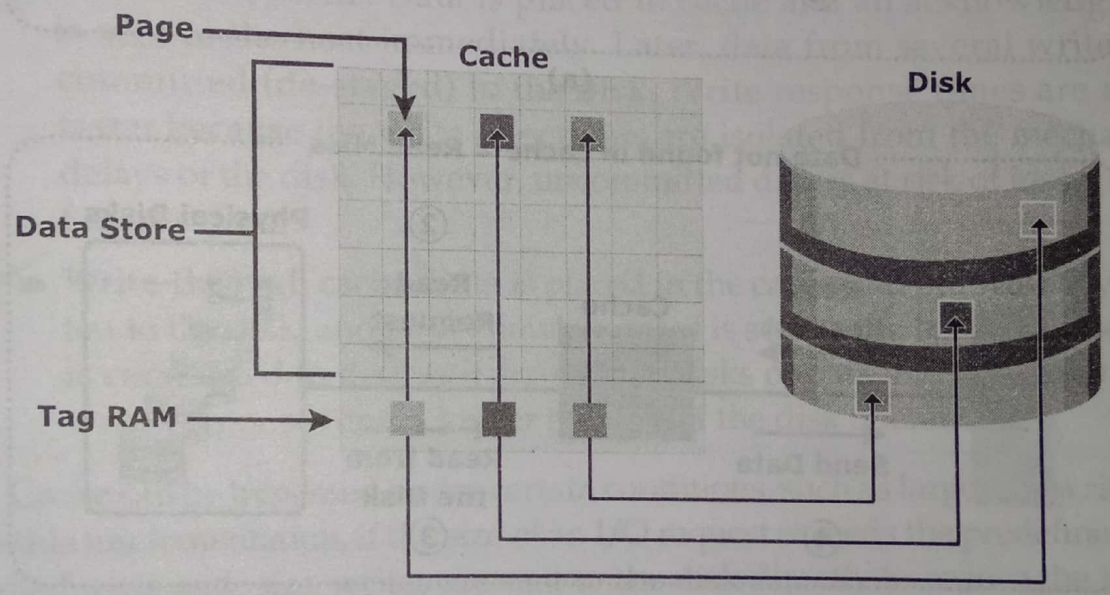


Figure 4-2: Structure of cache

Entries in tag RAM indicate where data is found in cache and where the data belongs on the disk. Tag RAM includes a *dirty bit* flag, which indicates whether the data in cache has been committed to the disk. It also contains time-based information, such as the time of last access, which is used to identify cached information that has not been accessed for a long period and may be freed up.

Read Operation with Cache

When a host issues a read request, the storage controller reads the tag RAM to determine whether the required data is available in cache. If the requested data is found in the cache, it is called a *read cache hit* or *read hit* and data is sent directly to the host, without any disk operation (see Figure 4-3 [a]). This provides

a fast response time to the host (about a millisecond). If the requested data is not found in cache, it is called a *cache miss* and the data must be read from the disk (see Figure 4-3 [b]). The back end accesses the appropriate disk and retrieves the requested data. Data is then placed in cache and finally sent to the host through the front end. Cache misses increase the I/O response time.

