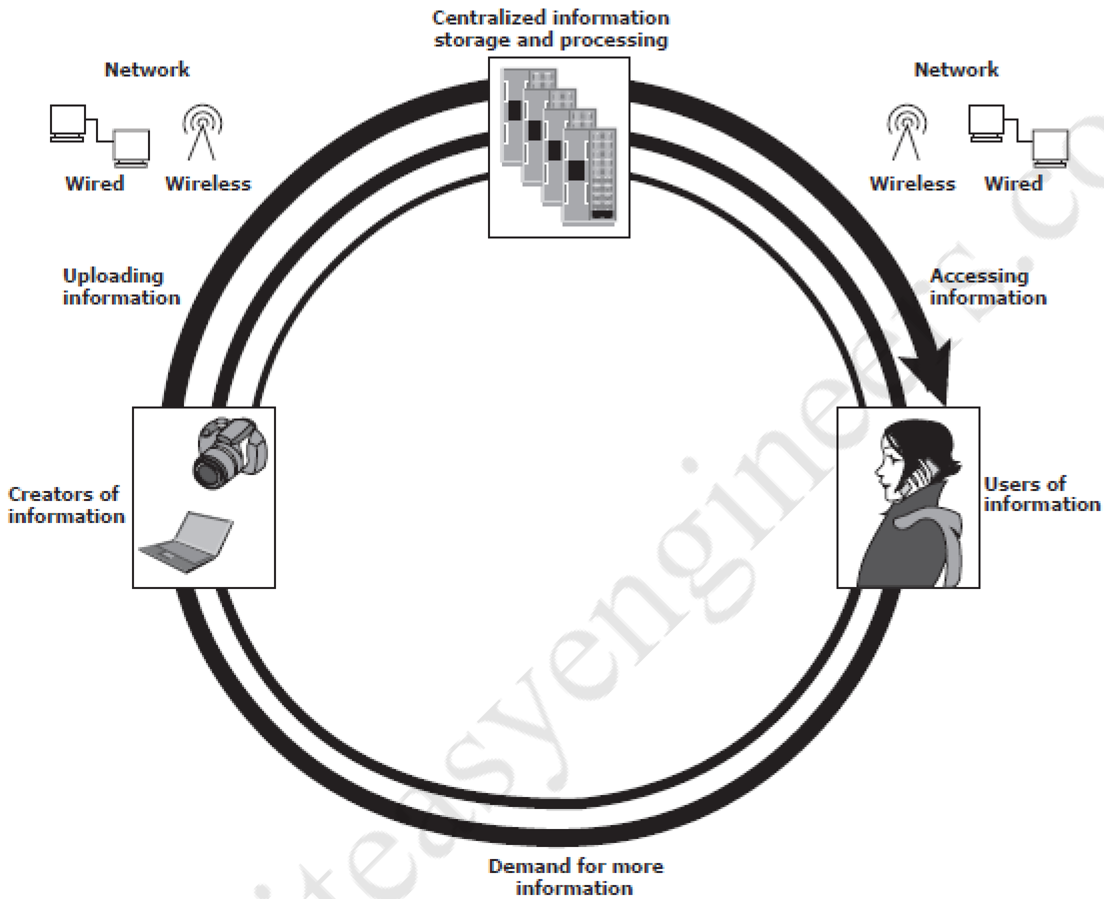
Module 1

STORAGE SYSTEM

1.1 Introduction to Information storage

1.1.1 Why Information management?

- Information is increasingly important in our daily lives. We have become information Dependents.
- We live in on-command, on-demand world that means we need information when and where it is required.
- We access the Internet every day to perform searches, participate in social networking, send and receive e-mails, share pictures and videos, and scores of other applications. Equipped with a growing number of content-generating devices, more information is being created by individuals than by businesses.
- The importance, dependency, and volume of information for the business world also continue to grow at astounding rates.
- Businesses depend on fast and reliable access to information critical to their success. Some of the business applications that process information include airline reservations, telephone billing systems, e-commerce, ATMs, product designs, inventory management, e-mail archives, Web portals, patient records, credit cards, life sciences, and global capital markets.
- The increasing criticality of information to the businesses has amplified the challenges in protecting and managing the data.
- Organizations maintain one or more data centers to store and manage information. A data center is a facility that contains information storage and other physical information technology (IT) resources for computing, networking, and storing information.



1.1.2 Information Storage

Businesses use data to derive information that is critical to their day-to-day operations. Storage is a repository that enables users to store and retrieve this digital data.

Data

- Data is a collection of raw facts from which conclusions may be drawn.
- Eg: a printed book, a family photograph, a movie on videotape, e-mail message, an e-book, a bitmapped image, or a digital movie are all examples of data.
- The data can be generated using a computer and stored in strings of 0s and 1s(as shown in Fig 1.1), is called digital data and is accessible by the user only after it is processed by a computer.

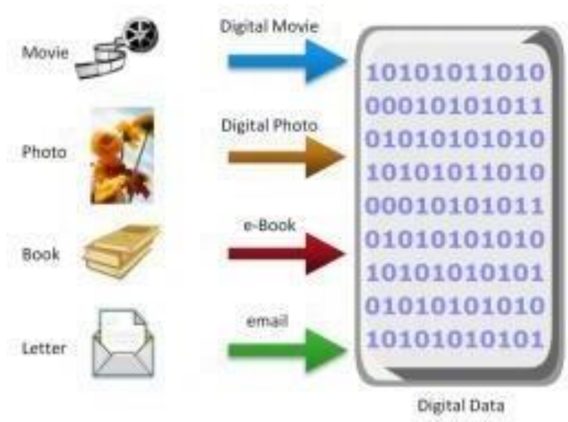


Fig 1.1: Digital data

The following is a list of some of the factors that have contributed to the growth of digital data :

1. **Increase in data processing capabilities**: Modern-day computers provide a significant increase in processing and storage capabilities. This enables the conversion of various types of content and media from conventional forms to digital formats.
2. **Lower cost of digital storage:** Technological advances and decrease in the cost of storage devices have provided low-cost solutions and encouraged the development of less expensive data storage devices. This cost benefit has increased the rate at which data is being generated and stored.
3. **Affordable and faster communication technology:** The rate of sharing digital data is now much faster than traditional approaches. A handwritten letter may take a week to reach its destination, whereas it only takes a few seconds for an e-mail message to reach its recipient.
4. **Proliferation of applications and smart devices:** Smartphones, tablets, and newer digital devices, along with smart applications, have significantly contributed to the generation of digital content.

1.1.3 Types of Data

Data can be classified as structured or unstructured (see Fig 1.2) based on how it is stored and managed.

- **Structured data:**
  - Structured data is organized in rows and columns in a rigidly defined format so that

applications can retrieve and process it efficiently.

- Structured data is typically stored using a database management system (DBMS).

➢ **Unstructured data**:

- Data is unstructured if its elements cannot be stored in rows and columns, and is therefore difficult to query and retrieve by business applications.
- Example: e-mail messages, business cards, or even digital format files such as .doc, .txt, and .pdf.

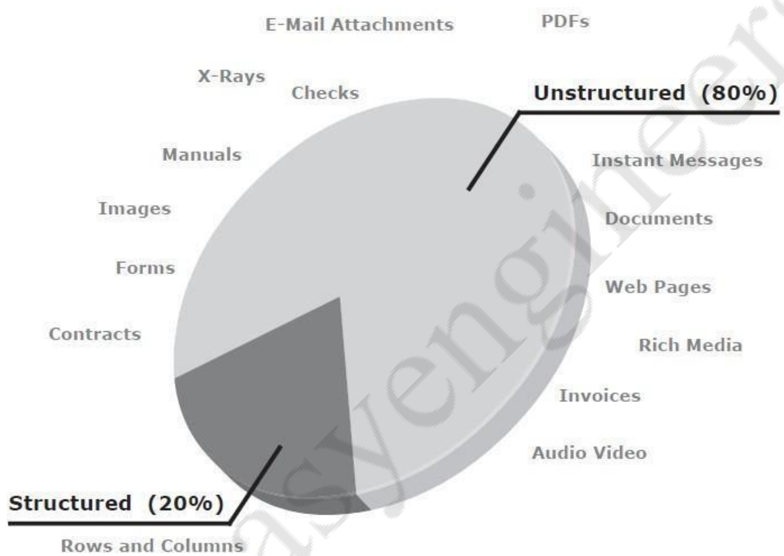


Fig 1.2: Types of data

1.1.4 Big Data

➢ Big data refers to data sets whose sizes are beyond the capability of commonly used software tools to capture, store, manage, and process within acceptable time limits.

➢ It includes both structured and unstructured data generated by a variety of sources, including business application transactions, web pages, videos, images, e-mails, social media, and so on.

