Computer Architecture
6. External Storage

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Faculty of Information Security

Posts & Telecommunications Institute of Technology

Main topics

- Magnetic disks
  - FDD
  - HDD
- SSD
- Optical disks
  - CD
  - DVD
- RAID
- NAS
- SAN

Introduction to Magnetic Disks

- Magnetic Disks are storage mediums:
  - Non-volatile storage
  - Mass storage medium
  - Based on magnetic principles and use ferromagnetic material to cover disk surface to store the information
  - Usually in the form of plastic or metal disks
- Types of magnetic disks
  - Floppy Disks
  - Hard disks or fixed disks

Floppy Disks & Drives

$5^1/_2$ inches disk and drive
(1.2MB)

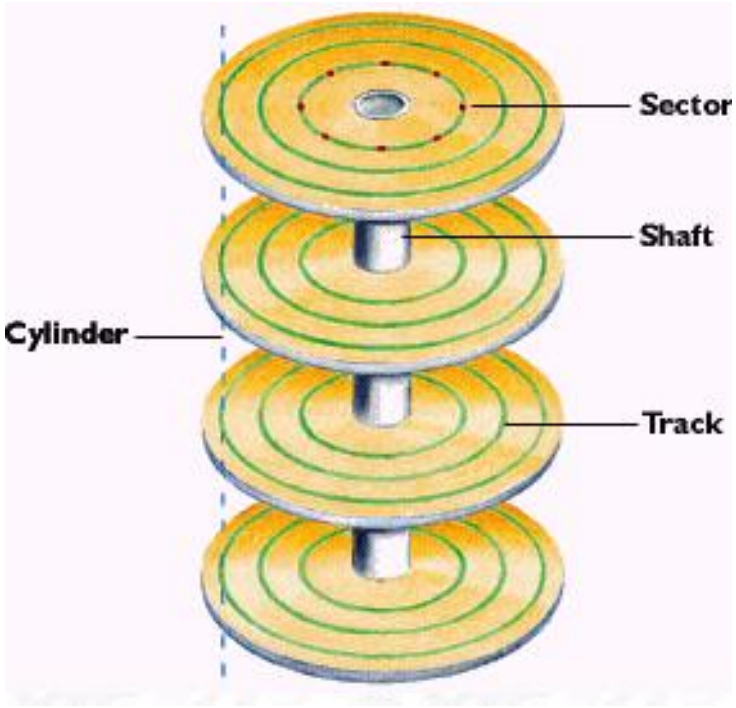
Floppy Disks & Drives

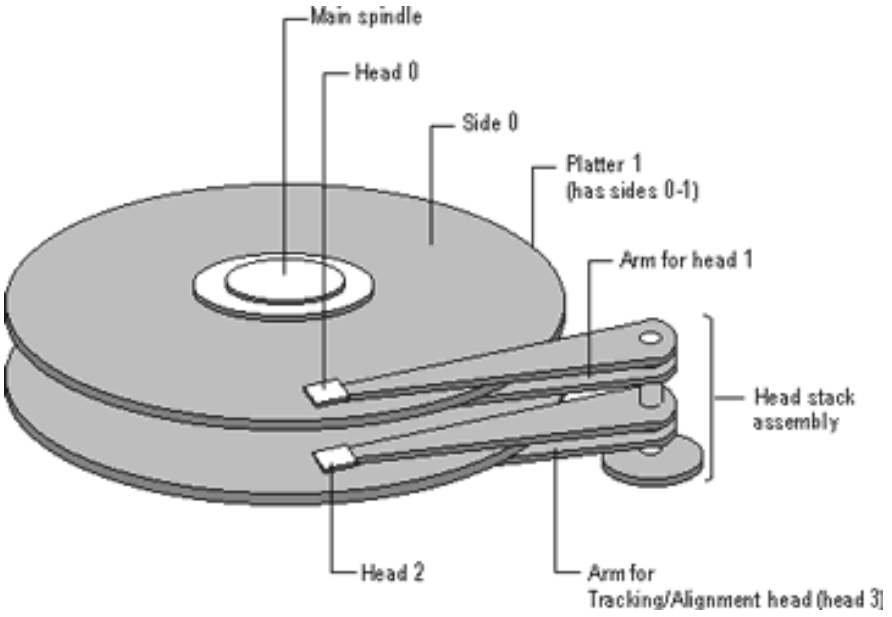
$3^1/_2$ inches disk and drive
(1.44MB)

HDD-Hard Disk Drives

HDD-Hard Disk Drives

HDD- Parameters





HDD- Elements

- Disks: a HDD may consist of several disks mounted on the same spindle:
  - A disk or a platter is usually made of aluminum or glass
  - The coated magnetic layer to store information is very thin, about 10-20nm.
    - Iron III oxide (Fe_2O_3) were used for old HDDs
    - Alloys of cobalt and iron are used in modern HDDs
  - One disk has 2 sides: side 0 and side 1

HDD- Elements

- Heads:
  - Are used for reading and writing information on disk surface
  - Not contact to but “fly” on disk surface
  - The number of heads is vary: 4, 8, 12, 16, 24, 32, 64, etc.
- Tracks:
  - Are circles on the disk surface.
  - Are numbered from outermost (0) to innermost.
  - There are thousands of tracks on the 3½ HDD surface.

HDD- Elements - Heads

HDD- Elements

- Sectors:
  - A sector is a part of a track
  - The common sector capacity is 512 bytes
  - Sector is the smallest management unit on HDDs.
- Cylinders:
  - A cylinder consists of a set of tracks that start at the same head position on the disk.
- HDD important parameters to calculate the capacity:
  - Number of cylinders (C)
  - Number of heads (H)
  - Number of sectors per track (S)

  HDD capacity = C x H x S x 512 (bytes)

HDD Interconnect Interfaces

- The most common types of HDD Interconnect Interfaces are:
  - Parallel ATA (PATA or IDE/EIDE - Integrated Drive Electronics) – Advanced Technology Attachments
  - Serial ATA (SATA)
  - SCSI – Small Computer System Interface (pronounce as scuzzy /skʌzi/)
  - Serial Attached SCSI (SAS)
  - iSCSI – Internet SCSI

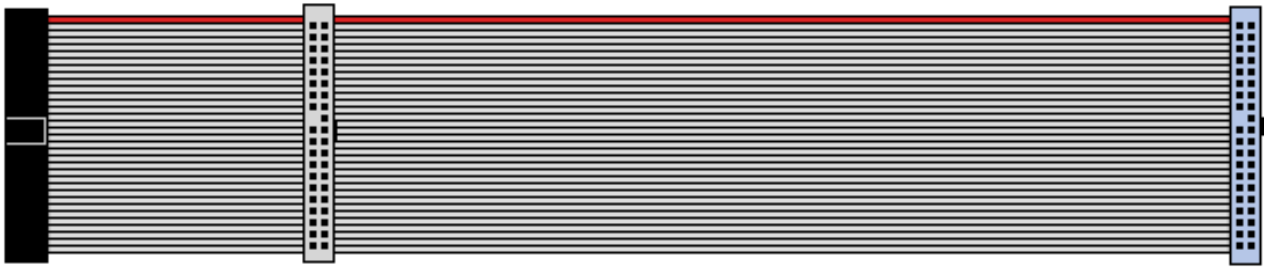
HDD-ATA/PATA/IDE/EIDE

- Use 40/80 pin cables to connect HDD to motherboard.
- One cable supports 2 drives:
  - One is the master (set by jumper)
  - The other one is slave (set by jumper)
- Data transfer speed:
  - Bandwidth: 16 bits
  - 16, 33, 66, 100 and 133MB/s.