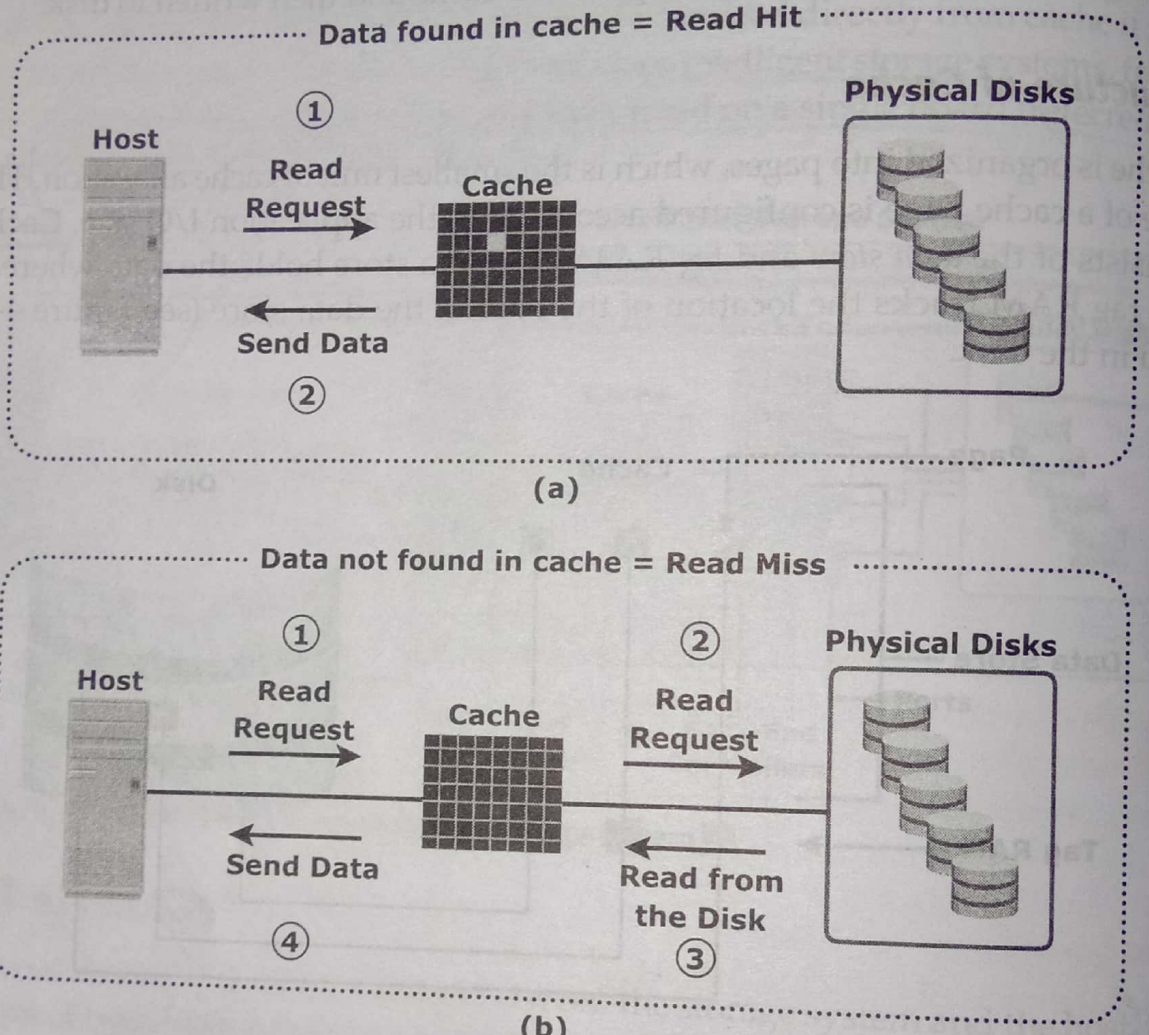


Figure 4-3: Read hit and read miss

A *prefetch* or *read-ahead* algorithm is used when read requests are sequential. In a sequential read request, a contiguous set of associated blocks is retrieved. Several other blocks that have not yet been requested by the host can be read from the disk and placed into cache in advance. When the host subsequently requests these blocks, the read operations will be read hits. This process significantly improves the response time experienced by the host. The intelligent storage system offers fixed and variable prefetch sizes. In *fixed prefetch*, the intelligent storage system prefetches a fixed amount of data. It is most suitable when host I/O sizes are uniform. In *variable prefetch*, the storage system prefetches an amount of data in multiples of the size of the host request. *Maximum prefetch* limits the number of data blocks that can be prefetched to prevent the disks from being rendered busy with prefetch at the expense of other I/Os.

Read performance is measured in terms of the *read hit ratio*, or the *hit rate*, usually expressed as a percentage. This ratio is the number of read hits with respect to the total number of read requests. A higher read hit ratio improves the read performance.

Write Operation with Cache

Write operations with cache provide performance advantages over writing directly to disks. When an I/O is written to cache and acknowledged, it is completed in far less time (from the host's perspective) than it would take to write directly to disk. Sequential writes also offer opportunities for optimization because many smaller writes can be coalesced for larger transfers to disk drives with the use of cache.

A write operation with cache is implemented in the following ways:

- **Write-back cache:** Data is placed in cache and an acknowledgment is sent to the host immediately. Later, data from several writes are committed (de-staged) to the disk. Write response times are much faster because the write operations are isolated from the mechanical delays of the disk. However, uncommitted data is at risk of loss if cache failures occur.
- **Write-through cache:** Data is placed in the cache and immediately written to the disk, and an acknowledgment is sent to the host. Because data is committed to disk as it arrives, the risks of data loss are low, but the write-response time is longer because of the disk operations.

Cache can be bypassed under certain conditions, such as large size write I/O. In this implementation, if the size of an I/O request exceeds the predefined size, called *write aside size*, writes are sent to the disk directly to reduce the impact of large writes consuming a large cache space. This is particularly useful in an environment where cache resources are constrained and cache is required for small random I/Os.

* FC SAN and component of FC SAN

5.2 The SAN and Its Evolution

A SAN carries data between servers (or *hosts*) and storage devices through Fibre Channel network (see Figure 5-1). A SAN enables storage consolidation and enables storage to be shared across multiple servers. This improves the utilization of storage resources compared to direct-attached storage architecture and reduces the total amount of storage an organization needs to purchase and manage. With consolidation, storage management becomes centralized and less complex, which further reduces the cost of managing information. SAN also enables organizations to connect geographically dispersed servers and storage.

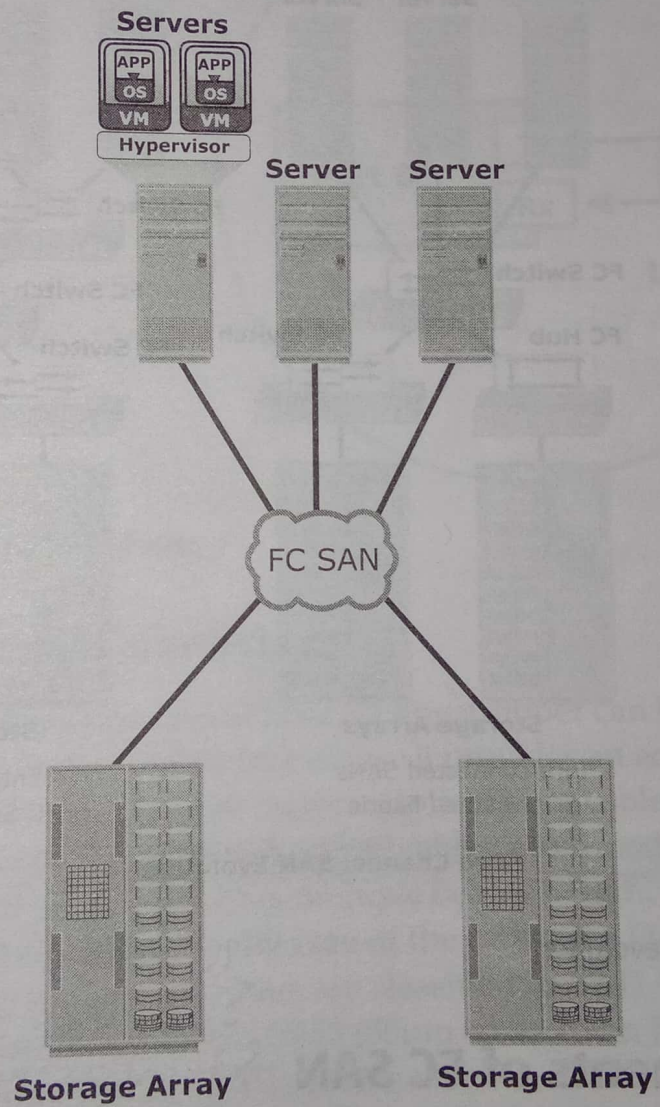


Figure 5-1: FC SAN implementation

In its earliest implementation, the FC SAN was a simple grouping of hosts and storage devices connected to a network using an FC hub as a connectivity device. This configuration of an FC SAN is known as a *Fibre Channel Arbitrated*

Loop (FC-AL). Use of hubs resulted in isolated FC-AL SAN islands because hubs provide limited connectivity and bandwidth.