➢ The big data ecosystem (see Fig 1.3) consists of the following:

1. Devices that collect data from multiple locations and also generate new data about this data (metadata).
2. Data collectors who gather data from devices and users.
3. Data aggregators that compile the collected data to extract meaningful information.
4. Data users and buyers who benefit from the information collected and aggregated by others in the data value chain .

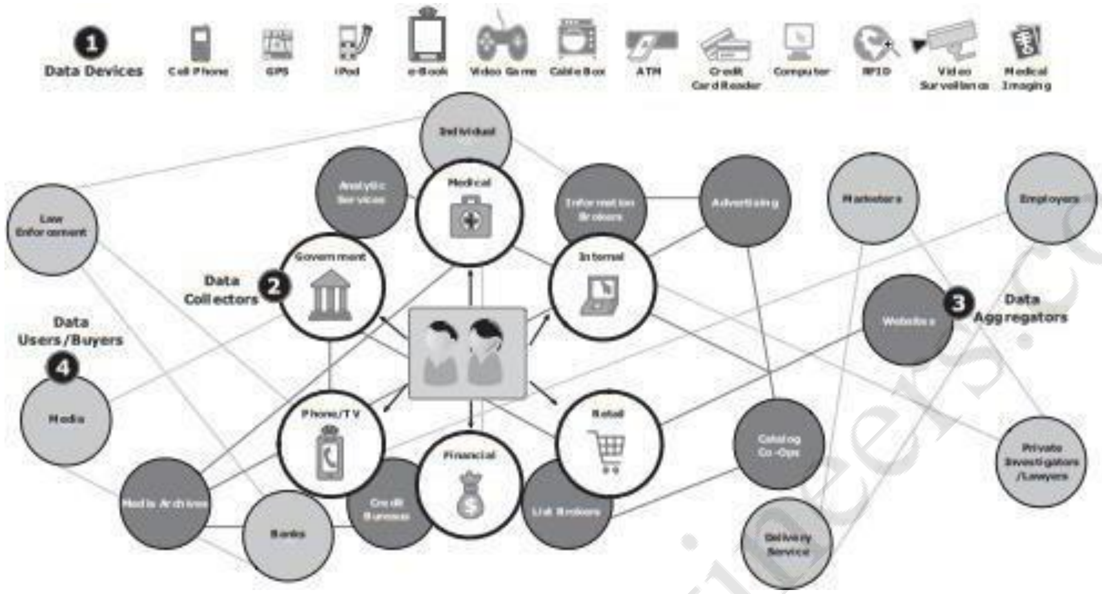


Fig 1.3: Big data Ecosystem

- Big data Analysis in real time requires new techniques, architectures, and tools that provide :
  1. high performance,
  2. massively parallel processing (MPP) data platforms,
  3. advanced analytics on the data sets.
- Big data Analytics provide an opportunity to translate large volumes of data into right decisions.

1.1.5 Information

- Data, whether structured or unstructured, does not fulfil any purpose for individuals or businesses unless it is presented in a meaningful form.
- Information is the intelligence and knowledge derived from data.
- Businesses analyze raw data in order to identify meaningful trends. On the basis of these trends, a company can plan or modify its strategy.
- For example, a retailer identifies customers’ preferred products and brand names by analyzing their purchase patterns and maintaining an inventory of those products.
- Because information is critical to the success of a business, there is an ever present concern about its availability and protection.

1.1.6 Storage

- Data created by individuals or businesses must be stored so that it is easily accessible for further processing.
- In a computing environment, devices designed for storing data are termed storage devices or simply storage.
- The type of storage used varies based on the type of data and the rate at which it is created and used.
- Devices such as memory in a cell phone or digital camera, DVDs, CD-ROMs, and hard disks in personal computers are examples of storage devices.
- Businesses have several options available for storing data including internal hard disks, external disk arrays and tapes.

1.2 Introduction to Evolution of Storage Architecture

- Historically, organizations had centralized computers (mainframe) and information storage devices (tape reels and disk packs) in their data center.
- The evolution of open systems and the affordability and ease of deployment that they offer made it possible for business units/departments to have their own servers and storage.
- In earlier implementations of open systems, the storage was typically internal to the server. This approach is referred to as **server-centric storage architecture** (see Fig 1.4 [a]).
- In this server-centric storage architecture, each server has a limited number of storage devices, and any administrative tasks, such as maintenance of the server or increasing storage capacity, might result in unavailability of information.
- The rapid increase in the number of departmental servers in an enterprise resulted in unprotected, unmanaged, fragmented islands of information and increased capital and operating expenses.
- To overcome these challenges, storage evolved from **server-centric to information-centric architecture** (see Fig 1.4 [b]).

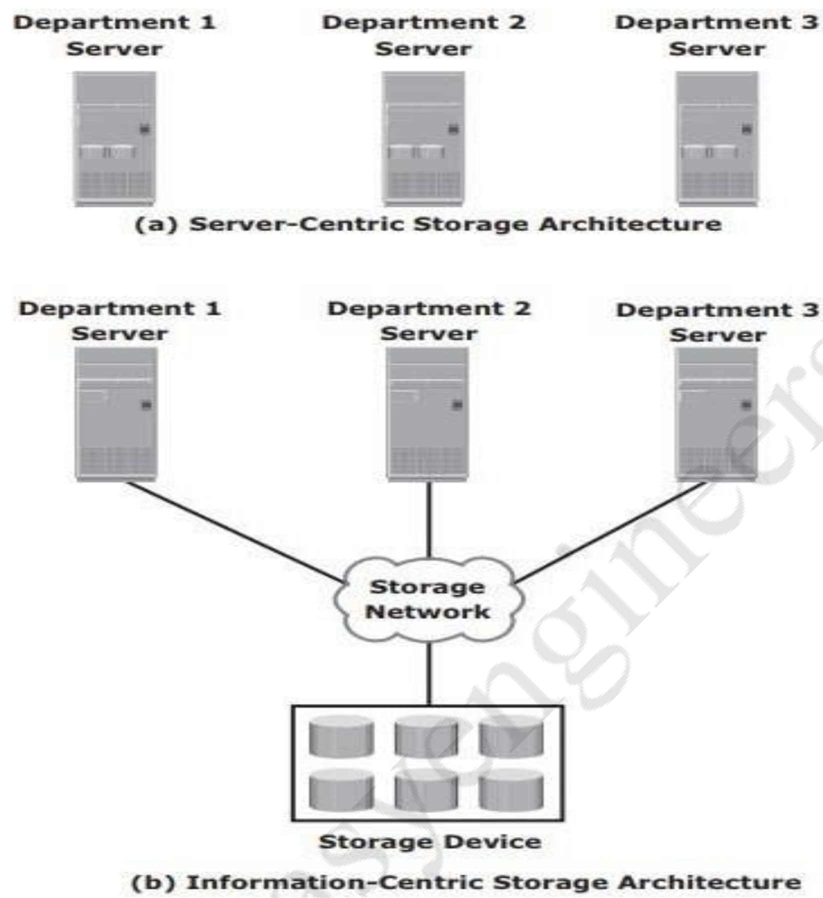


Fig 1.4: Evolution of storage architecture

- In information-centric architecture, storage devices are managed centrally and independent of servers.
- These centrally-managed storage devices are shared with multiple servers.
- When a new server is deployed in the environment, storage is assigned from the same shared storage devices to that server.
- The capacity of shared storage can be increased dynamically by adding more storage devices without impacting information availability.
- In this architecture, information management is easier and cost-effective.
- Storage technology and architecture continues to evolve, which enables organizations to consolidate, protect, optimize, and leverage their data to achieve the highest return on information assets.

1.3 Data Center Infrastructure

- Organizations maintain data centers to provide centralized data processing capabilities across the enterprise.
- The data center infrastructure includes computers, storage systems, network devices, dedicated power backups, and environmental controls (such as air conditioning and fire suppression).

1.3.1 Key Data Center Elements

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

1) **Application:** An application is a computer program that provides the logic for computing operations. Eg: order processing system.
2) **Database:** More commonly, a database management system (DBMS) provides a structured way to store data in logically organized tables that are interrelated. A DBMS optimizes the storage and retrieval of data.
3) **Host or compute:** A computing platform (hardware, firmware, and software) that runs applications and databases.
4) **Network:** A data path that facilitates communication among various networked devices.
5) **Storage array:** 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.
- Fig 1.5 shows an example of an order processing system that involves the five core elements of a data center and illustrates their functionality in a business process.
  1) A customer places an order through a client machine connected over a LAN/ WAN to a host running an order-processing application.
  2) 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.
  3) The DBMS uses the host operating system to write this data to the database located on physical disks in the storage array.
  4) The Storage Network provides the communication link between the host and the storage array and transports the request to read or write commands between them.

5) The storage array, after receiving the read or write request from the host, performs the necessary operations to store the data on physical disks.