HDD-ATA/PATA/IDE/EIDE

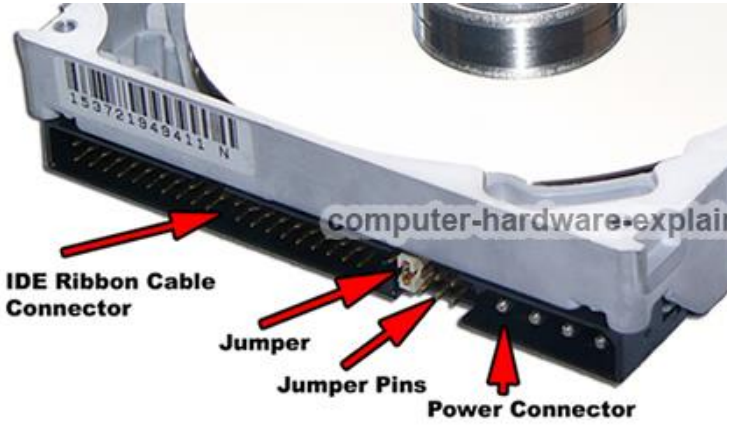
IDE plug

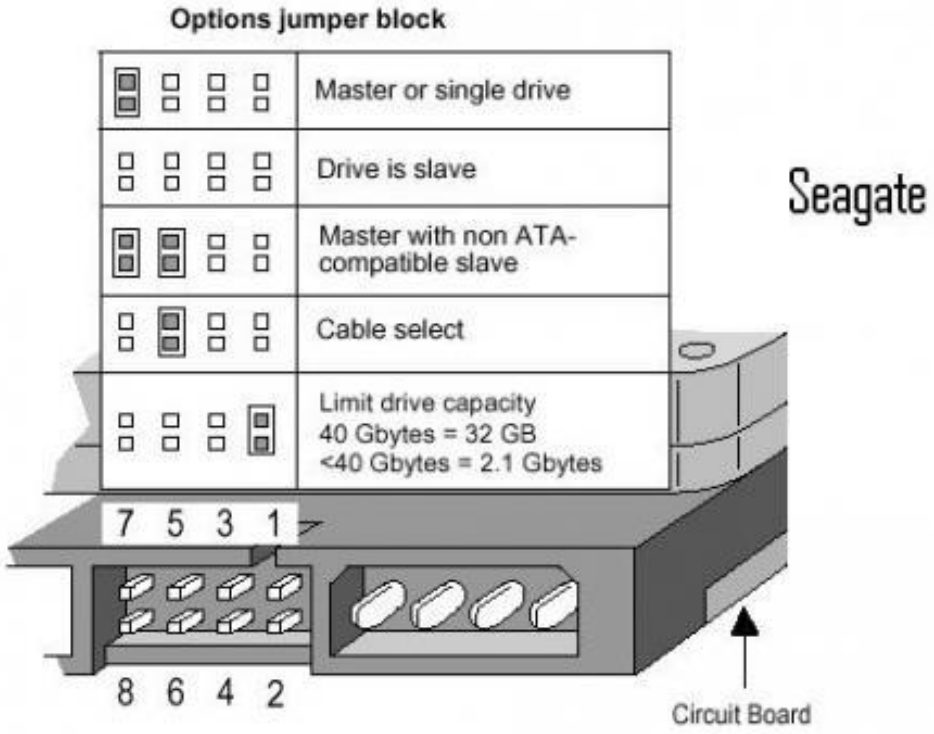
IDE sockets



IDE cable

HDD-ATA/PATA/IDE/EIDE



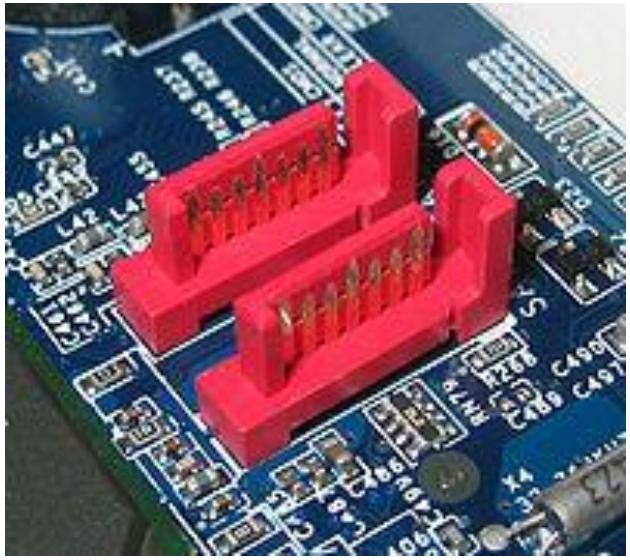


IDE HDD jumpers & setup jumpers

HDD-SATA

- SATA uses the same low-level commands as IDE, but SATA uses high-speed serial cable over two pairs of conductors.
- SATA controllers use the AHCI (Advanced Host Controller Interface)
- SATA offers more advanced features over IDE:
  - Faster and more efficient data transfer
  - Hot swapping (or hot plug)
  - Less number of cable wires
- SATA data transfer speed:
  - 1st generation: 1.5 Gb/s
  - 2nd generation: 3.0 Gb/s
  - 3rd generation: 6.0 Gb/s

HDD-SATA



SATA sockets

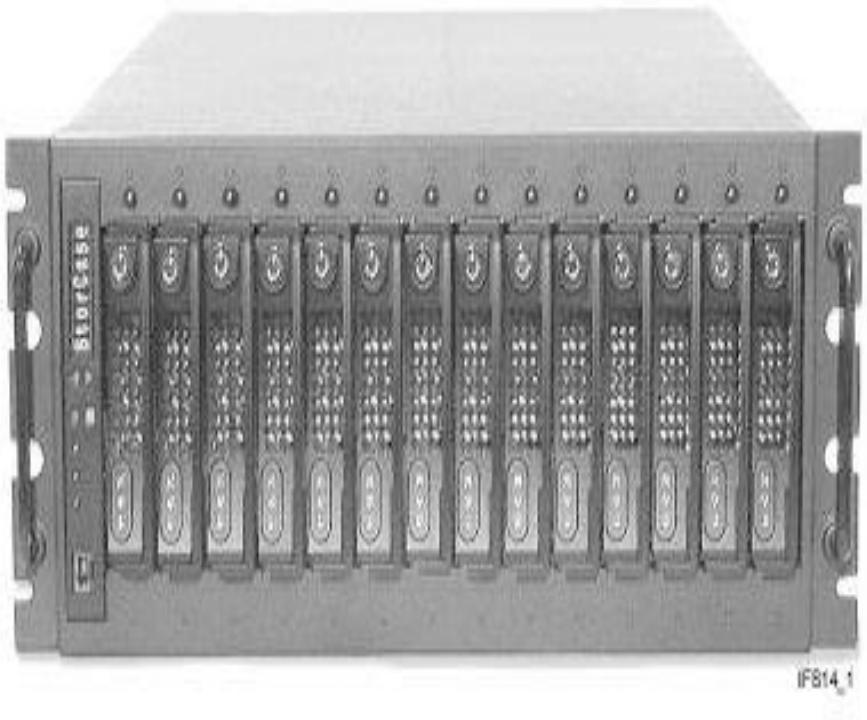
SATA data plug

SATA power plug

HDD - SCSI

- SCSI is is a set of standards for physically connecting and transferring data between computers and peripheral devices.
- Every device attaches to the SCSI bus in a similar manner; Up to 8 or 16 devices can be attached to a single bus.
- SCSI advanced features:
  - Very fast and stable data transfer
  - Hot swapping (or hot plug)
- SCSI data transfer speed: 5, 10, 20, 40MB/s (old SCSI) and 160, 320 and 640 MB/s.
- SCSI HDDs are usually expensive and used for servers and high-speed storage systems, such as RAID, NAS and SAN.

HDD - SCSI



Server rack for SCSI HDDs

HDD Format Levels

- There are 2 HDD format levels:
  - Low-level format:
    - Implement by system BIOS
    - Is the process of assigning ID for physical sectors
    - A HDD must be low-level formatted before it can be used (proceed with high-level format)
    - Modern HDDs are usually low-level formatted by manufacturers.
  - High-level format:
    - Implement by Operating System (OS)
    - Is the process of assigning ID for logical sectors and creating the file system.
    - A HDD must also be high-level formatted before it can be used to store information.

HDD Partitions

- A physical HDD can be divided into several parts for better use and management. Each part is called a partition.
  - One *primary partition*
  - One or more *extended partitions*
- One partition can be divided into one or more logical drives.
  - Primary partition can host only one logical drive
  - Extended partition can host one or more logical drives

HDD Partition Table

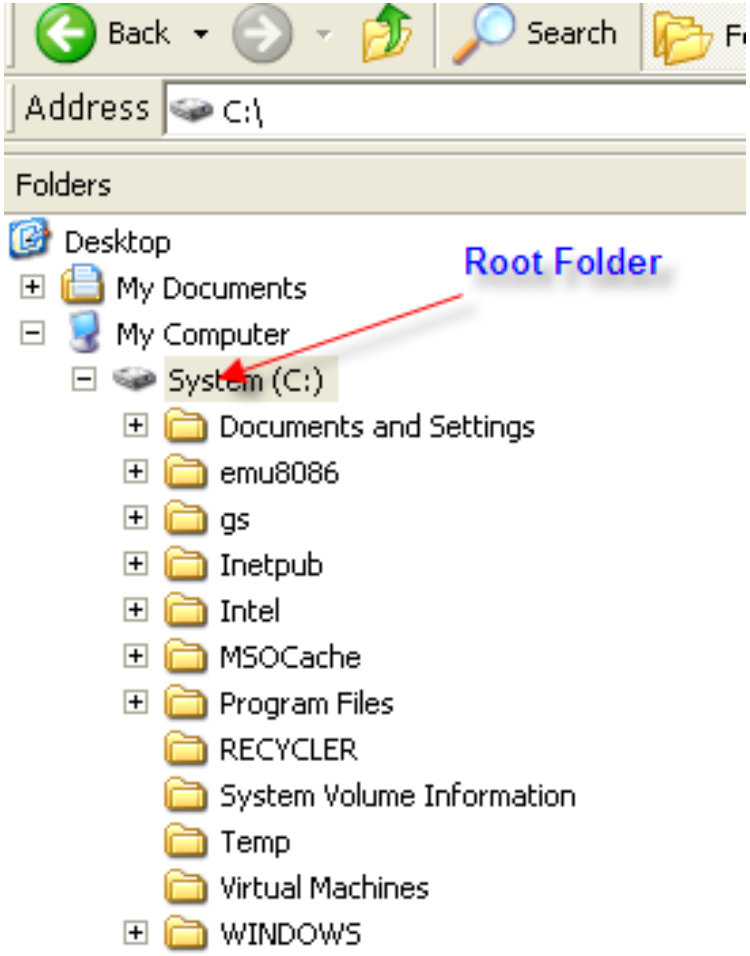
- Stores information about HDD partitions. The table has several records and one record for one partition:
  - The partition is active or not;
  - The Cylinder, Head and Sector of the start point of the partition;
  - The Cylinder, Head and Sector of the end point of the partition;
  - Format type of the partition (FAT, NTFS, EXT)
  - Size of the partition in number of sectors.