The inherent limitations associated with hubs gave way to high-performance FC *switches*. Use of switches in SAN improved connectivity and performance and enabled FC SANs to be highly scalable. This enhanced data accessibility to applications across the enterprise. Now, FC-AL has been almost abandoned for FC SANs due to its limitations but still survives as a back-end connectivity option to disk drives. Figure 5-2 illustrates the FC SAN evolution from FC-AL to enterprise SANs.

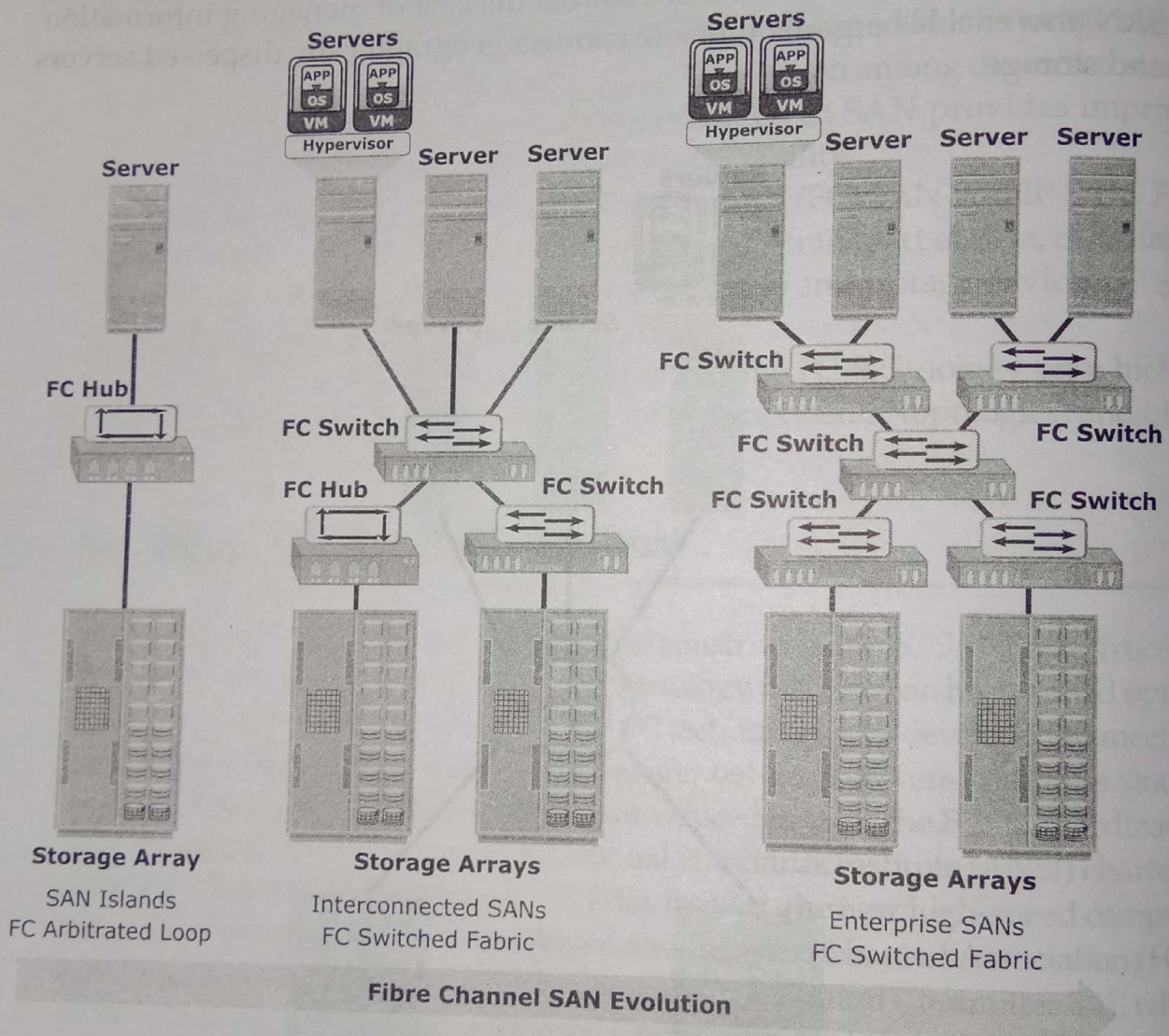


Figure 5-2: FC SAN evolution

1. Node Ports
2. Cables & Connectors
3. Interconnect devices
4. SAN management s/w

5.3 Components of FC SAN

FC SAN is a network of servers and shared storage devices. Servers and storage are the end points or devices in the SAN (called *nodes*). FC SAN infrastructure consists of node ports, cables, connectors, and interconnecting devices (such as FC switches or hubs), along with SAN management software.

5.3.1 Node Ports

In a Fibre Channel network, the end devices, such as hosts, storage arrays, and tape libraries, are all referred to as *nodes*. Each node is a source or destination of information. Each node requires one or more ports to provide a physical interface for communicating with other nodes. These ports are integral components of host adapters, such as HBA, and storage front-end controllers or adapters. In an FC environment a port operates in full-duplex data transmission mode with a *transmit* (Tx) link and a *receive* (Rx) link (see Figure 5-3).