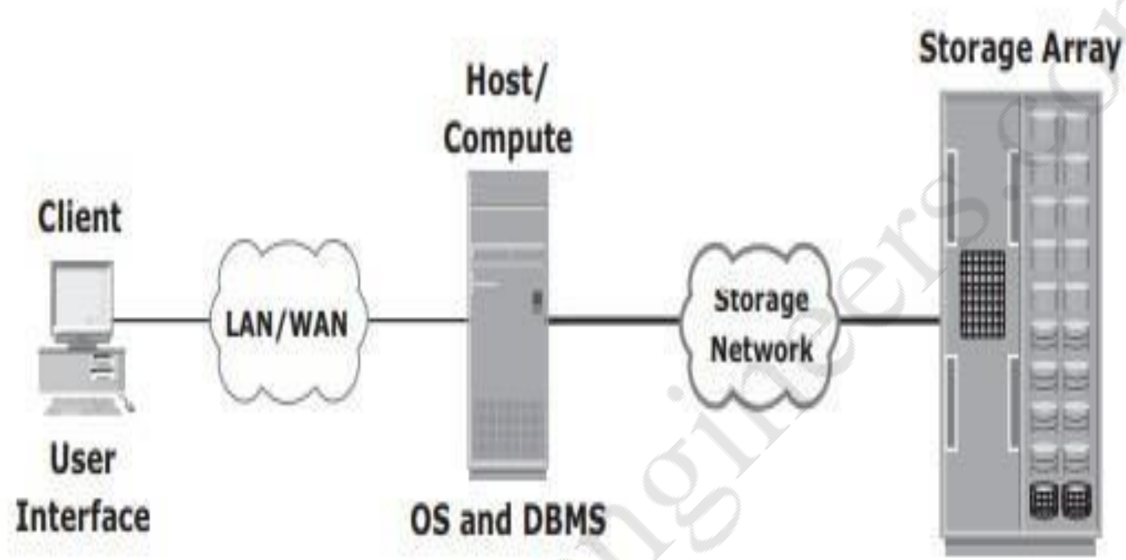


Fig 1.5: Example of an online order transaction system

1.4 Key characteristics for Data Center Elements

Key characteristics of data center elements are:

1) **Availability:** All data center elements should be designed to ensure accessibility. The inability of users to access data can have a significant negative impact on a business.
2) **Security:** Polices, procedures, and proper integration of the data center core elements that will prevent unauthorized access to information must be established. Specific mechanisms must enable servers to access only their allocated resources on storage arrays.
3) **Scalability:** Data center operations should be able to allocate additional processing capabilities (eg: servers, new applications, and additional databases) or storage on demand, without interrupting business operations. The storage solution should be able to grow with the business.
4) **Performance**: All the core elements of the data center should be able to provide optimal performance and service all processing requests at high speed. The infrastructure should be able to support performance requirements.

5) **Capacity:** Data center operations require adequate resources to store and process large amounts of data efficiently. When capacity requirements increase, the data center must be able to provide additional capacity without interrupting availability, or, at the very least, with minimal disruption. Capacity may be managed by reallocation of existing resources, rather than by adding new resources.

6) **Manageability:** A data center should perform all operations and activities in the most efficient manner. Manageability can be achieved through automation and the reduction of human (manual) intervention in common tasks.

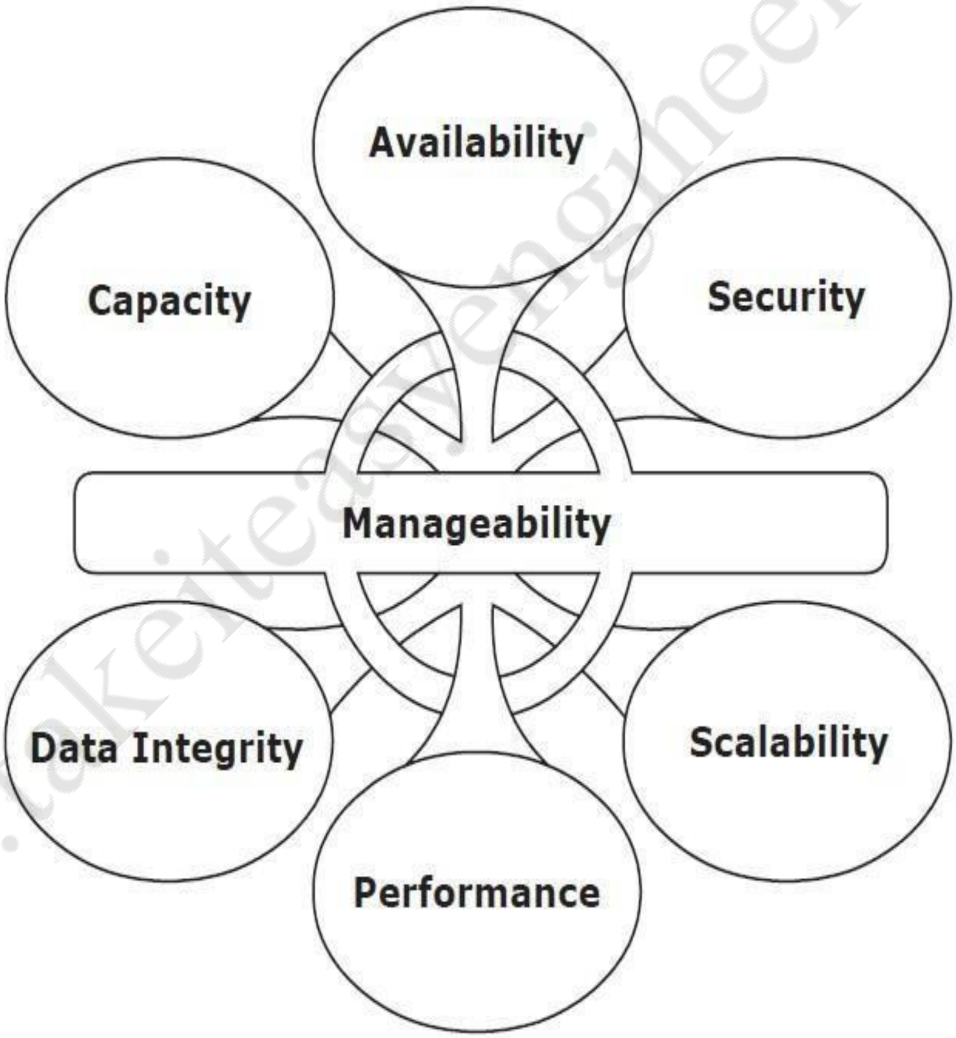


Fig 1.6: Key characteristics of data center elements

1.5 Virtualization

- Virtualization is a technique of abstracting physical resources, such as compute, storage, and network, and making them appear as logical resources.
- Virtualization has existed in the IT industry for several years and in different forms.
- Common examples of virtualization are virtual memory used on compute systems and partitioning of raw disks.
- Virtualization enables pooling of physical resources and providing an aggregated view of the physical resource capabilities. For example, storage virtualization enables multiple pooled storage devices to appear as a single large storage entity.
- Similarly, by using compute virtualization, the CPU capacity of the pooled physical servers can be viewed as the aggregation of the power of all CPUs (in megahertz).
- Virtualization also enables centralized management of pooled resources.
- Virtual resources can be created and provisioned from the pooled physical resources. For example, a virtual disk of a given capacity can be created from a storage pool or a virtual server with specific CPU power and memory can be configured from a compute pool.
- These virtual resources share pooled physical resources, which improves the utilization of physical IT resources.
- Based on business requirements, capacity can be added to or removed from the virtual resources without any disruption to applications or users.
- With improved utilization of IT assets, organizations save the costs associated management of new physical resources. Moreover, fewer physical resources means less space and energy, which leads to better economics and green computing.

1.6 Cloud Computing

- Cloud computing enables individuals or businesses to use IT resources as a service over the network.
- It provides highly scalable and flexible computing that enables provisioning of resources on demand.
- Users can scale up or scale down the demand of computing resources, including storage

capacity, with minimal management effort or service provider interaction.

- Cloud computing empowers self-service requesting through a fully automated request-fulfillment process.
- Cloud computing enables consumption-based metering; therefore, consumers pay only for the resources they use, such as CPU hours used, amount of data transferred, and gigabytes of data stored.
- Cloud infrastructure is usually built upon virtualized data centers, which provide resource pooling and rapid provisioning of resources.

1.7 Key Data center Elements

1.7.1 Application

- An application is a computer program that provides the logic for computing operations.
- The application sends requests to the underlying operating system to perform read/write (R/W) operations on the storage devices.
- Applications deployed in a data center environment are commonly categorized as business applications, infrastructure management applications, data protection applications, and security applications.
- Some examples of these applications are e-mail, enterprise resource planning (ERP), decision support system (DSS), resource management, backup, authentication and antivirus applications, and so on

1.7.2. DBMS

- A database is a structured way to store data in logically organized tables that are interrelated.
- A DBMS controls the creation, maintenance, and use of a database.