HDD Boot sector, File System

- Boot sector:
  - Is the 1st sector of the logical drive
  - Stores the Bootstrap loader which is a small program to trigger the loading of OS from HDD into internal memory.
- File System (FS):
  - Is a type of directories to manage files on disks
  - There are some FS depending on Operating Systems:
    - FAT (DOS, Windows 3.x, Windows 95, 98, ME)
    - NTFS (Windows NT, 2000, XP, 2003, Vista, 7, 8)
    - Ext2, Ext3, Ext4 (Unix, Linux)
    - MFS (Macintosh FS)/HFS (Hierarchical FS) (Mac OS)

HDD - Root Directory

- Root directory/folder is the lowest-level folder of the folder tree in a logical drive.
- Root folder doesn't have parent folder like other folders
- Like other folders, root folder can have its child folders and files.



SSD (Solid-State Drive)

- SSD is a type of drives that allow to store information for a long time (stored information exists without power supply);
- SSD uses solid-state flash memory chips to store data (similar to USB flash);
- SSDs are designed to replace HDDs to store large volume of information with following pros:
  - Higher accessing speed
  - Less power consumption
  - Smaller/more compact in size/weight.

SSD - Introduction

- SSD characteristics:
  - No metal disks are used and no mechanical structures are necessary for read/write operation.
  - Includes a flash controller and non-volatile NAND flash chips.
- SSDs use similar HDD interconnection interfaces, such as SATA and PCIe.

SSD - Introduction

The outer and inner case of an SSD

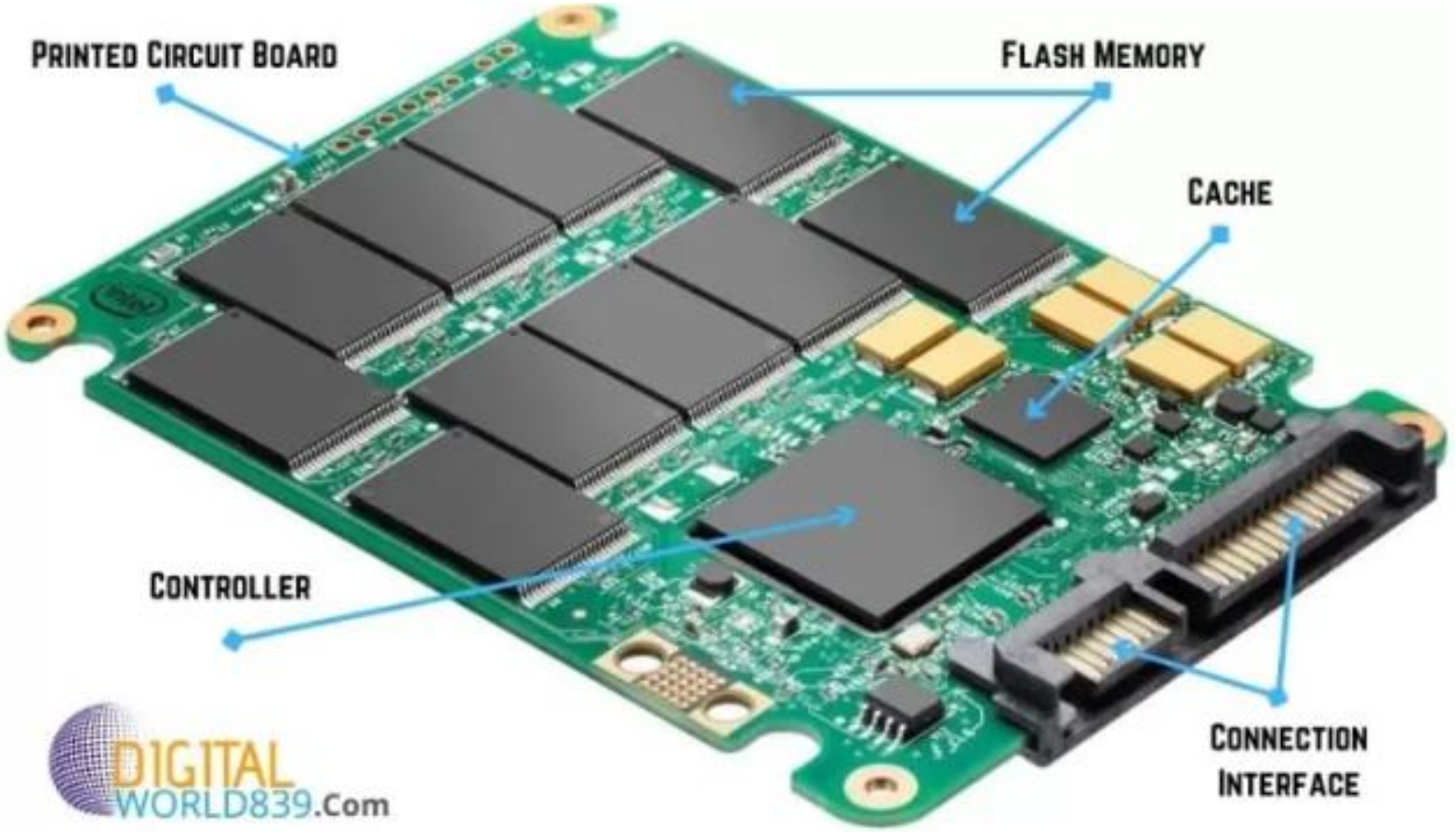
SSD – Pros and Cons

- Pros:
  - Faster read/write speed than HDDs
  - No mechanical structures are so:
    - Less power comsumption
    - No noise
    - Better resistance against mechanical and thermal shocks.
- Cons:
  - More expensive: SSD is generally more expensive than HDD with same capacity;
  - Shorter life because SSD life depends on the number of read/write cycles of the memory circuit;
  - Difficult to recover data when memory chip fails.

SSD – Some Interconnect Interfaces

- SAS (Serial Attached SCSI) - 12Gb/s
- SATA - 6Gb/s
- PCIe (PCI express)
- M.2 - 6Gb/s
- U.2: equivalent to PCIe 3.0 x 4
- USB
- Optical interconnect - 128 Gb/s.

SSD components



SSD components

- SSD components include:
  - Flash memory: usually includes non-volatile memory NAND chips to store data;
  - Controller: a dedicated controller to control read/write memory chips and connect to the system bus;
  - Cache: cache memory used to temporarily store data in communication with flash memory chips;
  - Connection interface: communicate with the system (power supply and connection to the system bus).

SSD Types

- SATA SSD

- M2 SATA SSD

SSD Types

- mSATA SSD (mini SATA SSD)