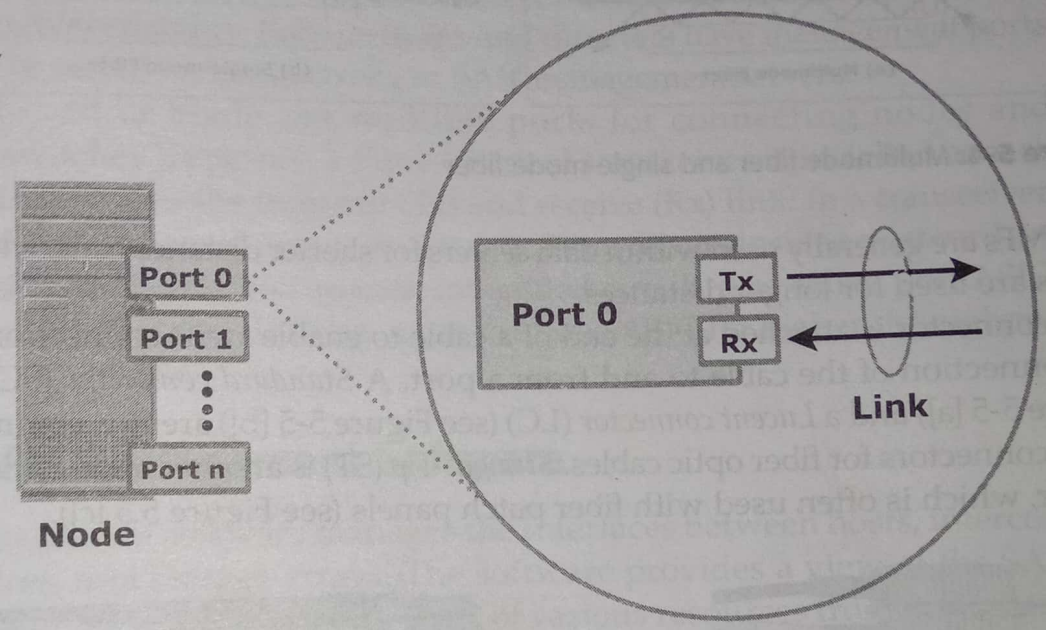


Figure 5-3: Nodes, ports, and links

5.3.2 Cables and Connectors

SAN implementations use optical fiber cabling. Copper can be used for shorter distances for back-end connectivity because it provides an acceptable signal-to-noise ratio for distances up to 30 meters. Optical fiber cables carry data in the form of light. There are two types of optical cables: multimode and single-mode. *Multimode fiber* (MMF) cable carries multiple beams of light projected at different angles simultaneously onto the core of the cable (see Figure 5-4 [a]). Based on the bandwidth, multimode fibers are classified as OM1 (62.5µm core), OM2 (50µm core), and laser-optimized OM3 (50µm core). In an MMF transmission, multiple light beams traveling inside the cable tend to disperse and collide. This collision weakens the signal strength after it travels a certain distance — a process known as *modal dispersion*. An MMF cable is typically used for short distances because of signal degradation (attenuation) due to modal dispersion. *Single-mode fiber* (SMF) carries a single ray of light projected at the center of the core (see Figure 5-4 [b]). These cables are available in core diameters of 7 to 11 microns;

the most common size is 9 microns. In an SMF transmission, a single light beam travels in a straight line through the core of the fiber. The small core and the single light wave help to limit modal dispersion. Among all types of fiber cables, single-mode provides minimum signal attenuation over maximum distance (up to 10 km). A single-mode cable is used for long-distance cable runs, and distance usually depends on the power of the laser at the transmitter and sensitivity of the receiver.

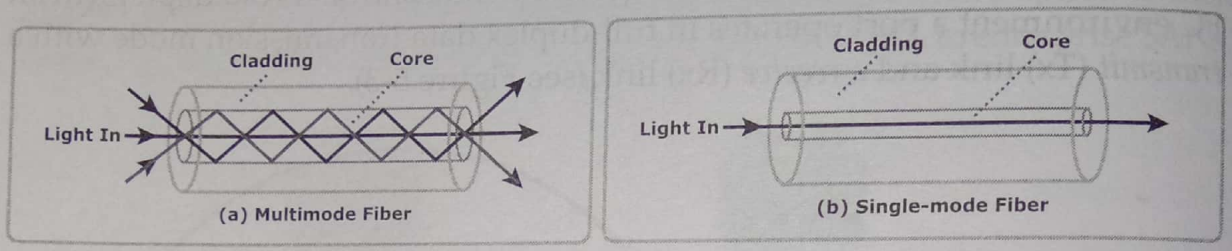


Figure 5-4: Multimode fiber and single-mode fiber

MMFs are generally used within data centers for shorter distance runs, whereas SMFs are used for longer distances.

A connector is attached at the end of a cable to enable swift connection and disconnection of the cable to and from a port. A *Standard connector* (SC) (see Figure 5-5 [a]) and a *Lucent connector* (LC) (see Figure 5-5 [b]) are two commonly used connectors for fiber optic cables. *Straight Tip* (ST) is another fiber-optic connector, which is often used with fiber patch panels (see Figure 5.5 [c]).

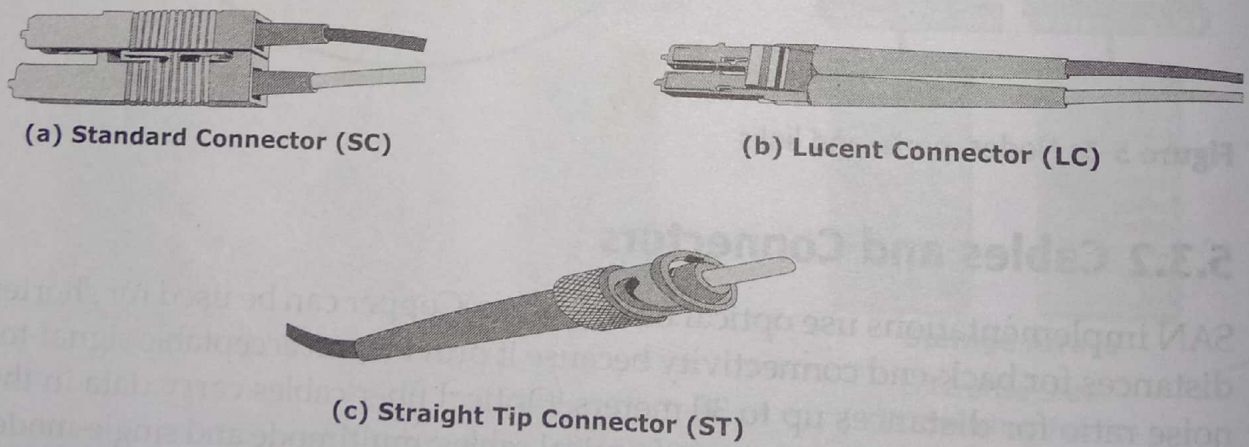


Figure 5-5: SC, LC, and ST connectors

5.3.3 Interconnect Devices

FC hubs, switches, and directors are the interconnect devices commonly used in FC SAN.