1.7.3 Host(or) Compute

- The computers on which applications run are referred to as hosts. Hosts can range from simple laptops to complex clusters of servers.
- Hosts can be physical or virtual machines.
- A compute virtualization software enables creating virtual machines on top of a physical compute infrastructure.

- A host consists of
  - ✓ CPU: The CPU consists of four components-Arithmetic Logic Unit (ALU), control unit, registers, and L1 cache
  - ✓ Memory: There are two types of memory on a host, Random Access Memory (RAM) and Read-Only Memory (ROM)
  - ✓ I/O devices : keyboard, mouse, monitor
  - ✓ a collection of software to perform computing operations- This software includes the operating system, file system, logical volume manager, device drivers, and so on.The following section details various software components that are essential parts of a host system.

1.7.3.1 Operating System

- In a traditional computing environment, an operating system controls all aspects of computing.
- It works between the application and the physical components of a compute system.
- In a virtualized compute environment, the virtualization layer works between the operating system and the hardware resources.

Functions of OS

- data access
- monitors and responds to user actions and the environment
- organizes and controls hardware components
- manages the allocation of hardware resources
- It provides basic security for the access and usage of all managed resources
- performs basic storage management tasks
- Manages the file system, volume manager, and device drivers.

Memory Virtualization

- Memory has been, and continues to be, an expensive component of a host.
- It determines both the size and number of applications that can run on a host. Memory virtualization is an operating system feature that virtualizes the physical memory(RAM) of a host.
- It creates virtual memory with an address space larger than the physical memory space present in the compute system.
- The operating system utility that manages the virtual memory is known as the virtual memory manager (VMM).

- The space used by the VMM on the disk is known as a swap space.
- A swap space (also known as page file or swap file) is a portion of the disk drive that appears to be physical memory to the operating system.
- In a virtual memory implementation, the memory of a system is divided into contiguous blocks of fixed-size pages.
- A process known as paging moves inactive physical memory pages onto the swap file and brings them back to the physical memory when required.

1.7.3.2 Device Drivers

- A device driver is special software that permits the operating system to interact with a specific device, such as a printer, a mouse, or a disk drive.

1.7.3.3 Volume Manager

- In the early days, disk drives appeared to the operating system as a number of continuous disk blocks. The entire disk drive would be allocated to the file system or other data entity used by the operating system or application.

Disadvantages:

- ✓ lack of flexibility.
- ✓ When a disk drive ran out of space, there was no easy way to extend the file system's size.
- ✓ as the storage capacity of the disk drive increased, allocating the entire disk drive for the file system often resulted in underutilization of storage capacity

Solution: evolution of Logical Volume Managers (LVMs)

- LVM enabled dynamic extension of file system capacity and efficient storage management.
- The LVM is software that runs on the compute system and manages logical and physical storage.
- LVM is an intermediate layer between the file system and the physical disk.
- LVM can partition a larger-capacity disk into virtual, smaller-capacity volumes(called Partitioning) or aggregate several smaller disks to form a larger virtual volume. The process is called concatenation.
- Disk partitioning was introduced to improve the flexibility and utilization of disk drives.
- In partitioning, a disk drive is divided into logical containers called logical volumes (LVs) (see Fig 1.7)

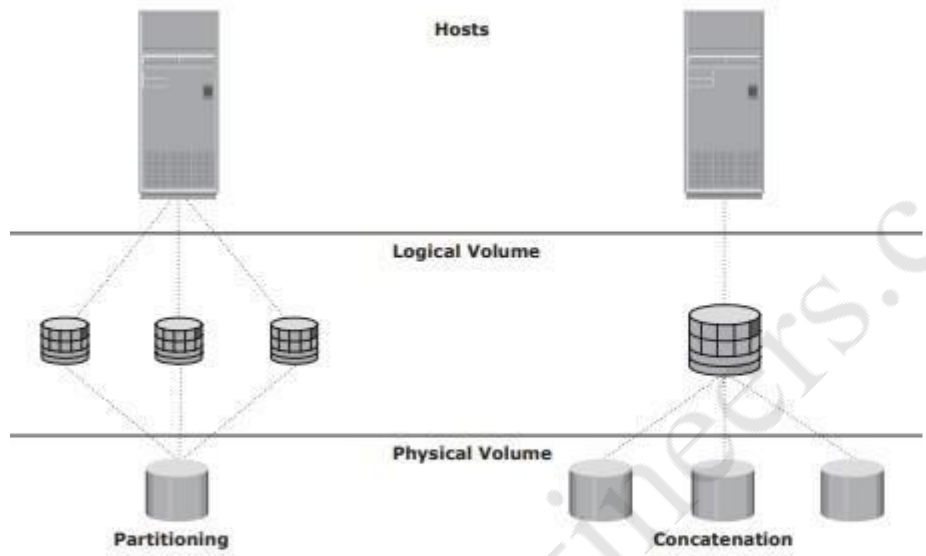


Fig 1.7: Disk Partitioning and concatenation

- Concatenation is the process of grouping several physical drives and presenting them to the host as one big logical volume.
- The basic LVM components are **physical volumes, volume groups, and logical volumes**.
- Each physical disk connected to the host system is a **physical volume (PV).**
- A **volume group** is created by grouping together one or more physical volumes. A unique physical volume identifier (PVID) is assigned to each physical volume when it is initialized for use by the LVM. Each physical volume is partitioned into equal-sized data blocks called **physical extents** when the volume group is created.
- **Logical volumes** are created within a given volume group. A logical volume can be thought of as a disk partition, whereas the volume group itself can be thought of as a disk.

1.7.3.4 File System

- A file is a **collection of related records** or data stored as a unit with a name.
- A file system is a hierarchical structure of files.
- A file system enables easy access to data files residing within a disk drive, a disk partition, or a logical volume.
- It provides users with the functionality to create, modify, delete, and access files.

- Access to files on the disks is controlled by the permissions assigned to the file by the owner, which are also maintained by the file system.
- A file system organizes data in a structured hierarchical manner via the use of directories, which are containers for storing pointers to multiple files.
- All file systems maintain a pointer map to the directories, subdirectories, and files that are part of the file system.
- Examples of common file systems are:
  - ✓ FAT 32 (File Allocation Table) for Microsoft Windows
  - ✓ NT File System (NTFS) for Microsoft Windows
  - ✓ UNIX File System (UFS) for UNIX
  - ✓ Extended File System (EXT2/3) for Linux
- The file system also includes a number of other related records, which are collectively called the **metadata**.
- For example, the metadata in a UNIX environment consists of the **superblock, the inodes, and the list of data blocks free and in use.**
- A superblock contains important information about the file system, such as the file system type, creation and modification dates, size, and layout.
- An inode is associated with every file and directory and contains information such as the file length, ownership, access privileges, time of last access/modification, number of links, and the address of the data.
- A file system block is the smallest “unit” allocated for storing data.
- The following list shows the process of mapping user files to the disk storage subsystem with an LVM (see Fig 1.8)
  1. Files are created and managed by users and applications.
  2. These files reside in the file systems.
  3. The file systems are mapped to file system blocks.
  4. The file system blocks are mapped to logical extents of a logical volume.
  5. These logical extents in turn are mapped to the disk physical extents either by the operating system or by the LVM.
  6. These physical extents are mapped to the disk sectors in a storage subsystem.

If there is no LVM, then there are no logical extents. Without LVM, file system blocks are directly mapped to disk sectors.

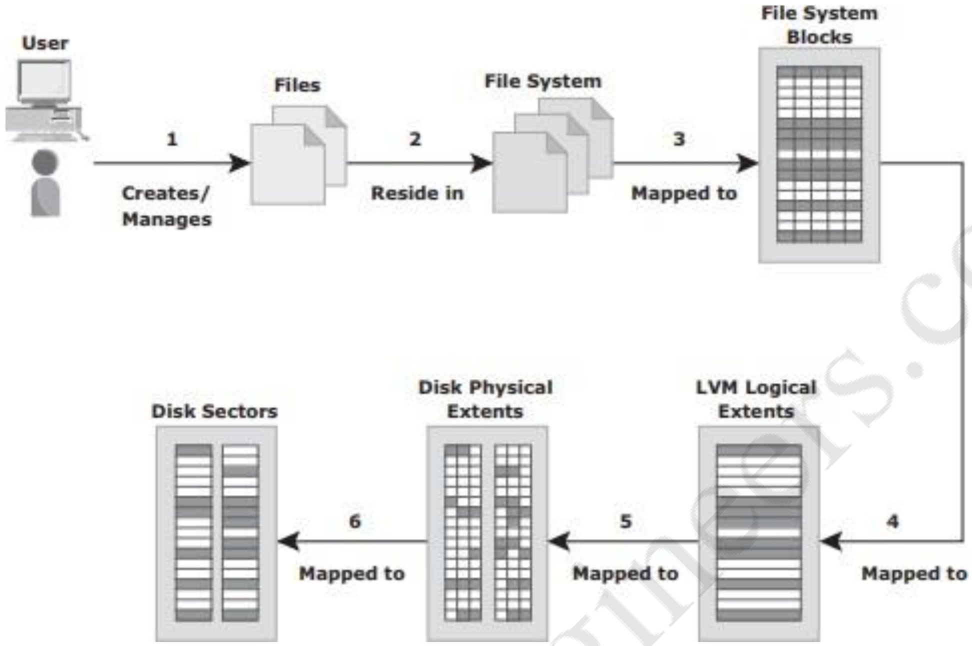


Fig 1.8: Process of mapping user files to disk storage

- The file system tree starts with the root directory. The root directory has a number of subdirectories.
- A file system can be either :
  - ✓ a journaling file system
  - ✓ a nonjournaling file system.

