Types of External Memory

- Magnetic Disk
  - RAID
  - Removable
- Optical
  - CD-ROM
  - CD-Recordable (CD-R)
  - CD-R/W
  - DVD
- Magnetic Tape

Magnetic Disk
- Disk substrate coated with magnetizable material (iron oxide...rust)
- Substrate used to be aluminium
- Now glass
  - Improved surface uniformity
    - Increases reliability
  - Reduction in surface defects
    - Reduced read/write errors
  - Lower flight heights (See later)
  - Better stiffness
  - Better shock/damage resistance

Read and Write Mechanisms
- Recording & retrieval via conductive coil called a head
- May be single read/write head or separate ones
- During read/write, head is stationary, platter rotates
- Write
  - Current through coil produces magnetic field
  - Pulses sent to head
  - Magnetic pattern recorded on surface below
- Read (traditional)
  - Magnetic field moving relative to coil produces current
  - Coil is the same for read and write
- Read (contemporary)
  - Separate read head, close to write head
  - Partially shielded magneto resistive (MR) sensor
  - Electrical resistance depends on direction of magnetic field
  - High frequency operation
    - Higher storage density and speed
Data Organization and Formatting

- Concentric rings or tracks
  - Gaps between tracks
  - Reduce gap to increase capacity
  - Same number of bits per track (variable packing density)
  - Constant angular velocity
- Tracks divided into sectors
- Minimum block size is one sector
- May have more than one sector per block

Disk Velocity

- Bit near centre of rotating disk passes fixed point slower than bit on outside of disk
- Increase spacing between bits in different tracks
- Rotate disk at constant angular velocity (CAV)
  - Gives pie shaped sectors and concentric tracks
  - Individual tracks and sectors addressable
  - Move head to given track and wait for given sector
  - Waste of space on outer tracks
    - Lower data density
- Can use zones to increase capacity
  - Each zone has fixed bits per track
  - More complex circuitry
Finding Sectors
- Must be able to identify start of track and sector
- Format disk
  - Additional information not available to user
  - Marks tracks and sectors

Winchester Disk Format
Seagate ST506

Characteristics
- Fixed (rare) or movable head
- Removable or fixed
- Single or double (usually) sided
- Single or multiple platter
- Head mechanism
  - Contact (Floppy)
  - Fixed gap
  - Flying (Winchester)
Fixed/Movable Head Disk

- **Fixed head**
  - One read write head per track
  - Heads mounted on fixed ridged arm
- **Movable head**
  - One read write head per side
  - Mounted on a movable arm

Removable or Not

- **Removable disk**
  - Can be removed from drive and replaced with another disk
  - Provides unlimited storage capacity
  - Easy data transfer between systems
- **Nonremovable disk**
  - Permanently mounted in the drive

Multiple Platter

- One head per side
- Heads are joined and aligned
- Aligned tracks on each platter form cylinders
- Data is striped by cylinder
  - reduces head movement
  - Increases speed (transfer rate)
**Tracks and Cylinders**

- Floppy Disk
  - 8”, 5.25”, 3.5”
  - Small capacity
    - Up to 1.44Mbyte (2.88M never popular)
  - Slow
  - Universal
  - Cheap
  - Obsolete?

**Winchester Hard Disk (1)**
- Developed by IBM in Winchester (USA)
- Sealed unit
- One or more platters (disks)
- Heads fly on boundary layer of air as disk spins
- Very small head to disk gap
- Getting more robust

**Winchester Hard Disk (2)**
- Universal
- Cheap
- Fastest external storage
- Getting larger all the time
  - 250 Gigabyte now easily available
**Speed**
- Seek time
  - Moving head to correct track
- (Rotational) latency
  - Waiting for data to rotate under head
- Access time = Seek + Latency
- Transfer rate

**Timing of Disk I/O Transfer**

**RAID**
- Redundant Array of Independent Disks
- Redundant Array of Inexpensive Disks
- 6 levels in common use
- Not a hierarchy
- Set of physical disks viewed as single logical drive by O/S
- Data distributed across physical drives
- Can use redundant capacity to store parity information