- M.2 PCI-E SSD

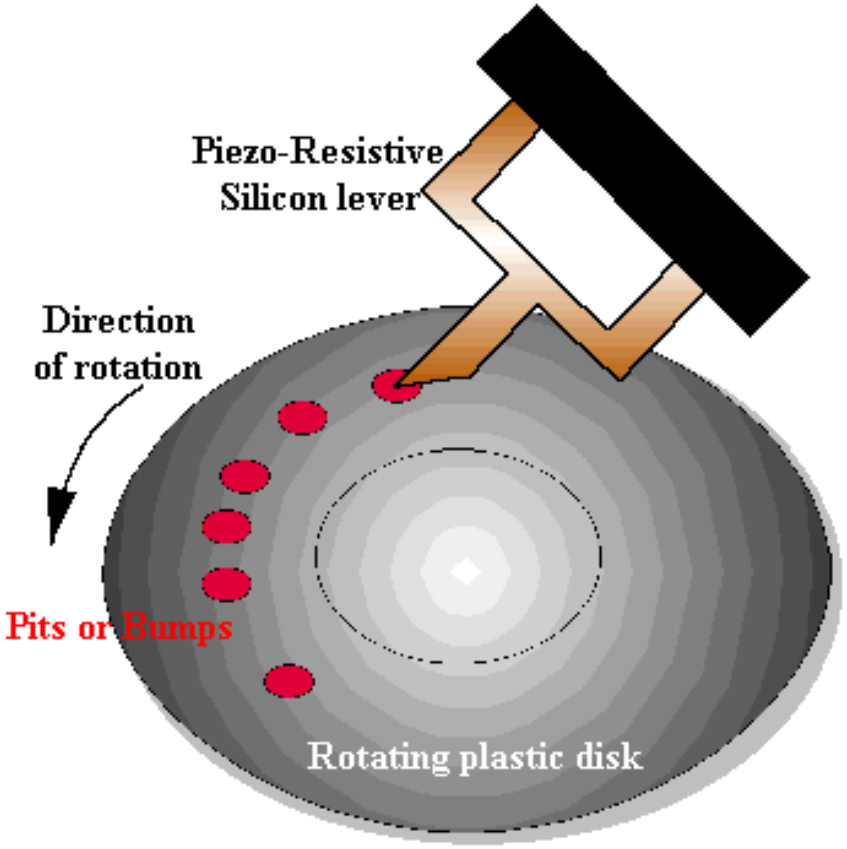
SSD Types

- M.2 NVMe SSD - up to 5 times faster than SATA SSD

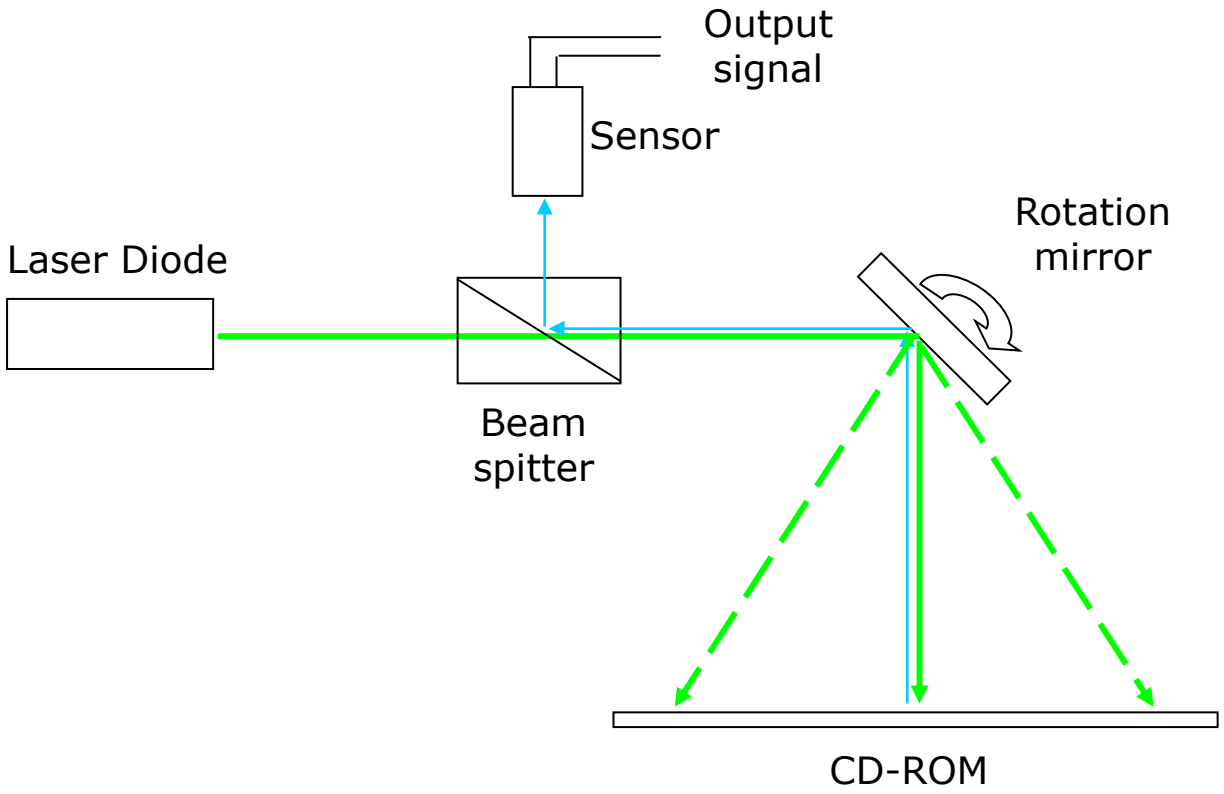
Introduction to Optical Disks

- Optical Disks operate based on optical principles:
  - A disk is made of polycarbonate plastic
  - A very thin layer of aluminium is placed at one side of the disk for laser beam reflection
  - The patterns of pits and lands represent the information stored.
- How CD-ROMs are created:
  - A master copy of the CD-ROM is created
  - Use the master copy to make multiple copies by “stamping” the blank CDs.

Optical Disks – Storing Information



CD-ROM – Info Reading Principle



CD-ROM – Info Reading Principle

- Laser beam from laser diode goes through a beam splitter and then to a rotation mirror;
- The rotation mirror controlled by the read signal makes the beam point to the expected reading position on the CD;
- The strength of reflective beam represented the CD surface pattern comes back to the rotation mirror;
- The rotation mirror forwards the reflective beam to the beam splitter and then to a sensor.
- The sensor converts the reflective beam strength to output signal.

Types of Optical Disks

- CD (Compact Disk)
  - CD-ROM: Read Only CD
  - CD-R: Recordable CD
  - CD-RW: Rewritable CD
- DVD (Digital Video Disk)
  - DVD-ROM: Read Only DVD
  - DVD-R: Recordable DVD
  - DVD-RW: Rewritable DVD
  - HD-DVD: High-density DVD
  - Blu-ray DVD: Ultra-high density DVD

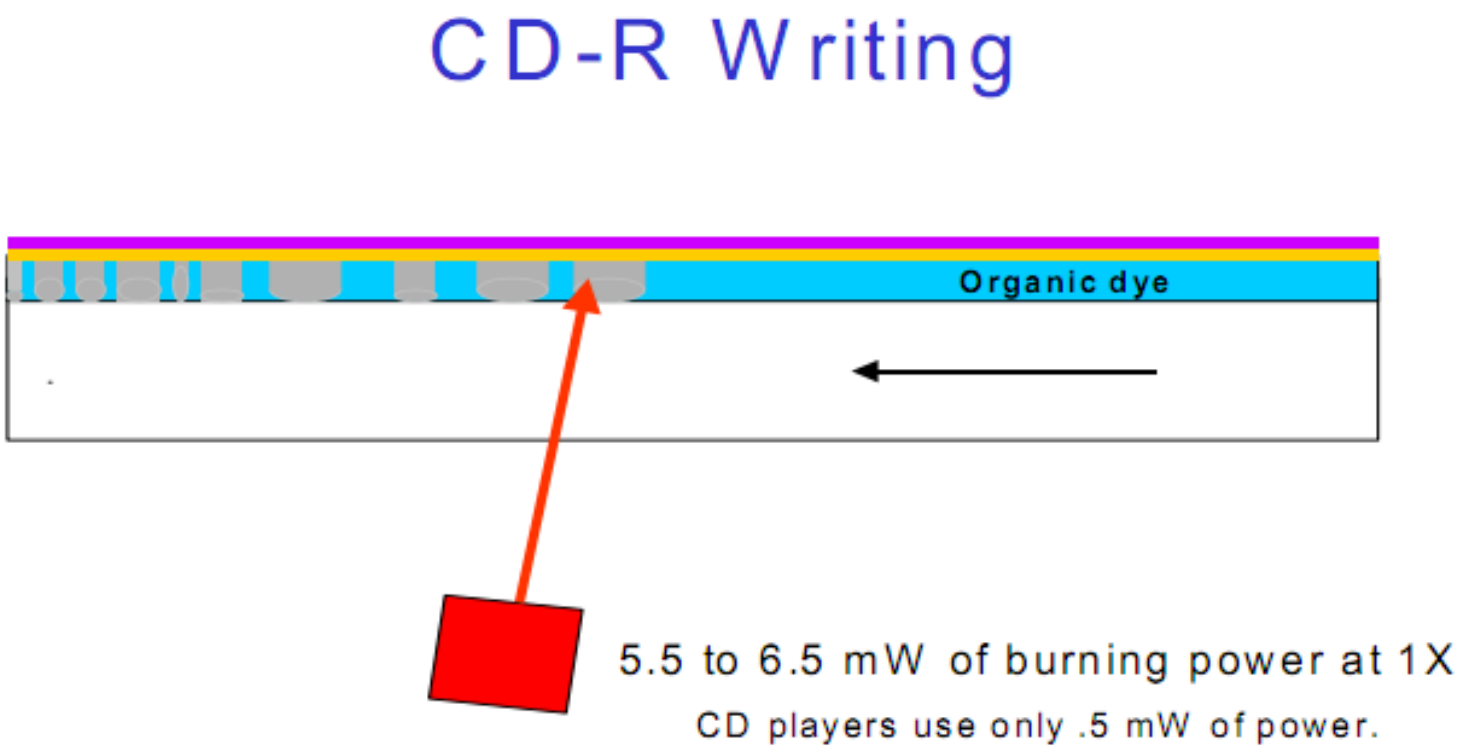
Compact Disks

- Max capacity is about 700MB (80mins audio)
- Use infrared laser at 780nm wave length
- Data transfer speed:
  - Base speed: 150KB/s
  - Real speed: multiply ratio x base speed
    - 4 x = 4 x 150KB/s = 600 KB/s
    - 50 x = 50 x 150 = 7500 KB/s

CD-Recordable

- CD-R is similar to CD-ROM
- The differences are:
  - There is one more layer called “organic dye” between the plastic and the reflective layer
  - The modulation laser beam is used to “burn” the “organic dye” to create pits and lands to represent the stored information.
  - CD-R can only be written once.