Nonjournaling file system : Nonjournaling file systems cause a potential loss of files because they use separate writes to update their data and metadata. If the system crashes during the write process, the metadata or data might be lost or corrupted. When the system reboots, the file system attempts to update the metadata structures by examining and repairing them. This operation takes a long time on large file systems. If there is insufficient information to re-create the wanted or original structure, the files might be misplaced or lost, resulting in corrupted file systems.

Journaling file system: Journaling File System uses a separate area called a *log* or *journal*. This journal might contain all the data to be written (physical journal) or just the metadata to be updated (logical journal). Before changes are made to the file system, they are written to this separate area. After the journal has been updated, the operation on the file system can be performed. If the system crashes during the operation, there is enough information in the log to "*replay*" the log record and complete the operation. Nearly all file system implementations today use journaling

Advantages:

- Journaling results in a quick file system check because it looks only at the active, most recently accessed parts of a large file system.
- Since information about the pending operation is saved, the risk of files being lost is reduced.

Disadvantage:

- they are slower than other file systems. This slowdown is the result of the extra operations that have to be performed on the journal each time the file system is changed.
- But the advantages of lesser time for file system checks and maintaining file system integrity far outweighs its disadvantage.

1.7.3.5 Compute Virtualization

- Compute virtualization is a technique for *masking* or *abstracting* the physical hardware from the operating system. It enables multiple operating systems to run concurrently on single or clustered physical machines.
- This technique enables creating portable virtual compute systems called *virtual machines* (VMs) running its own operating system and application instance in an isolated manner.
- Compute virtualization is achieved by a virtualization layer that resides between the hardware and virtual machines called the *hypervisor*. The hypervisor provides hardware resources, such as CPU, memory, and network to all the virtual machines.
- A virtual machine is a logical entity but appears like a physical host to the operating system, with its own CPU, memory, network controller, and disks. However, all VMs share the same underlying physical hardware in an isolated manner.

- Before Compute virtualization:
  - ✓ A physical server often faces resource-conflict issues when two or more applications running on the same server have conflicting requirements. As a result, only one application can be run on a server at a time, as shown in Fig 1.9 (a).
  - ✓ Due to this, organizations will need to purchase new physical machines for every application they deploy, resulting in expensive and inflexible infrastructure.
  - ✓ Many applications do not fully utilize complete hardware capabilities available to them. Resources such as processors, memory and storage remain underutilized.

- ✓ Compute virtualization enables users to overcome these challenges (see Fig 1.9 (b)).

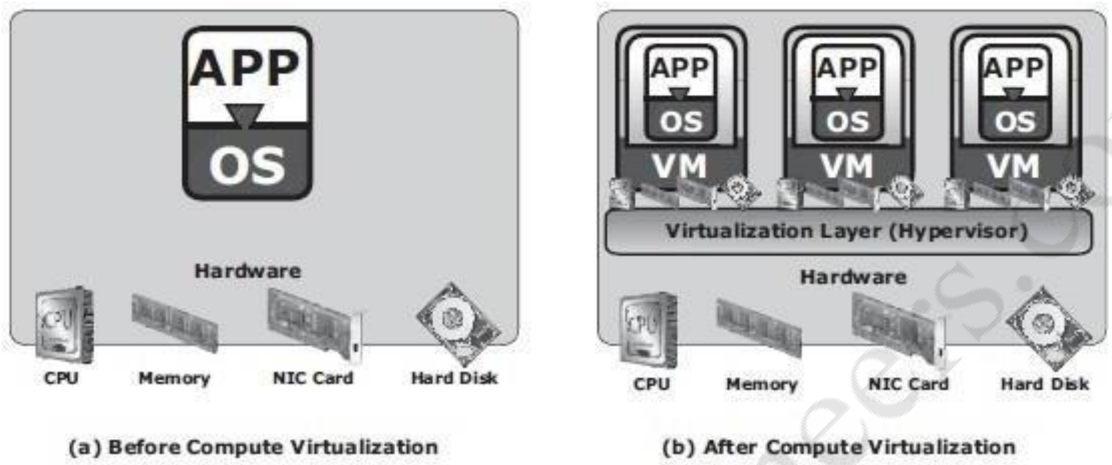


Fig 1.9: Server Virtualization

- ➢ After Compute virtualization:
  - ✓ This technique significantly improves server utilization and provides server consolidation.
  - ✓ *Server consolidation* enables organizations to run their data center with fewer physical servers.
  - ✓ This, in turn,
    - reduces cost of new server acquisition,
    - reduces operational cost,
    - saves data center floor and rack space.
  - ✓ Individual VMs can be restarted, upgraded, or even crashed, without affecting the other VMs.
  - ✓ VMs can be copied or moved from one physical machine to another (non-disruptive migration) without causing application downtime. This is required for maintenance activities

1.8 Connectivity

- ➢ Connectivity refers to the interconnection between hosts or between a host and peripheral devices, such as printers or storage devices.
- ➢ Connectivity and communication between host and storage are enabled using:
  - ✓ physical components
  - ✓ interface protocols.

1.8.1 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 (refer Fig 1.10):
  - ✓ the host interface device
  - ✓ port
  - ✓ cable.

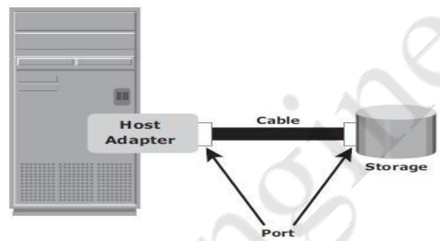


Fig 1.10: Physical components of connectivity

- A *host interface device* or *host adapter* connects a host to other hosts and storage devices.
  - ✓ Eg: host bus adapter (HBA) and network interface card (NIC).
  - ✓ HBA 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.
- *Cables* connect hosts to internal or external devices using copper or fiber optic media.

1.8.2 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:
  i. Integrated Device Electronics/Advanced Technology Attachment (IDE/ATA)
  ii. Small Computer System Interface (SCSI),
  iii. Fibre Channel (FC)
  iv. 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.
- If performance of the drive is important, sharing a port between two devices is not recommended.
- The serial version of this protocol is known as Serial ATA (SATA) and supports single bit serial transmission.
- *High performance* and *low cost* SATA has 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.
- The high cost associated with SCSI limits its popularity among home or personal desktop users.
- SCSI supports up to 16 devices on a single bus and provides data transfer rates up to **640 MB/s.**
- **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.**

Fibre Channel (FC):

- **Fibre Channel** is a widely used protocol for high-speed communication to the storage device.
- 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.**

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:
  - ✓ cost
  - ✓ maturity
  - ✓ enables organizations to leverage their existing IP-based network.
- **iSCSI** and **FCIP** protocols are common examples that leverage IP for host-to-storage communication.

1.9 Storage

- Storage is a core component in a data center.
- A storage device uses magnetic, optic, or solid state media.
- Disks, tapes, and diskettes use magnetic media,
- CD/DVD uses optical media.
- Removable Flash memory or Flash drives uses solid state media.

Tapes

- In the past, **tapes** were the most popular storage option for backups because of their low cost.
- Tapes have various limitations in terms of performance and management, as listed below:
  i. Data is stored on the tape linearly along the length of the tape. Search and retrieval of data are done sequentially, and it invariably takes several seconds to access the data. As a result, **random data access is slow and time-consuming**.
  ii. In a shared computing environment, data stored on tape **cannot be accessed by multiple applications simultaneously**, restricting its use to one application at a time.
  iii. On a tape drive, the read/write head touches the tape surface, so the tape degrades or wears out after repeated use.
  iv. The storage and retrieval requirements of data from the tape and the overhead associated with managing the tape media are significant.
- Due to these limitations and availability of low-cost disk drives, tapes are no longer a preferred choice as a backup destination for enterprise-class data centers.

Optical Disc Storage:

- It is popular in small, single-user computing environments.
- It is frequently used by individuals to store photos or as a backup medium on personal or laptop computers.
- It is also used as a distribution medium for small applications, such as games, or as a means to transfer small amounts of data from one computer system to another.
- The capability to **write once and read many (WORM)** is one advantage of optical disc storage. Eg: CD-ROM
- Collections of optical discs in an array, called a **jukebox**, are still used as a fixed-content storage solution.
- Other forms of optical discs include CD-RW, Blu-ray disc, and other variations of DVD.