**RAID 0**
- No redundancy
- Data striped across all disks
- Round Robin striping
- Increase speed
  - Multiple data requests probably not on same disk
  - Disks seek in parallel
  - A set of data is likely to be striped across multiple disks
<table>
<thead>
<tr>
<th>RAID 1</th>
<th>RAID 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirrored Disks</td>
<td>Disks are synchronized</td>
</tr>
<tr>
<td>Data is striped across disks</td>
<td>Very small stripes</td>
</tr>
<tr>
<td>2 copies of each stripe on separate disks</td>
<td>— Often single byte/word</td>
</tr>
<tr>
<td>Read from either</td>
<td>Error correction calculated across corresponding bits on disks</td>
</tr>
<tr>
<td>Write to both</td>
<td>Multiple parity disks store Hamming code error correction in corresponding positions</td>
</tr>
<tr>
<td>Recovery is simple</td>
<td>Lots of redundancy</td>
</tr>
<tr>
<td>— Swap faulty disk &amp; re-mirror</td>
<td>— Expensive</td>
</tr>
<tr>
<td>— No down time</td>
<td>— Not used</td>
</tr>
<tr>
<td>Expensive</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RAID 3</th>
<th>RAID 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar to RAID 2</td>
<td>Each disk operates independently</td>
</tr>
<tr>
<td>Only one redundant disk, no matter how large the array</td>
<td>Good for high I/O request rate</td>
</tr>
<tr>
<td>Simple parity bit for each set of corresponding bits</td>
<td>Large stripes</td>
</tr>
<tr>
<td>Data on failed drive can be reconstructed from surviving data and parity info</td>
<td>Bit by bit parity calculated across stripes on each disk</td>
</tr>
<tr>
<td>Very high transfer rates</td>
<td>Parity stored on parity disk</td>
</tr>
</tbody>
</table>
**RAID 5**
- Like RAID 4
- Parity striped across all disks
- Round robin allocation for parity stripe
- Avoids RAID 4 bottleneck at parity disk
- Commonly used in network servers
- N.B. DOES NOT MEAN 5 DISKS!!!!!

**RAID 6**
- Two parity calculations
- Stored in separate blocks on different disks
- User requirement of N disks needs N+2
- High data availability
  - Three disks need to fail for data loss
  - Significant write penalty

**RAID 0, 1, 2, 3 & 4**
Optical Storage CD-ROM

- Originally for audio
- 650Mbytes giving over 70 minutes audio
- Polycarbonate coated with highly reflective coat, usually aluminium
- Data stored as pits
- Read by reflecting laser
- Constant packing density
- Constant linear velocity
**CD-ROM Drive Speeds**

- Audio is single speed
  - Constant linear velocity
  - 1.2 ms\(^{-1}\)
  - Track (spiral) is 5.27km long
  - Gives 4391 seconds = 73.2 minutes
- Other speeds are quoted as multiples
  - e.g. 24x
- Quoted figure is maximum drive can achieve

**CD-ROM Format**

- Mode 0 = blank data field
- Mode 1 = 2048 byte data + error correction
- Mode 2 = 2336 byte data

**Random Access on CD-ROM**

- Difficult
- Move head to rough position
- Set correct speed
- Read address
- Adjust to required location
  - (Yawn!)
### Other Optical Storage

- **CD-Recordable (CD-R)**
  - WORM
  - Now affordable
  - Compatible with CD-ROM drives
- **CD-RW**
  - Erasable
  - Getting cheaper
  - Mostly CD-ROM drive compatible
  - Phase change
    - Material has two different reflectivities in different phase states

### DVD - what’s in a name?

- **Digital Video Disk**
  - Used to indicate a player for movies
    - Only plays video disks
- **Digital Versatile Disk**
  - Used to indicate a computer drive
    - Will read computer disks and play video disks
- **Dogs Veritable Dinner**
- **Officially - nothing!!!**

### DVD - technology

- Multi-layer
- Very high capacity (4.7G per layer)
- Full length movie on single disk
  - Using MPEG compression
- Finally standardized (honest!)
- Movies carry regional coding
- Players only play correct region films
- Can be “fixed”

### DVD – Writable

- Loads of trouble with standards
- First generation DVD drives may not read first generation DVD-W disks
- First generation DVD drives may not read CD-RW disks
- Wait for it to settle down before buying!
**CD and DVD**

- Serial access
- Slow
- Very cheap
- Backup and archive

**Magnetic Tape**

- Serial access
- Slow
- Very cheap
- Backup and archive

**Internet Resources**

- Optical Storage Technology Association
  - Good source of information about optical storage technology and vendors
  - Extensive list of relevant links
- DLTtape
  - Good collection of technical information and links to vendors
- Search on RAID