Hubs are used as communication devices in FC-AL implementations. Hubs physically connect nodes in a logical loop or a physical star topology. All the nodes must share the loop because data travels through all the connection points. Because of the availability of low-cost and high-performance switches, hubs are no longer used in FC SANs.

Switches are more intelligent than hubs and directly route data from one physical port to another. Therefore, nodes do not share the bandwidth. Instead, each node has a dedicated communication path.

Directors are high-end switches with a higher port count and better fault-tolerance capabilities.

Switches are available with a fixed port count or with modular design. In a modular switch, the port count is increased by installing additional port cards to open slots. The architecture of a director is always modular, and its port count is increased by inserting additional line cards or blades to the director's chassis. High-end switches and directors contain redundant components to provide high availability. Both switches and directors have management ports (Ethernet or serial) for connectivity to SAN management servers.

A port card or blade has multiple ports for connecting nodes and other FC switches. Typically, a Fibre Channel transceiver is installed at each port slot that houses the transmit (Tx) and receive (Rx) link. In a transceiver, the Tx and Rx links share common circuitry. Transceivers inside a port card are connected to an application specific integrated circuit, also called port ASIC. Blades in a director usually have more than one ASIC for higher throughput.

5.3.4 SAN Management Software

SAN management software manages the interfaces between hosts, interconnect devices, and storage arrays. The software provides a view of the SAN environment and enables management of various resources from one central console.

It provides key management functions, including mapping of storage devices, switches, and servers, monitoring and generating alerts for discovered devices, and *zoning* (discussed in section 5.9 "Zoning" later in this chapter).

FC SWITCH VERSUS FC HUB

Scalability and performance are the primary differences between switches and hubs. Addressing in a switched fabric supports more than 15 million nodes within the fabric, whereas the FC-AL implemented in hubs supports only a maximum of 126 nodes.

Fabric switches provide full bandwidth between multiple pairs of ports in a fabric, resulting in a scalable architecture that supports multiple simultaneous communications.

Hubs support only one communication at a time. They provide a low-cost connectivity expansion solution. Switches, conversely, can be used to build dynamic, high-performance fabrics through which multiple communications can take place simultaneously. Switches are more expensive than hubs.

* Disc drive component with diagram

2.6 Disk Drive Components

The key components of a hard disk drive are platter, spindle, read-write head, actuator arm assembly, and controller board (see Figure 2-5).

I/O operations in a HDD are performed by rapidly moving the arm across the rotating flat platters coated with magnetic particles. Data is transferred between the disk controller and magnetic platters through the read-write (R/W) head which is attached to the arm. Data can be recorded and erased on magnetic platters any number of times. Following sections detail the different components of the disk drive, the mechanism for organizing and storing data on disks, and the factors that affect disk performance.