Disk Drives:

- **Disk drives** are the most popular storage medium used in modern computers for storing and accessing data for performance-intensive, online applications.
- Disks support rapid access to random data locations.
- Disks have large capacity.
- Disk storage arrays are configured with multiple disks to provide **increased capacity** and **enhanced performance**.
- Disk drives are accessed through predefined protocols, such as ATA, SATA, SAS, and FC.
- These protocols are implemented on the disk interface controllers.
- Disk interface controllers were earlier implemented as separate cards, which were connected to the motherboard.
- Modern disk interface controllers are integrated with the disk drives; therefore, disk drives are known by the protocol interface they support, for example SATA disk, FC disk, etc.

Disk Drive Components

Key components of a disk drive are platter, spindle, read/write head, actuator armassembly, and controller.

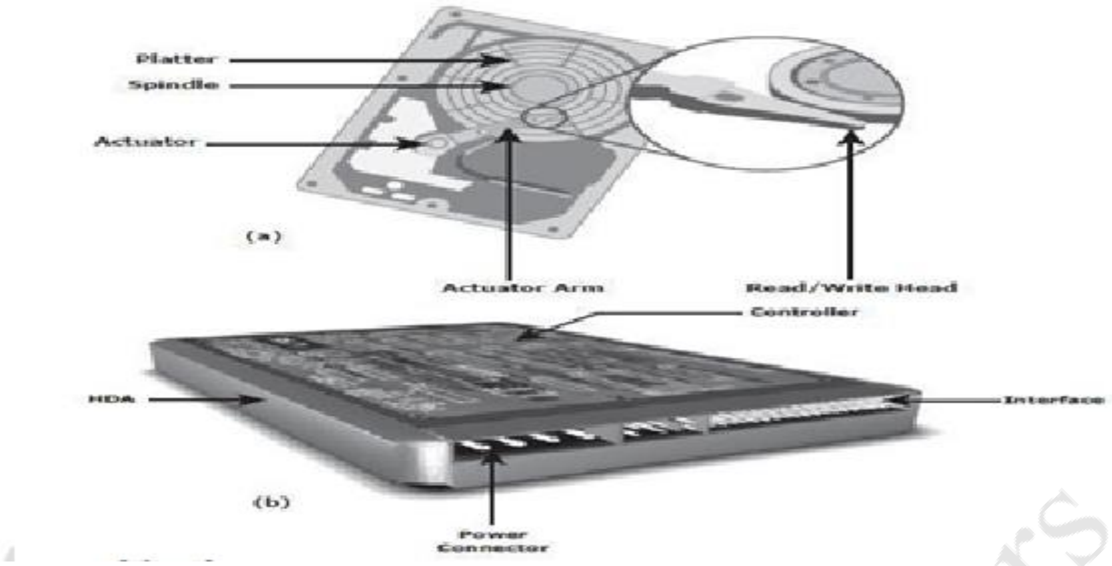


Figure 8: Disk Drive Components

Platter

- A typical HDD consists of one or more flat circular disks called platters (Figure 8).
- The data is recorded on these platters in binary codes (0s and1s).
- The set of rotating platters is sealed in a case, called a **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.

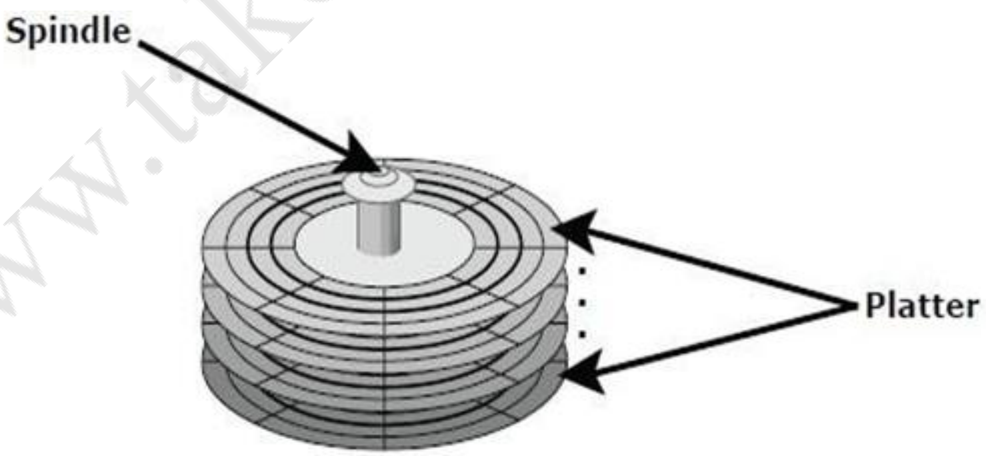


Figure 5: Spindle & Platters

A spindle connects all the platters, as shown in Figure 9, and is connected to a motor. The motor of the spindlerotates with a constant speed.The disk platter spins at a speed of several thousands of revolutions per minute (rpm). Disk drives havespindle speeds of 7,200 rpm, 10,000 rpm, or 15,000 rpm.

Read/Write Head

- Read/Write (R/W) heads, shown in Figure 10, read and write data from or to a platter.
- 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, this head detects 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 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.
- 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.

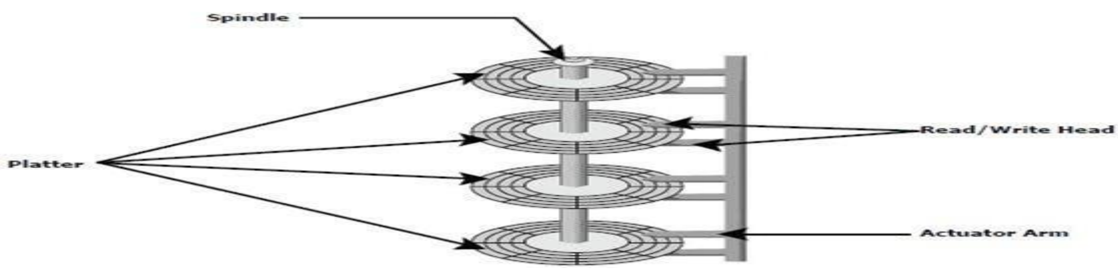


Figure 10: Actuator arm assembly

Actuator Arm Assembly

- The R/W heads are mounted on the actuator arm assembly (refer to Figure 8[a]), which positions the R/W head at the location on the platter where the data needs to be written or read.
- The R/W heads for all platters on a drive are attached to one actuator arm assembly and move across the platters simultaneously.
- There are two R/W heads per platter, one for each surface, as shown in Figure 10.

Controller

- The controller (see Figure 8[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 power to the spindle motor and the speed of the motor.
- It also manages 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.

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 10.
- 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 formatting operation.

- ➢ The number of sectors per track varies according to the specific drive.
- ➢ 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 sector number head number or platter number, and track number. This information helps the controller to locate the data on the drive, but storing this information consumes space on the disk.
- ➢ A cylinder is the set of identical tracks on both surfaces of each drive platter.
- ➢ The location of drive heads is referred to by cylinder number, not by track number.

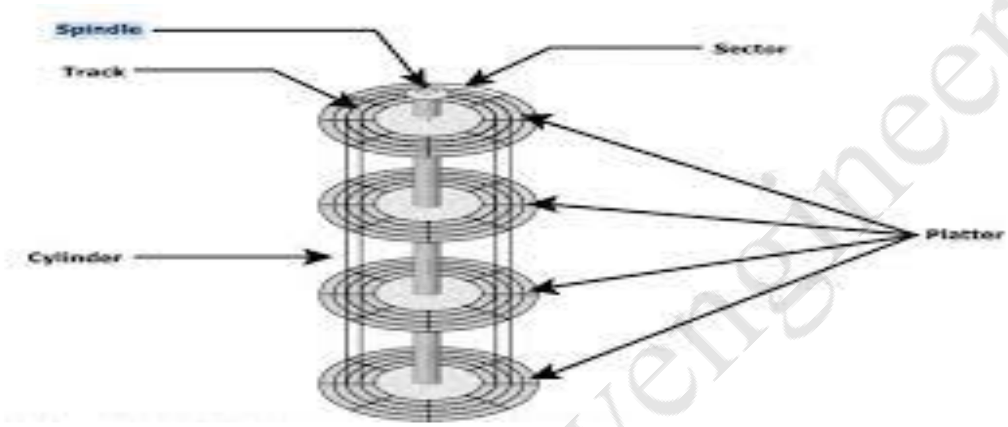


Figure 11: Disk structure: sectors, tracks, and cylinders

Zoned Bit Recording

- □ Because the 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, as shown in Figure 12(a).
- □ 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 available space.
- □ Zone bit recording utilizes the disk efficiently. As shown in Figure 12(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.