CD-Recordable



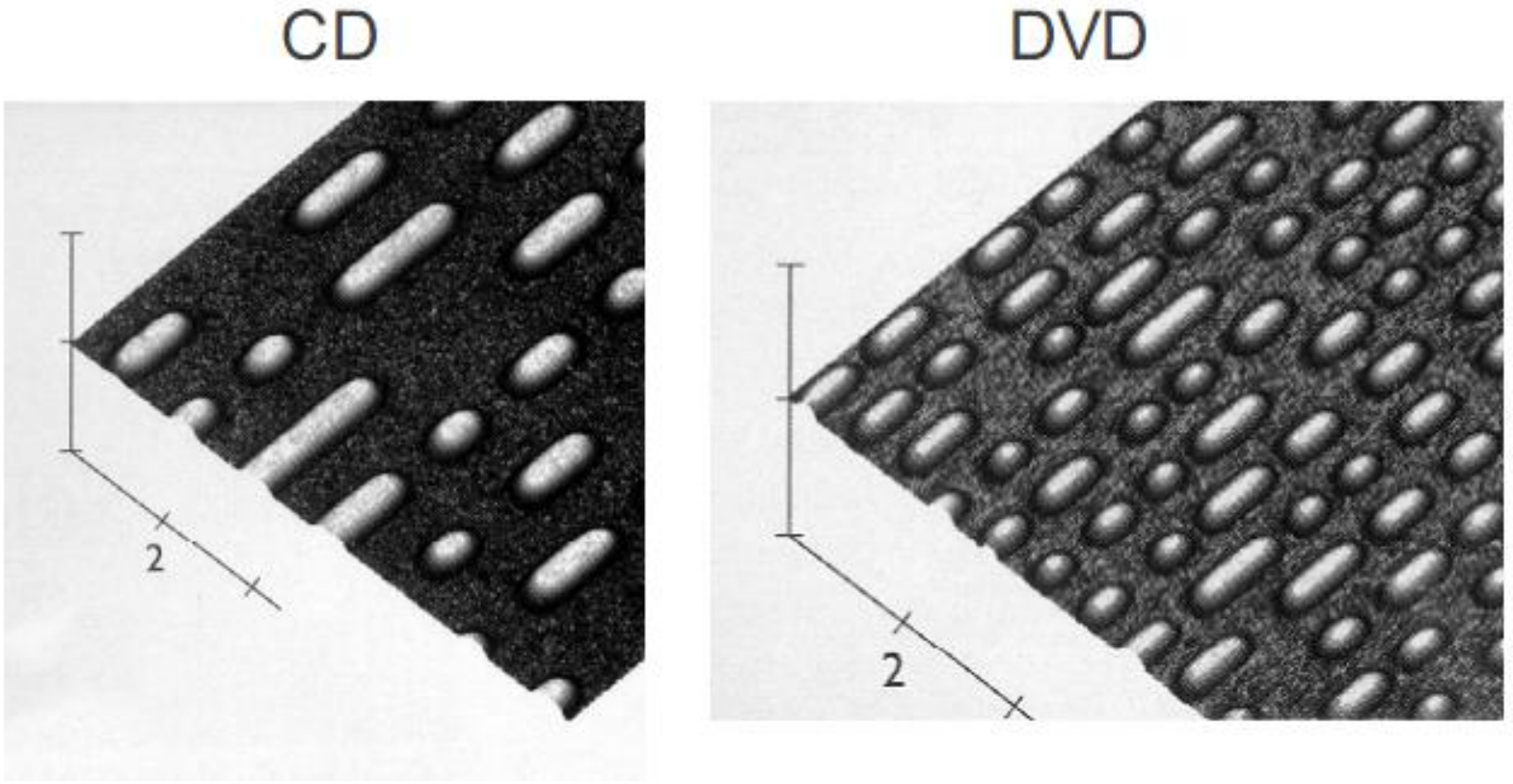
CD-Rewritable

- CD-RW is similar to CD-R
- The differences are:
  - The “organic dye” is replaced by a semi-metal alloy vacuum.
  - The semi-metal alloy layer can be burn again up to 1000 times (by theory).

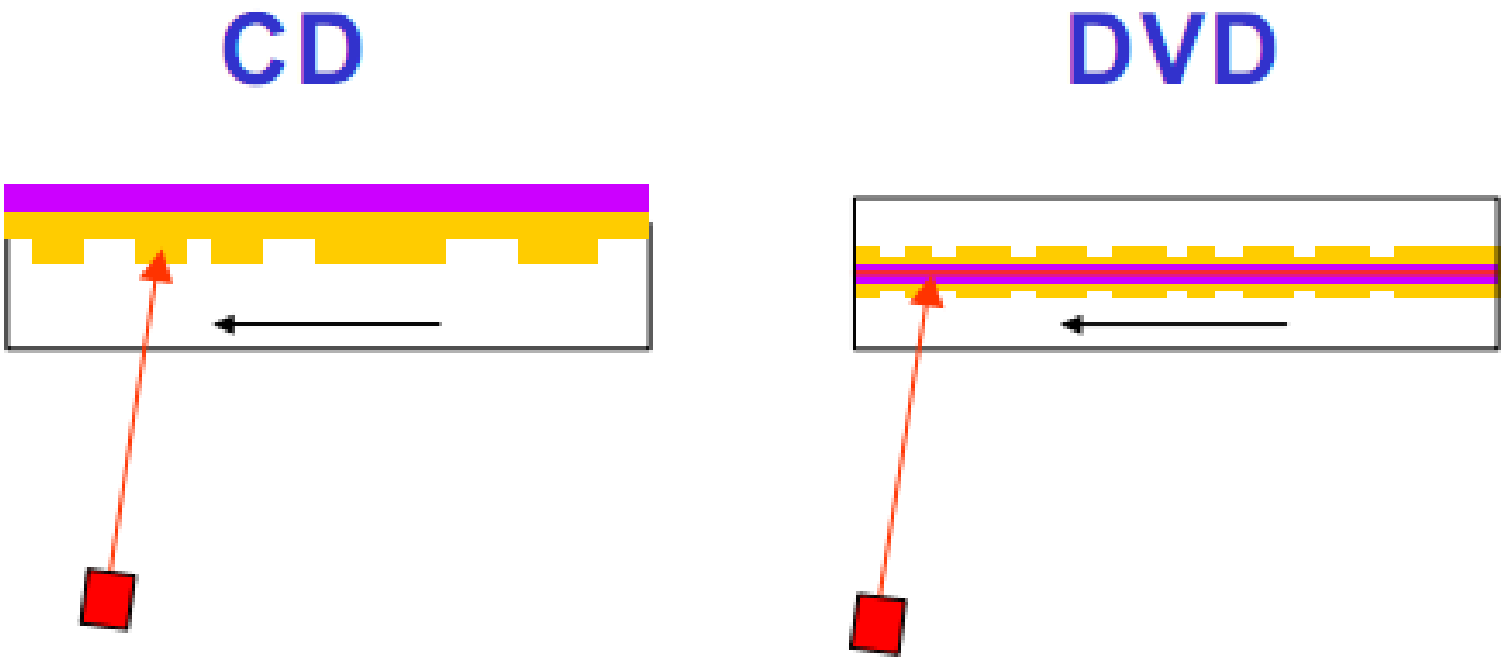
DVD

- Max capacity is about 4.7GB for single layer and 8.5GB for double layers.
- Use infrared laser at 650nm wave length
- Data transfer speed:
  - Base speed: 1350KB/s
  - Real speed: multiply ratio x base speed
    - 4 x = 4 x 1350KB/s = 540 KB/s
    - 16 x = 16 x 1350KB/s = 21600 KB/s