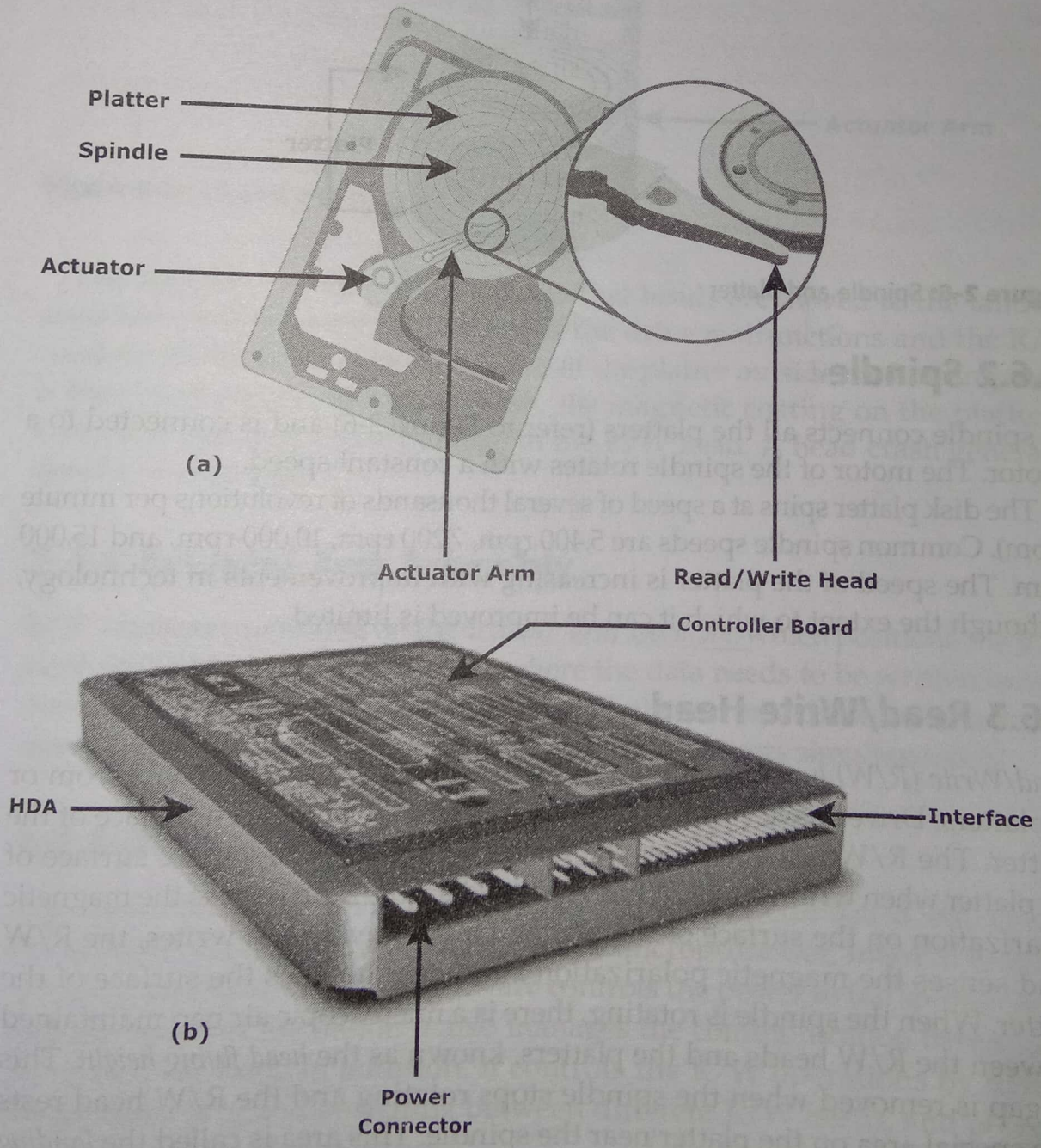


Figure 2-5: Disk drive components

2.6.1 Platter

A typical HDD consists of one or more flat circular disks called *platters* (Figure 2-6). The data is recorded on these platters in binary codes (0s and 1s). The set of rotating platters is sealed in a case, called the *Head Disk Assembly* (HDA). A platter is a rigid, round disk coated with magnetic material on both surfaces (top and bottom). The data is encoded by polarizing the magnetic area, or domains, of the disk surface. Data can be written to or read from both surfaces of the platter. The number of platters and the storage capacity of each platter determine the total capacity of the drive.

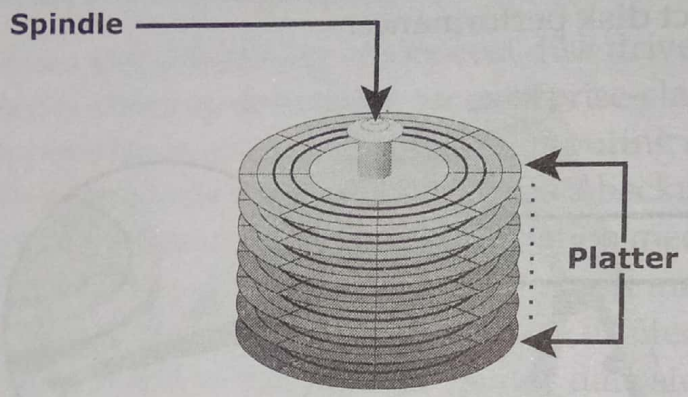


Figure 2-6: Spindle and platter

2.6.2 Spindle

A spindle connects all the platters (refer to Figure 2-6) and is connected to a motor. The motor of the spindle rotates with a constant speed.

The disk platter spins at a speed of several thousands of revolutions per minute (rpm). Common spindle speeds are 5,400 rpm, 7,200 rpm, 10,000 rpm, and 15,000 rpm. The speed of the platter is increasing with improvements in technology, although the extent to which it can be improved is limited.

2.6.3 Read/Write Head

Read/Write (R/W) heads, as shown in Figure 2-7, read and write data from or to platters. Drives have two R/W heads per platter, one for each surface of the platter. The R/W head changes the magnetic polarization on the surface of the platter when writing data. While reading data, the head detects the magnetic polarization on the surface of the platter. During reads and writes, the R/W head senses the magnetic polarization and never touches the surface of the platter. When the spindle is rotating, there is a microscopic air gap maintained between the R/W heads and the platters, known as the *head flying height*. This air gap is removed when the spindle stops rotating and the R/W head rests on a special area on the platter near the spindle. This area is called the *landing*

zone. The landing zone is coated with a lubricant to reduce friction between the head and the platter.

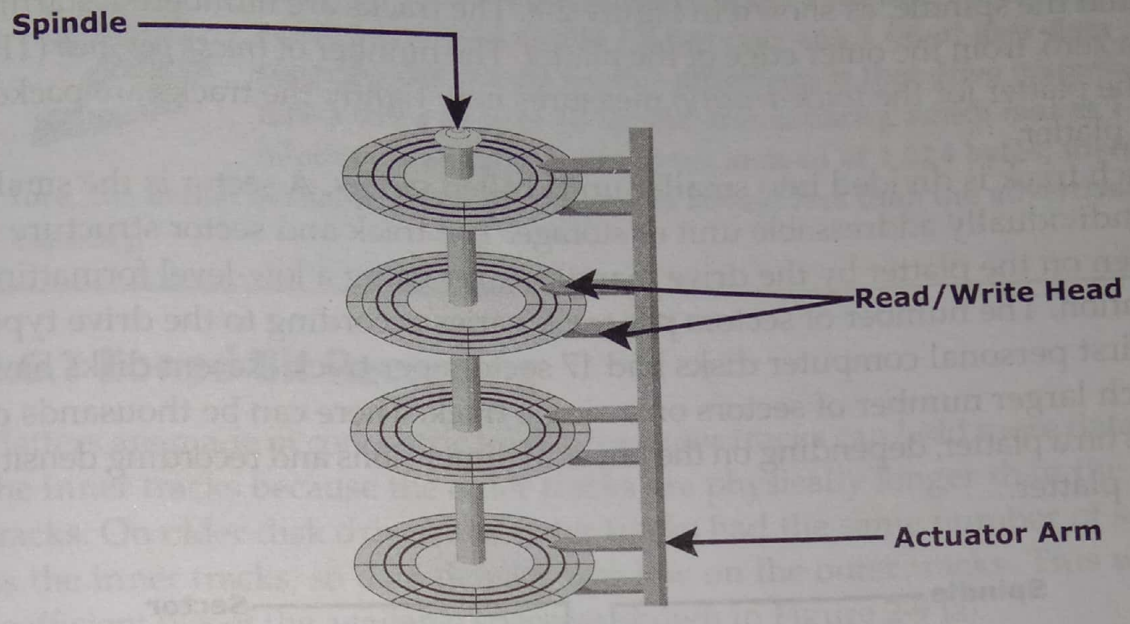


Figure 2-7: Actuator arm assembly

The logic on the disk drive ensures that heads are moved to the landing zone before they touch the surface. If the drive malfunctions and the R/W head accidentally touches the surface of the platter outside the landing zone, a *head crash* occurs. In a head crash, the magnetic coating on the platter is scratched and may cause damage to the R/W head. A head crash generally results in data loss.