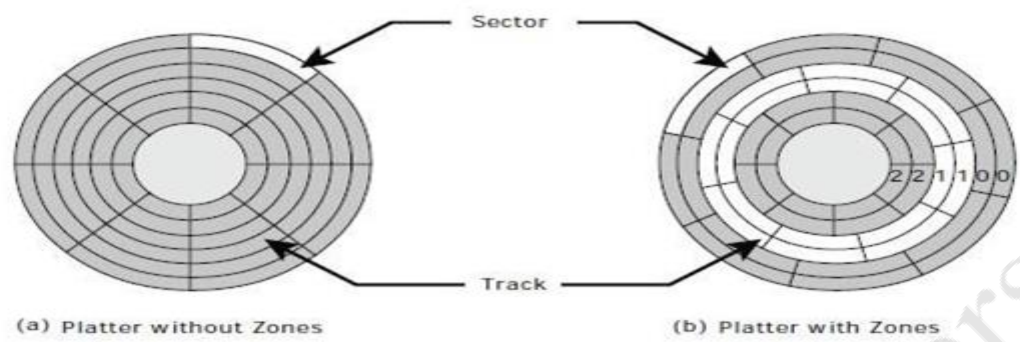


Figure 12: Zoned bit recording

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 13(a), and the host operating system had to be aware of the geometry of each disk being used.
- Logical block addressing (LBA), shown in Figure 13(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 only needs to know 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.

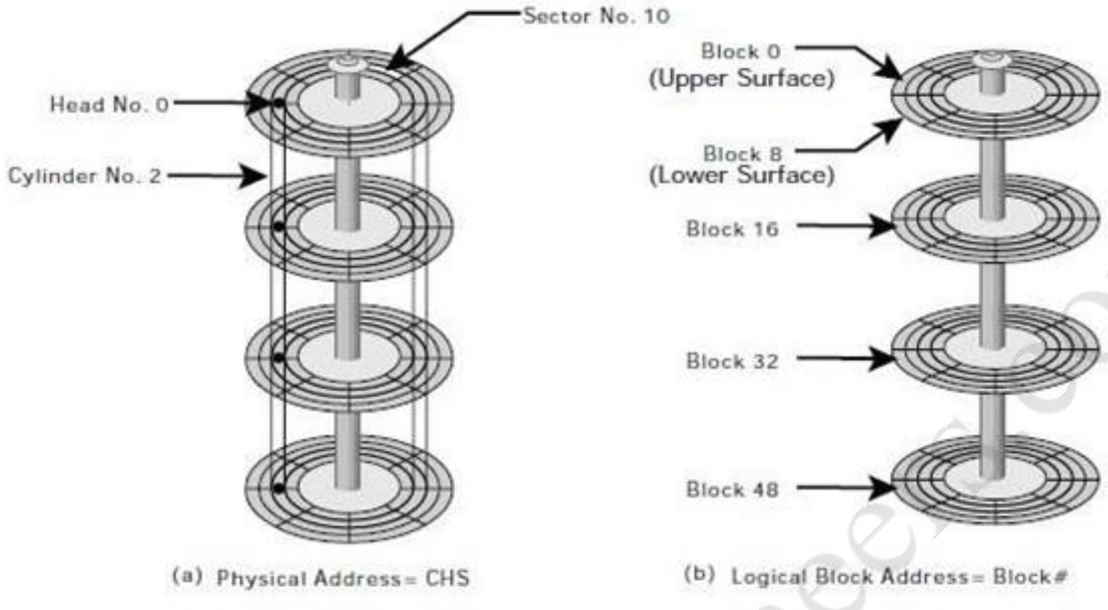
- In Figure 13(b), the drive shows eight sectors per track, eight heads, and four cylinders. This means a total of $8 \times 8 \times 4 = 256$ blocks, so the block number ranges from 0 to 255.
- Each block has its own unique address.

Disk Drive Performance

A disk drive is an electromechanical device that governs the overall performance of the storage system environment. The various factors that affect the performance of disk drives are:

- Disk Service Time
- Rotational Latency
- Data Transfer Rate.

- Disk service time is the time taken by a disk to complete an I/O request.



(a) Physical Address = CHS (b) Logical Block Address = Block#

Seek Time

- The seek time (also called access time) describes the **time taken to positionthe R/W heads across the platter** with a radial movement.
- In other words, it is the time taken to reposition and settle the arm and the headover the correct track.
    - The lower the seek time, the faster the I/O operation.
    - Disk vendors publish the following seek time specifications:
        - **Full Stroke:** The time taken by the R/W head to move across the **entire width of the disk,** from the innermost track to the outermost track.
        - **Average:** The average time taken by the R/W head to move from **one random track to anothe**r, normally listed as the time for one-third of a full stroke.
        - **Track-to-Track:** The time taken by the R/W head to move between **adjacent tracks**.
- Each of these specifications is measured in milliseconds.

Rotational Latency

- The time taken by the platter to rotate and position the data under the R/W head iscalled **rotational latency**.

- This latency depends on the rotation speed of the spindle and is measured in milliseconds.
- The rotational latency has more impact on the reading/writing of random sectors on the disk than on the same operations on adjacent sectors.

Data Transfer Rate

- The data transfer rate (also called transfer rate) refers to the average amount of data per unit time that the drive can deliver to the HBA.
- In a read operation, the data first moves from disk platters to R/W heads, and then it moves to the drive's internal buffer. Finally, data moves from the buffer through the interface to the host HBA.
- In a write operation, the data moves from the HBA to the internal buffer of the disk drive through the drive's interface. The data then moves from the buffer to the R/W heads. Finally, it moves from the R/W heads to the platters.
- The data transfer rates during the R/W operations are measured in terms of internal and external transfer rates, as shown in Figure 14.

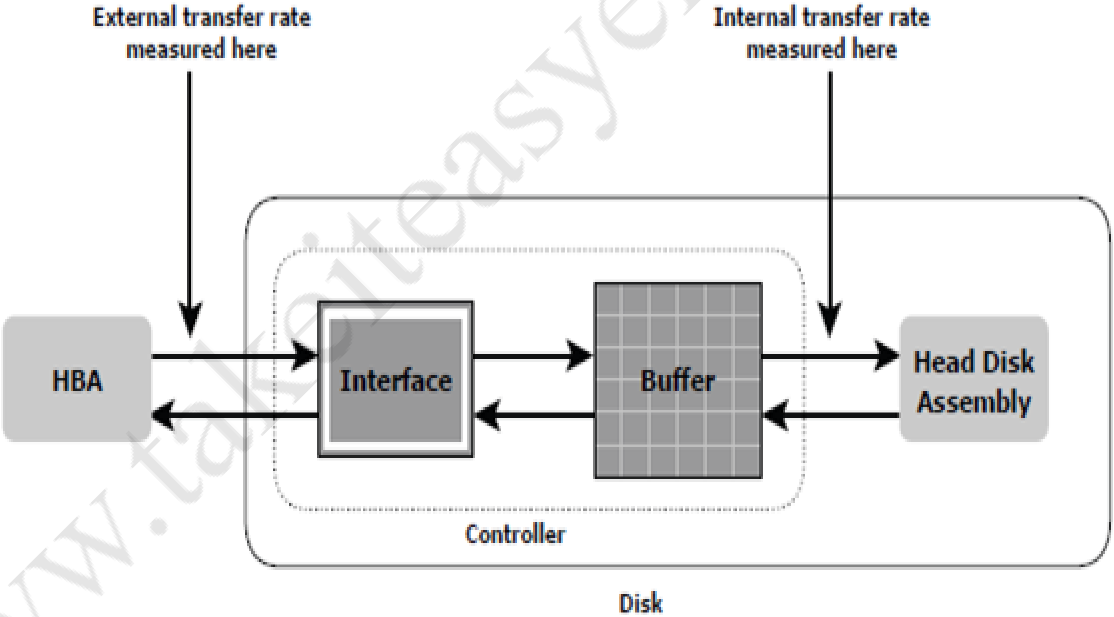


Figure 14: Data transfer rate

- **Internal transfer rate** is the speed at which data moves from a single track of aplatter's surface to internal buffer (cache) of the disk.
- **External transfer rate** is the rate at which data can be moved through the interface to

the HBA.

Logical Components of the Host

- The logical components of a host consist of the software applications and protocolsthat enable data communication with the user as well as the physical components.
- Following are the logical components of a host are:

- Operating system
- Device drivers
- Volume manager
- File system
- Application.

Operating System

- An operating system controls all aspects of the computing environment.
- It works between the application and physical components of the computer system.
- Services provided by operating system are:
  - It provides data access to the application.
  - It also monitors and responds to user actions and the environment.
  - It organizes and controls hardware components and manages the allocation ofhardware resources.
  - It provides basic security for the access and usage of all managed resources.
  - Performs basic storage management tasks while managing other underlying components, such as the file system, volume manager, and device drivers.