CD vs. DVD in Density



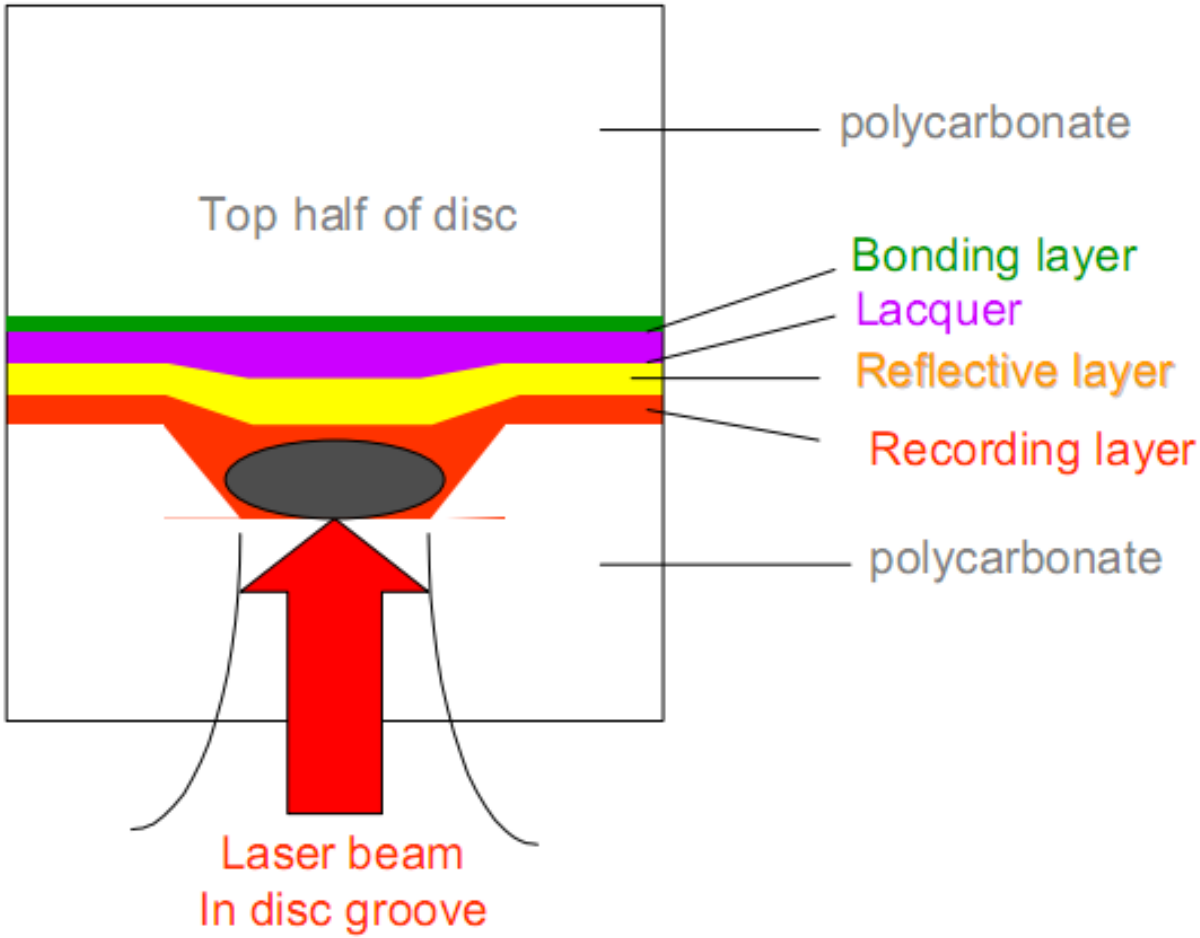
CD vs. DVD in Density



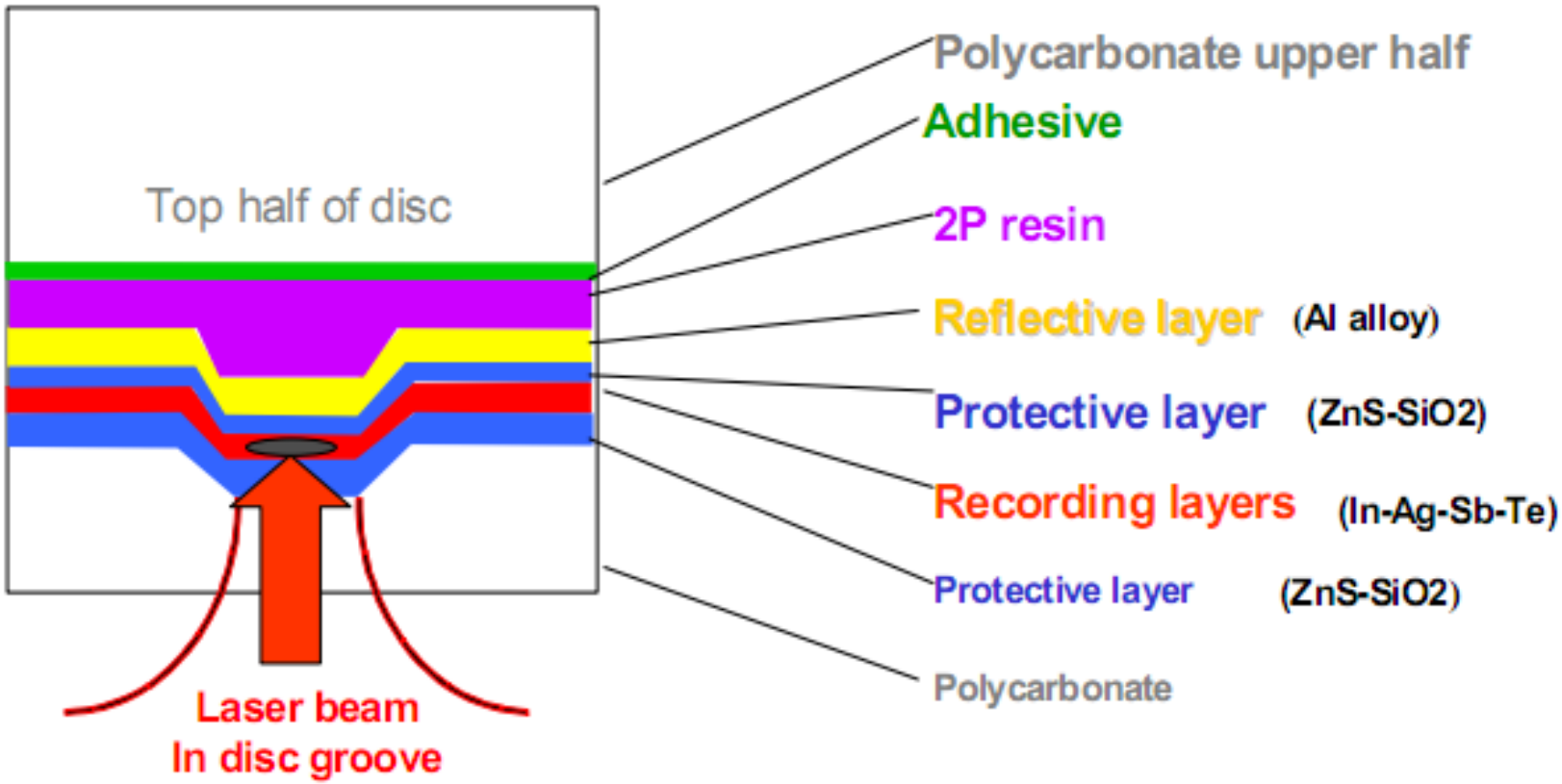
DVD-R, RW, HD and Blu-ray DVD

- DVD-R is similar to CD-R, but the laser wave length is shorter (650nm).
- DVD-RW is similar to CD-RW, but the laser wave length is shorter (650nm).
- HD DVD (High-Definition/Density DVD) was invented by Toshiba:
  - Use blue laser with shorter wave length
  - Capacity: 15GB one layer, 30GB dual layer
  - Stopped from Feb 2008.
- Blu-ray disc: invented by Sony
  - Use laser with 405nm wave length
  - 25GB one layer, 50GB dual layer

DVD-R Disk Structure



DVD-RW Disk Structure



Introduction to RAID

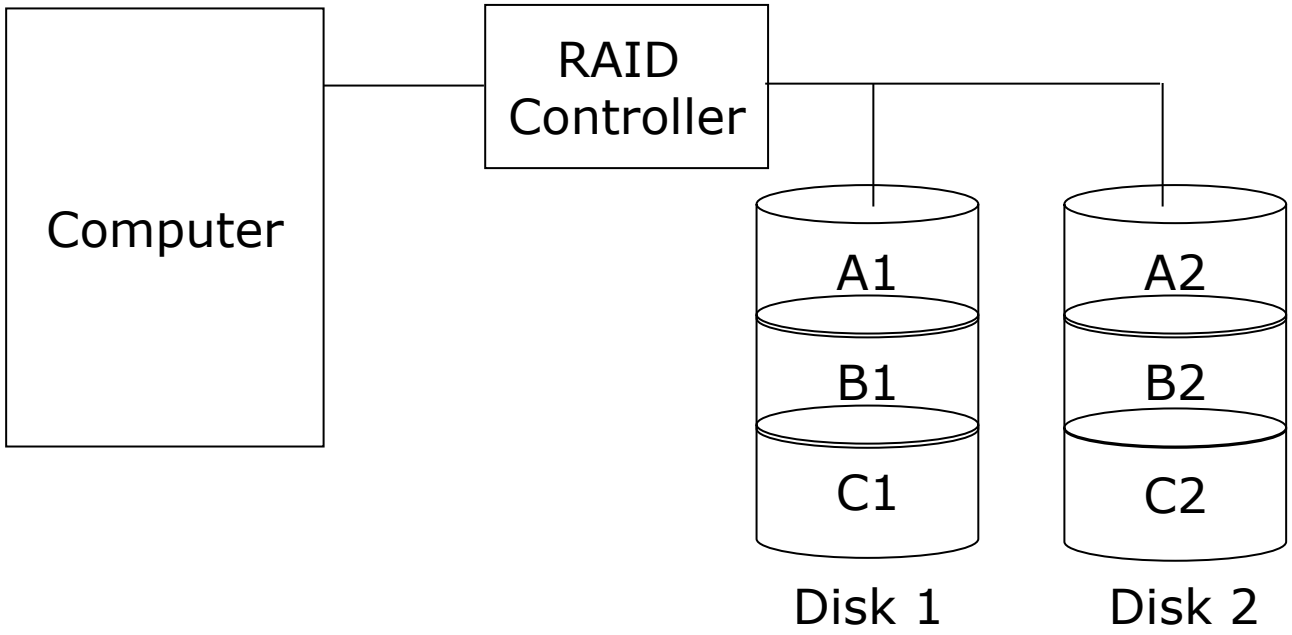
- RAID (Redundant Array of Independent Disks) is an advanced storage technology which aims at the following purposes:
  - High performance / speed
  - High reliability
  - Large volume
- RAID is an array of HDDs

RAID Techniques

- Two basic techniques are used in RAIDs:
  - Disk striping
    - Data are divided into blocks and each block is written into a separate disk in parallel;
    - Then blocks of data can be read from HDDs in parallel.