2.6.4 Actuator Arm Assembly

R/W heads are mounted on the *actuator arm assembly,* which positions the R/W head at the location on the platter where the data needs to be written or read (refer to Figure 2-7). The R/W heads for all platters on a drive are attached to one actuator arm assembly and move across the platters simultaneously.

2.6.5 Drive Controller Board

The controller (refer to Figure 2-5 [b]) is a printed circuit board, mounted at the bottom of a disk drive. It consists of a microprocessor, internal memory, circuitry, and firmware. The firmware controls the power to the spindle motor and the speed of the motor. It also manages the communication between the drive and the host. In addition, it controls the R/W operations by moving the actuator arm and switching between different R/W heads, and performs the optimization of data access.

2.6.6 Physical Disk Structure

Data on the disk is recorded on *tracks*, which are concentric rings on the platter around the spindle, as shown in Figure 2-8. The tracks are numbered, starting from zero, from the outer edge of the platter. The number of *tracks per inch* (TPI) on the platter (or the *track density*) measures how tightly the tracks are packed on a platter.

Each track is divided into smaller units called *sectors*. A sector is the smallest, individually addressable unit of storage. The track and sector structure is written on the platter by the drive manufacturer using a low-level formatting operation. The number of sectors per track varies according to the drive type. The first personal computer disks had 17 sectors per track. Recent disks have a much larger number of sectors on a single track. There can be thousands of tracks on a platter, depending on the physical dimensions and recording density of the platter.

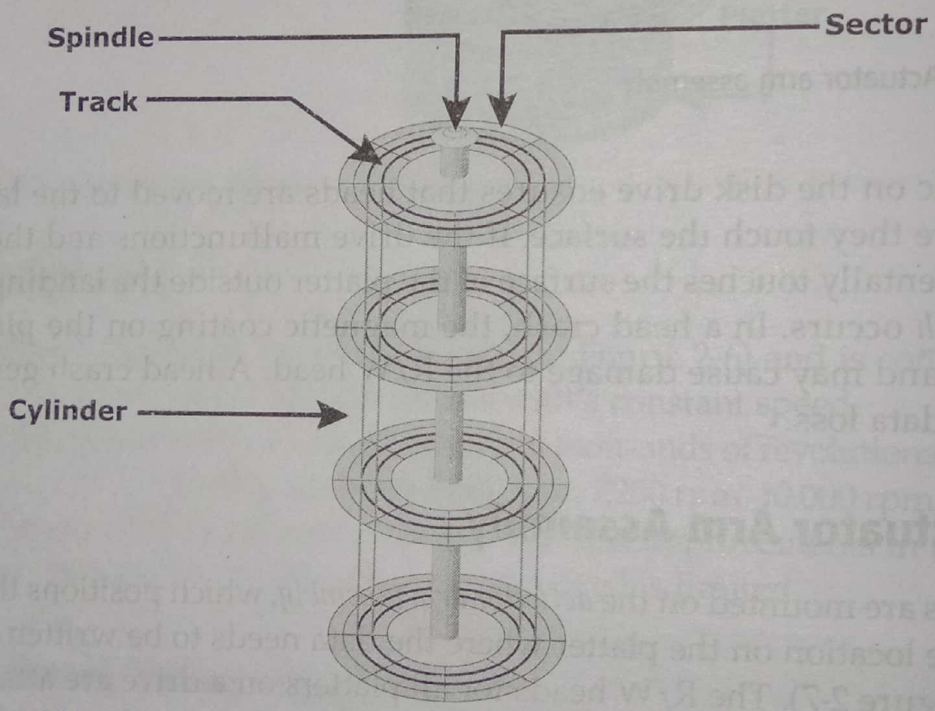


Figure 2-8: Disk structure: sectors, tracks, and cylinders

Typically, a sector holds 512 bytes of user data, although some disks can be formatted with larger sector sizes. In addition to user data, a sector also stores other information, such as the sector number, head number or platter number, and track number. This information helps the controller to locate the data on the drive.

A cylinder is a set of identical tracks on both surfaces of each drive platter. The location of R/W heads is referred to by the cylinder number, not by the track number.

DISK ADVERTISED CAPACITY VERSUS AVAILABLE CAPACITY

A difference exists between the advertised capacity of a disk and the actual space available for data storage. For example, a disk advertised as 500 GB has only 465.7 GB of user-data capacity. The reason for this difference is that drive manufacturers use a base of 10 for the disk capacity, which means 1 kilobyte is equal to 1,000 bytes instead of 1,024 bytes; therefore, the actual available capacity of a disk is always less than the advertised capacity.

2.6.7 Zoned Bit Recording

Platters are made of concentric tracks; the outer tracks can hold more data than the inner tracks because the outer tracks are physically longer than the inner tracks. On older disk drives, the outer tracks had the same number of sectors as the inner tracks, so data density was low on the outer tracks. This was an inefficient use of the available space, as shown in Figure 2-9 (a).

Zoned bit recording uses the disk efficiently. As shown in Figure 2-9 (b), this mechanism groups tracks into zones based on their distance from the center of the disk. The zones are numbered, with the outermost zone being zone 0. An appropriate number of sectors per track are assigned to each zone, so a zone near the center of the platter has fewer sectors per track than a zone on the outer edge. However, tracks within a particular zone have the same number of sectors.