Device Driver

- A device driver is special software that permits the operating system to interact with a specific device, such as a printer, a mouse, or a hard drive.
- A device driver enables the operating system to recognize the device and to use a standard interface (provided as an application programming interface, or *API*) to access and control devices.
- Device drivers are hardware dependent and operating system specific.

Volume Manager

- In the early days, an HDD appeared to the operating system as a number of continuous disk blocks. The entire HDD would be allocated for the file system or other data entity used by the operating system or application.

- The disadvantage was **lack of flexibility**: As an HDD ran out of space, there was no easy way to extend the file system's size. As the storage capacity of the HDD increased, allocating the entire HDD for the file system often resulted in underutilization of storage capacity.
- **Disk partitioning** was introduced to improve the flexibility and utilization of HDDs.
- In partitioning, an HDD is divided into logical containers called **logical volumes** (LVs) (see Figure 15).
- For example, a large physical drive can be partitioned into multiple LVs to maintaindata according to the file system's and applications' requirements.
- The host's file system accesses the partitions without any knowledge of partitioningand the physical structure of the disk.

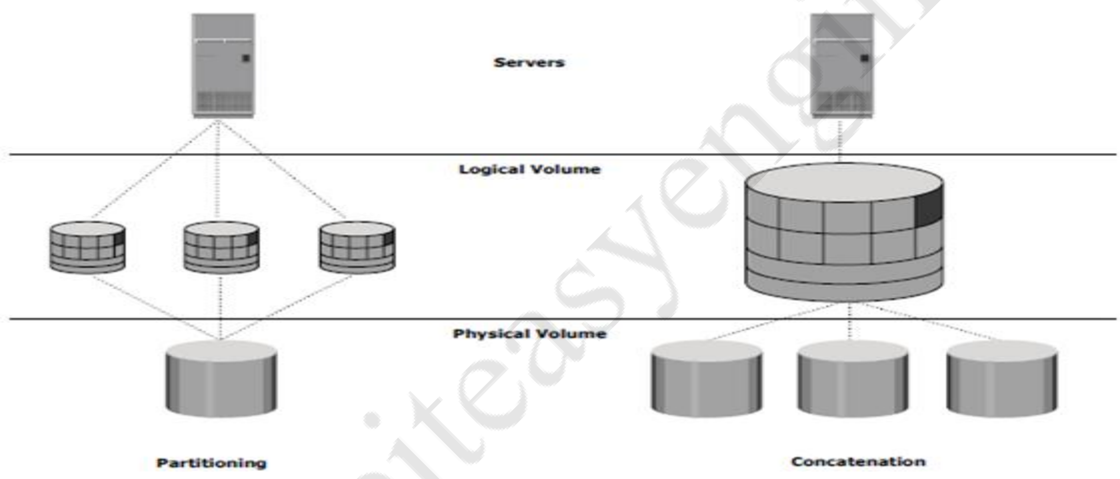


Figure 15: Disk partitioning and concatenation

Concatenation is the process of grouping several smaller physical drives andpresenting them to the host as one logical drive (see Figure 15).

The evolution of **Logical Volume Managers (LVMs)** enabled the dynamicextension of file system capacity and efficient storage management.

LVM is software that runs on the host computer and manages the logical andphysical storage.

LVM is an optional, intermediate layer between the file system and the physical disk.

It can aggregate several smaller disks to form a larger virtual disk or to partition a larger-capacity disk into virtual, smaller-capacity disks, which are then presented to applications.

- The LVM provides optimized storage access and simplifies storage resourcemanagement.
- The basic **LVM components** are:
  - **physical volumes**
  - **volume groups and**
  - **logical volumes.**
- In LVM terminology, each physical disk connected to the host system is a **physical volume (PV).**
- LVM converts the physical storage provided by the physical volumes to a logical view of storage, which is then used by the operating system and applications.
- A **volume group** is created by grouping together one or more physical volumes. A unique **physical volume identifier (PVID)** is assigned to each physical volume when it is initialized for use by the LVM.
- Physical volumes can be added or removed from a volume group dynamically.
- They cannot be shared between volume groups; the entire physical volume becomes part of a volume group.
- Each physical volume is partitioned into equal-sized data blocks called **physical extents** when the volume group is created.
- **Logical volumes** are created **within a given volume group**. A logical volume can be thought of as a virtual disk partition, while the volume group itself can be thought ofas a disk.
- A volume group can have a number of logical volumes.
- The logical volume appears as a physical device to the operating system.
- A file system can be created on a logical volume and logical volumes can be configured for optimal performance to the application and can be mirrored to provide enhanced data availability.

DIRECT-ATTACHED STORAGE

→ **Direct-Attached Storage (DAS)** is an architecture where storage connects directly to servers. Applications access data from DAS using block-level access protocols. The internal HDD of a host, tape libraries, and directly connected external HDD packs are some examples of DAS.

Types of DAS

DAS is classified as

1. **Internal**
2. **External**

Based on the location of the storage device with respect to the host.

Internal DAS

— In internal *DAS* architectures, the **storage device is internally connected to the host** bya serial or parallel bus.

— The physical bus has **distance limitations** and can only be sustained over a shorter distance for high-speed connectivity.

— Most internal buses can **support only a limited number of devices**, and they occupy a large amount of space inside the host, making maintenance of other components difficult.

External DAS

— In external DAS architectures, **the server connects directly to the external storage device** (see Figure 5-1). In most cases, communication between the host and the storage device takes place over SCSI or FC protocol.

— Compared to internal DAS, an external DAS overcomes the distance and device count limitations and provides centralized management of storage devices.

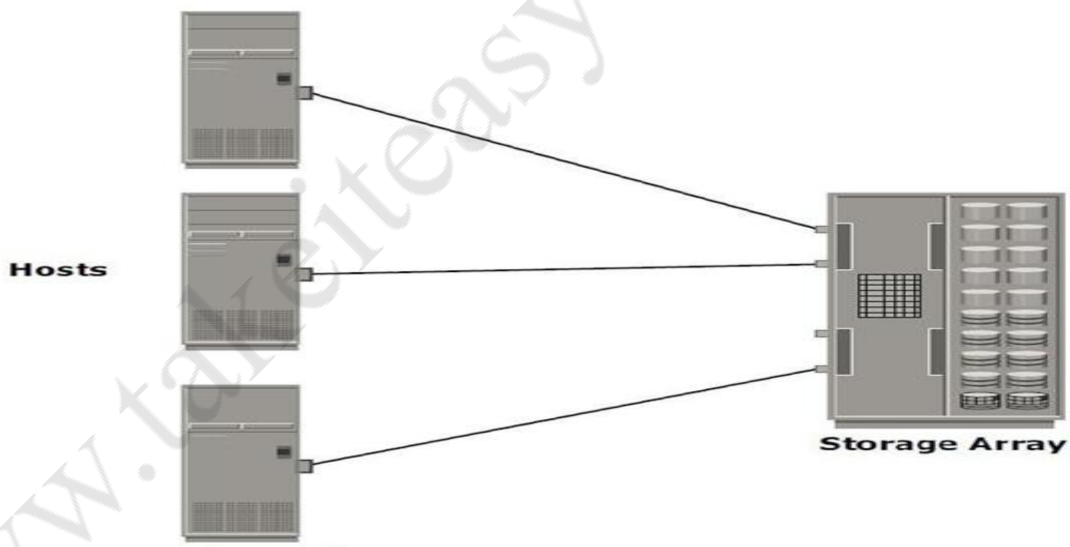


Figure : External DAS architecture

DAS Benefits and Limitations

❖ Benefits

→ DAS requires a **lower initial investment** than storage networking.

→ DAS configuration is **simple** and can be deployed easily and rapidly.

→ Setup is managed using host-based tools, such as the **host OS**, which makes **storage management** tasks easy for small and medium enterprises

→ DAS is the simplest solution when compared to other storage networking models and requires fewer management tasks, and less hardware and software elements to set up andoperate.

❖ Limitations

→ DAS does **not scale** well.

→ A storage device has a **limited number of ports**, which restricts the number of hosts thatcan directly connect to the storage.

→ A **limited bandwidth** in DAS restricts the available I/O processing capability.

→ When capacities are being reached, the service availability may be compromised, and this has a ripple effect on the performance of all hosts attached to that specific device or array.

→ The **distance limitations** associated with implementing DAS because of direct connectivity requirements can be addressed by using Fibre Channel connectivity.

→ DAS **does not make optimal use of resources** due to its limited ability to share front endports.

→ In DAS environments, unused resources cannot be easily re-allocated, resulting in islandsof **over-utilized and under-utilized storage pools**.

→ Disk utilization, throughput, and cache memory of a storage device, along with virtualmemory of a host govern the performance of DAS.

→ RAID-level configurations, storage controller protocols, and the efficiency of the bus areadditional factors that **affect the performance of DAS**.