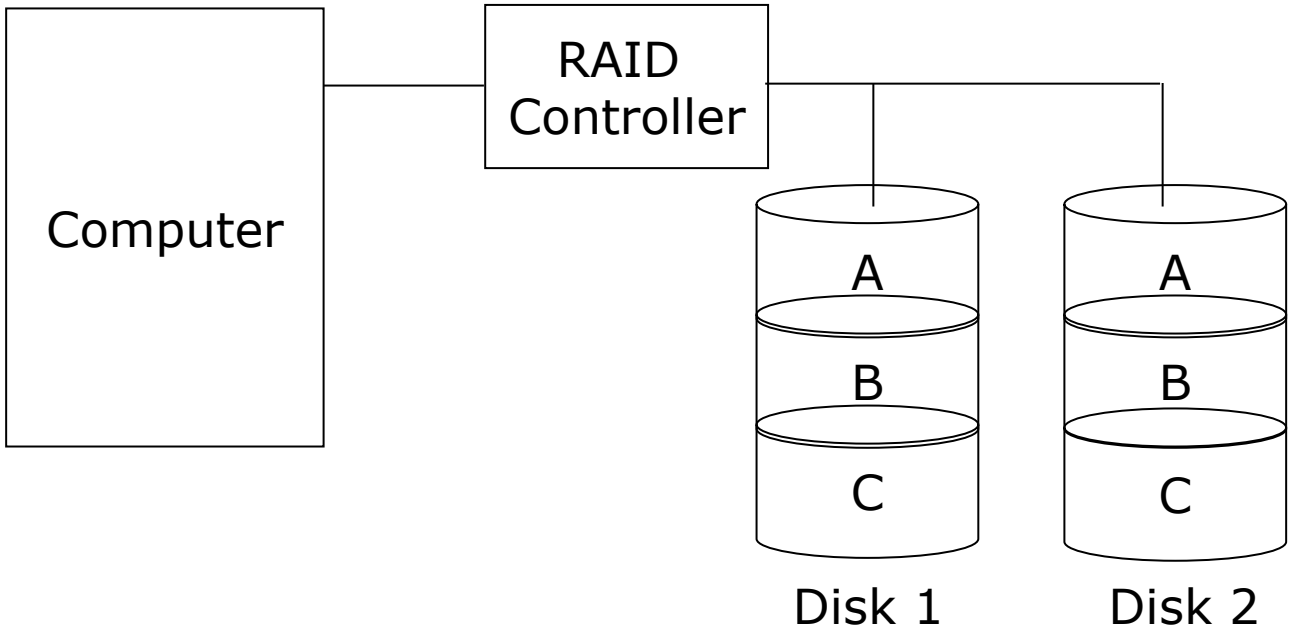
    ===> access speed is improved.
  - Disk mirroring
    - Data are divided into blocks and each block is written into a number of physical disks;
    - At any time, there are more than one copy of the data available ==> reliability is improved.

RAID- Disk Striping Technique



Disk striping technique

RAID- Disk Mirroring Technique

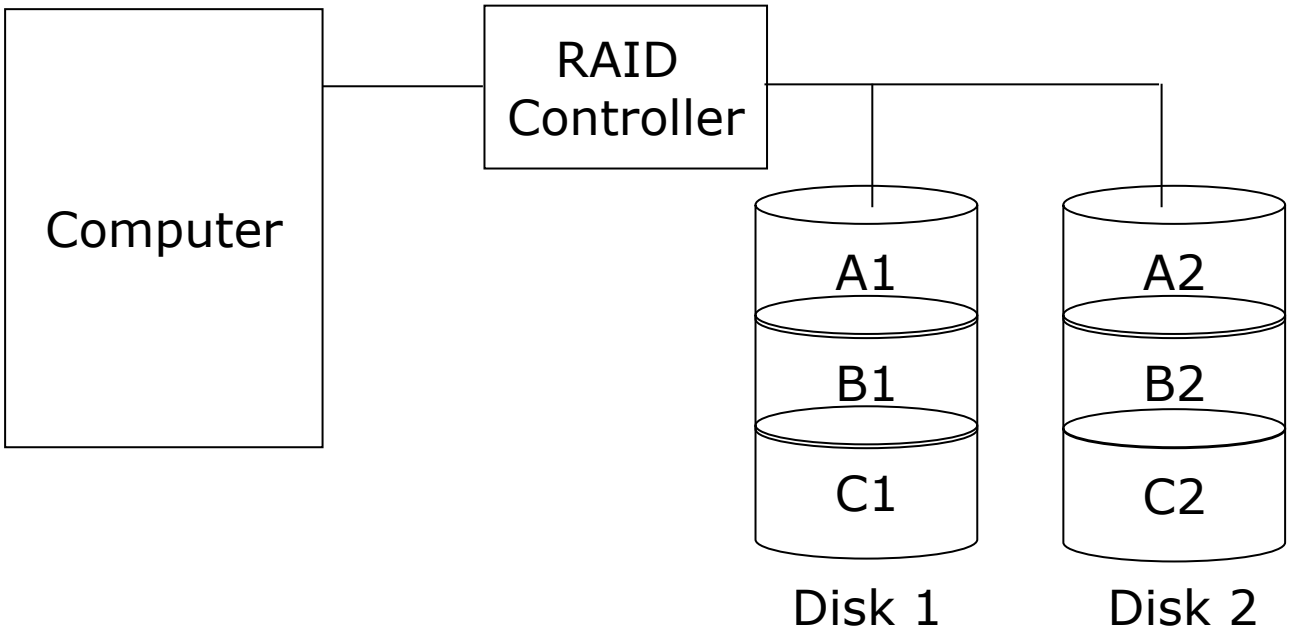


Disk mirroring technique

Types of RAIDs

- There are several types of RAIDs. Most common RAID types are:
  - RAID 0
  - RAID 1
  - RAID 10
  - RAID 01
  - RAID 2
  - RAID 3
  - RAID 4
  - RAID 5
  - RAID 6

RAID 0 – Disk Striping

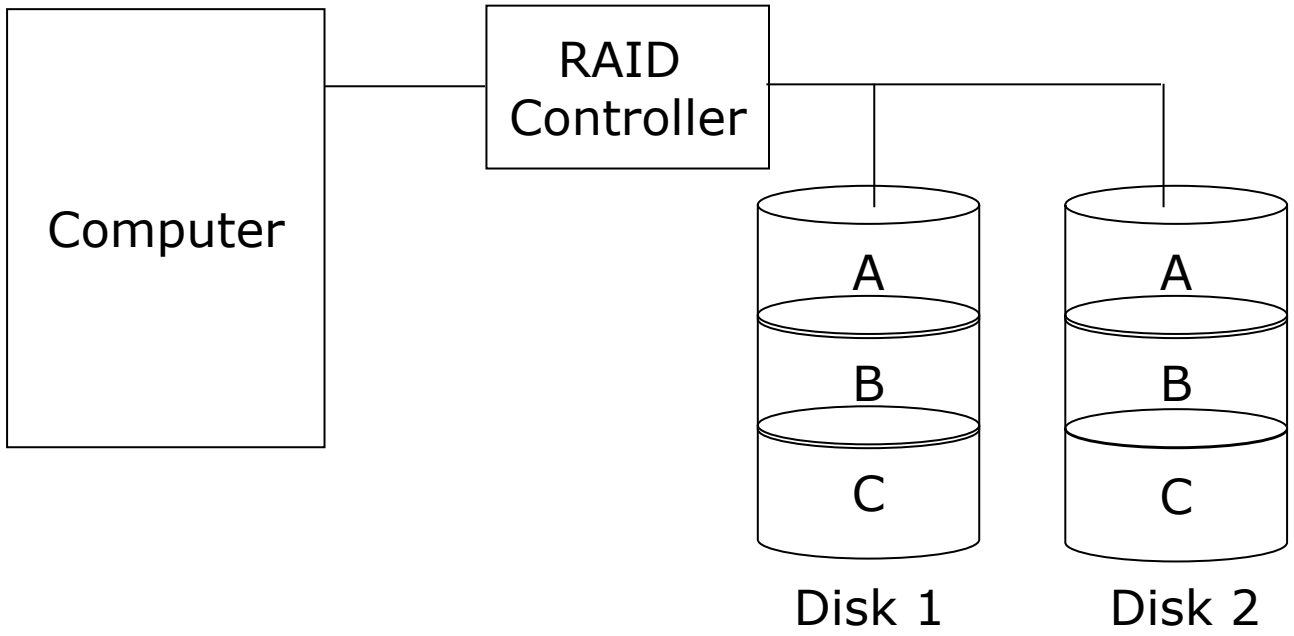


RAID 0 - Disk striping

RAID 0 – Disk Striping

- Characteristics:
  - Minimum 2 HDDs are required
  - Based on disk stripping technique (parallel writing/reading)
- Pros:
  - Faster than a single disk
  - Capacity is the total capacity of all disks
- Cons:
  - Reliability is the same as a single disk