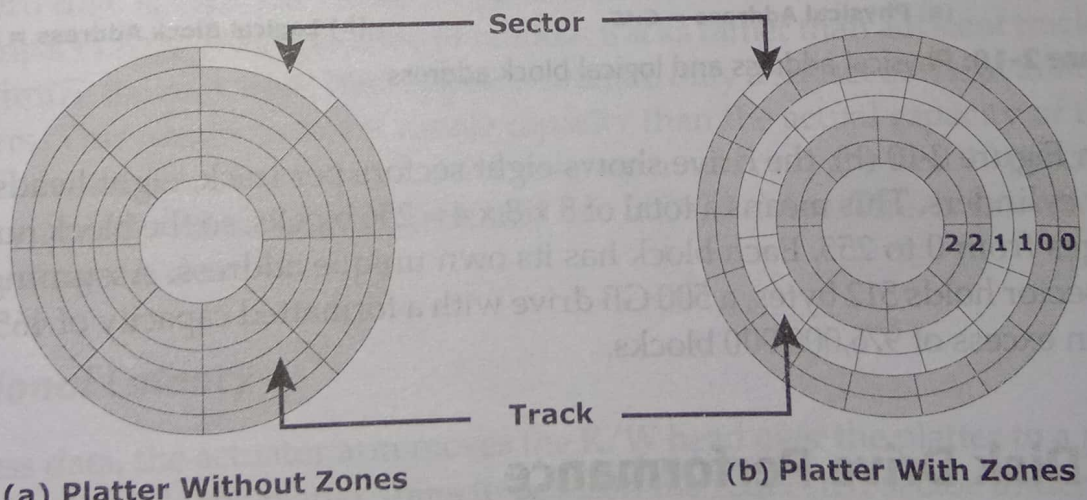
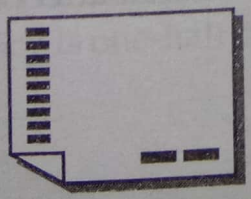


Figure 2-9: Zoned bit recording



The data transfer rate drops while accessing data from zones closer to the center of the platter. Applications that demand high performance should have their data on the outer zones of the platter.

2.6.8 Logical Block Addressing

Earlier drives used physical addresses consisting of the *cylinder, head,* and *sector* (CHS) number to refer to specific locations on the disk, as shown in Figure 2-10 (a), and the host operating system had to be aware of the geometry of each disk used. *Logical block addressing* (LBA), as shown in Figure 2-10 (b), simplifies addressing by using a linear address to access physical blocks of data. The disk controller translates LBA to a CHS address, and the host needs to know only the size of the disk drive in terms of the number of blocks. The logical blocks are mapped to physical sectors on a 1:1 basis.

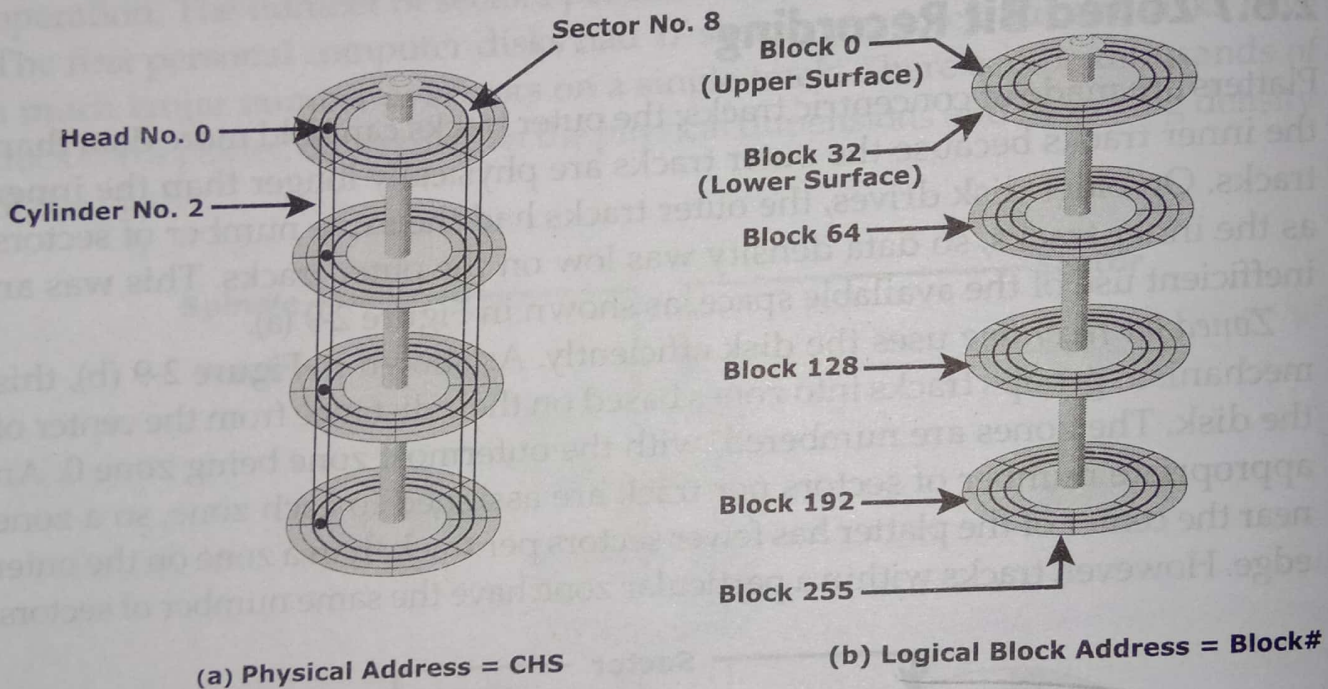


Figure 2-10: Physical address and logical block address

In Figure 2-10 (b), the drive shows eight sectors per track, eight heads, and four cylinders. This means a total of 8 × 8 × 4 = 256 blocks, so the block number ranges from 0 to 255. Each block has its own unique address. Assuming that the sector holds 512 bytes, a 500 GB drive with a formatted capacity of 465.7 GB has in excess of 976,000,000 blocks.