RAID 1 – Disk Mirroring

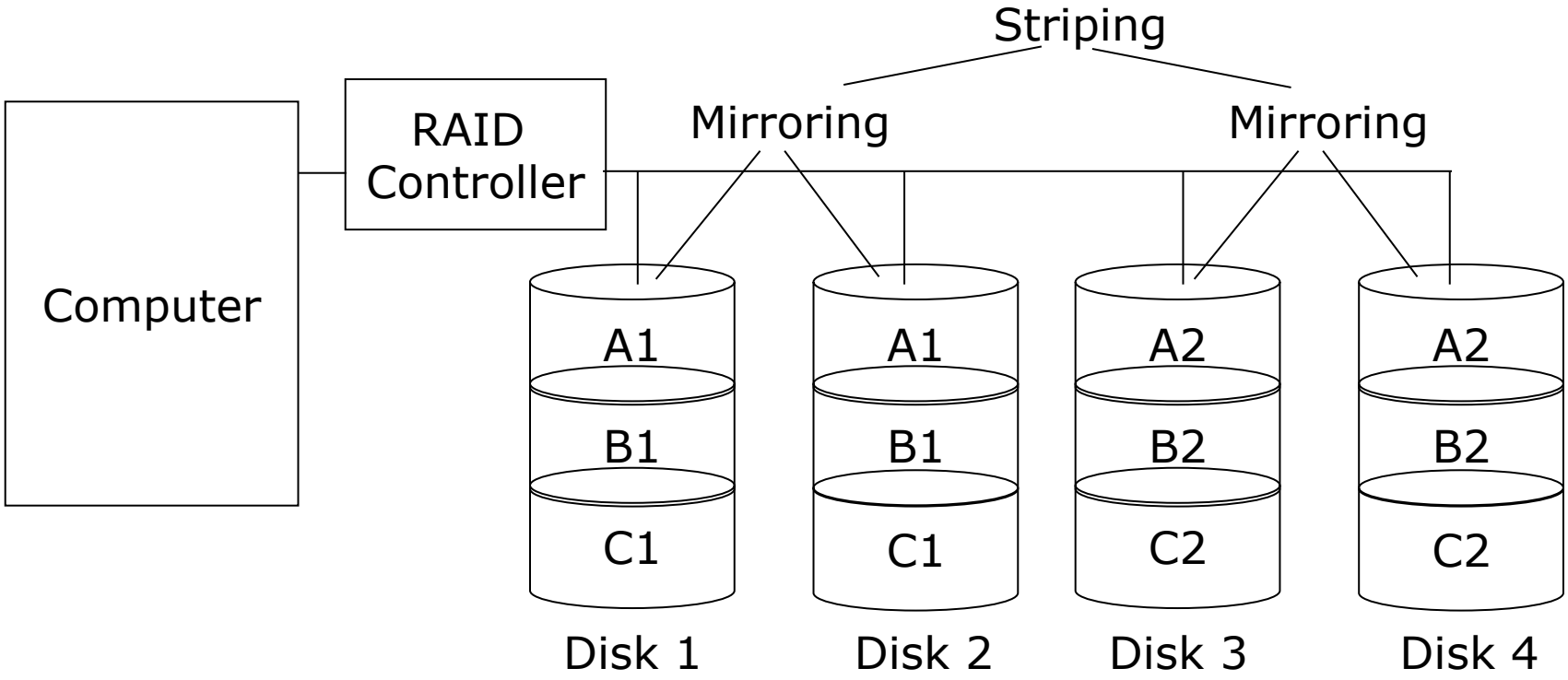


RAID 1 - Disk mirroring

RAID 1 – Disk Mirroring

- Characteristics:
  - Minimum 2 HDDs are required
  - Based on disk mirroring technique (multiple copies)
- Pros:
  - More reliable than a single disk
- Cons:
  - Capacity is the same as a single disk
  - Speed is the same as a single disk

RAID 10 – Disk Mirroring & Striping



RAID 10 - Disk mirroring & striping

RAID 10 – Mirroring & Striping

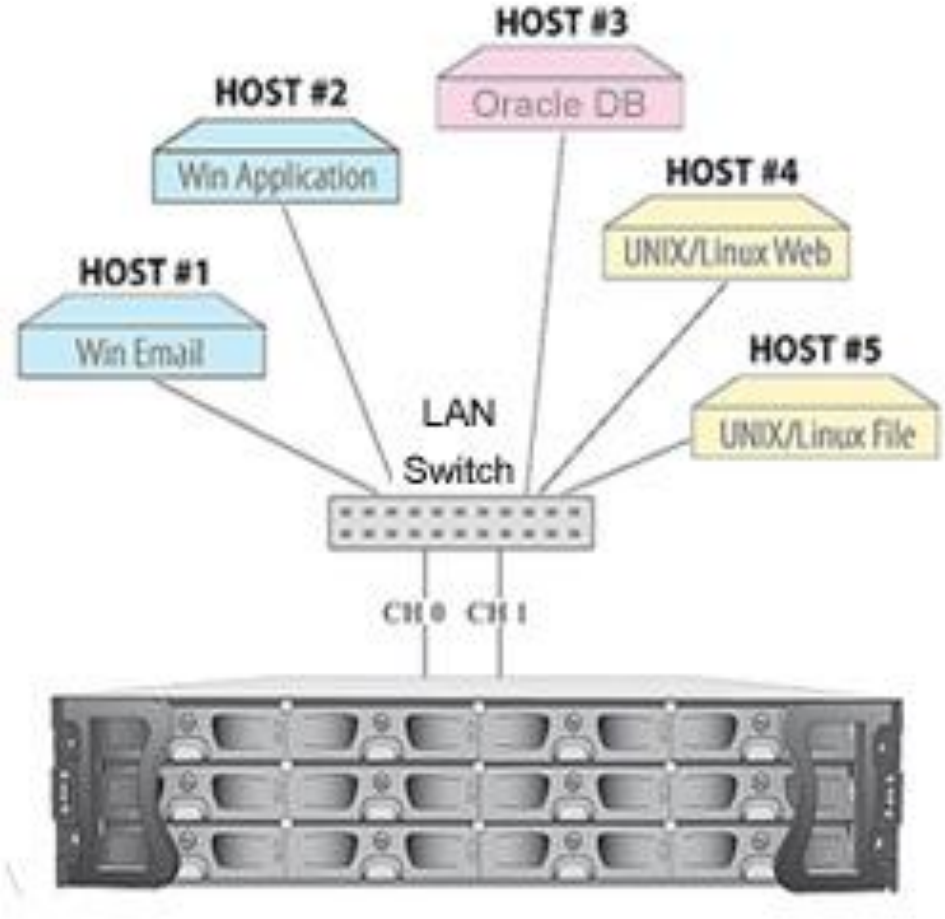
- Characteristics:
  - Minimum 4 HDDs are required
  - Based on disk striping and mirroring techniques
- Pros:
  - Faster than a single disk
  - More reliable than a single disk
- Cons:
  - Capacity is a half of the total capacity of all disks
  - Expensive.

NAS – Network Attached Storage

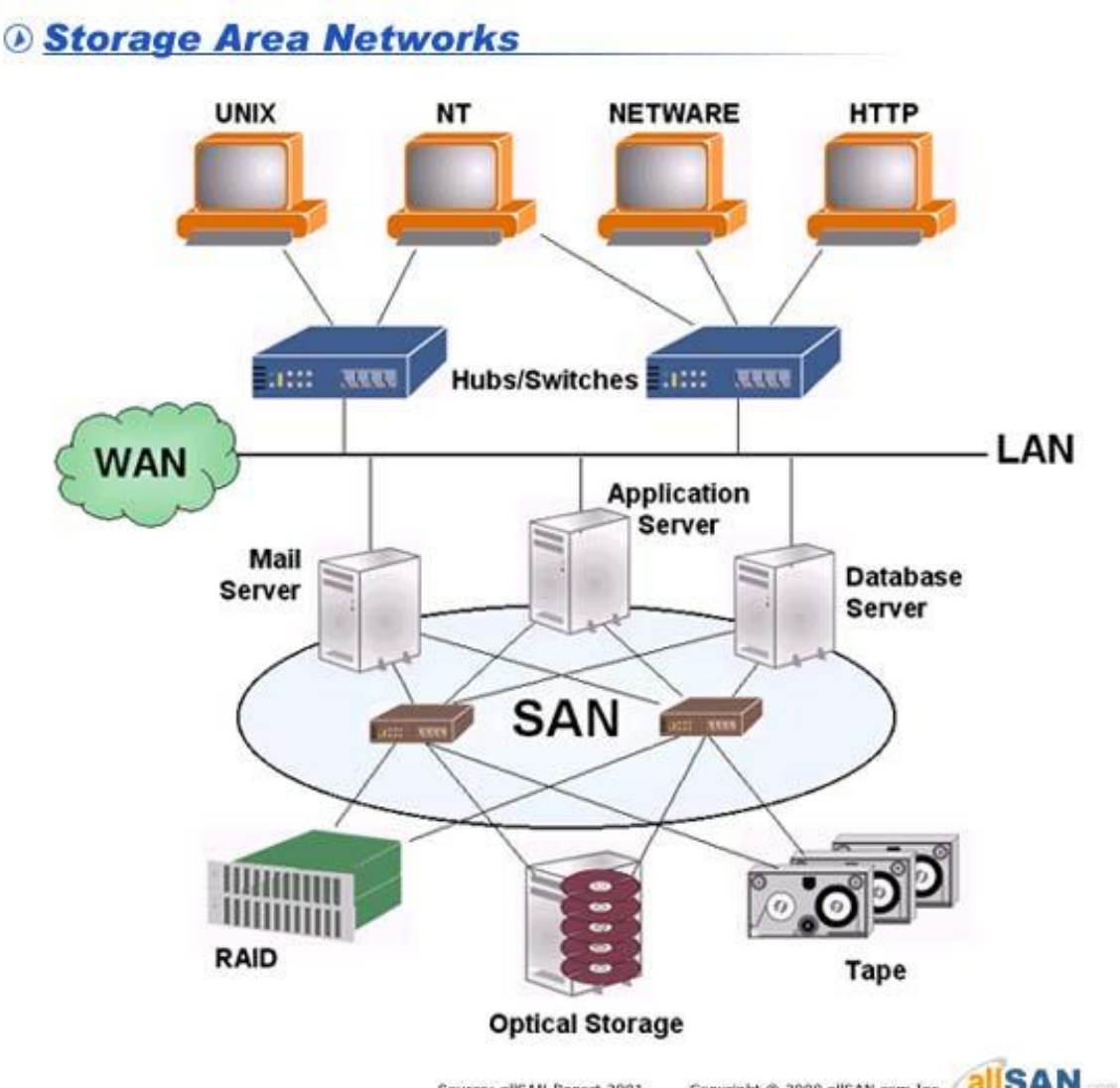
NAS – Network Attached Storage

- NAS is a server which is dedicated for storage;
- NAS is plugged into network and provided storage services via network;
- NAS is based on a high speed, reliable and large capacity RAID;
- NAS can work with almost any types of servers.

NAS – Network Attached Storage



SAN – Storage Area Network



SAN – Storage Area Network

- SAN is a network of servers which is dedicated for storage services;
- SAN usually provides:
  - Very high access speed
  - Extreme large capacity
  - Very high reliability
- SAN is usually a form of a distributed file system (DFS).

Google SAN

Google FS Architecture