**Chapter 2: Basics**

**Chapter 3: Multimedia Systems – Communication Aspects and Services**

**Chapter 4: Multimedia Systems – Storage Aspects**

- Optical Storage Media
- Multimedia File Systems
- Multimedia Database Systems

**Chapter 5: Multimedia Usage**

4.1: Optical Storage Media

- Basic Technology
- Compact Disc - Digital Audio
- Compact Disc - Read Only Memory
- Other CD Types
- Digital Versatile Disc





## History of Optical Disks

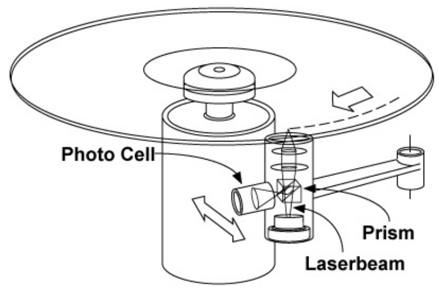
- 1982 Compact Disc - Digital Audio (CD-DA)
- 1985 Compact Disc - Read Only Memory (CD-ROM)
- 1988 Compact Disc - Interactive (CD-I)
- 1989 Compact Disc - Read Only Memory/Extended Architecture (CD-ROM/XA)
- 1990 Compact Disc - Write Once (CD-WO), Compact Disc - Magneto-Optical (CD-MO)
- 1991 Compact Disc - Recordable (CD-R)
- 1992 Photo Compact Disc (Photo-CD)
- 1995 Compact Disk - Read Write (CD-RW)
- 1996 Multimedia Compact Disc (MMCD)
- 1996 Super Density (SD)
- 1997 Digital Versatile (Video) Disk developed: DVD-ROM and DVD-Video
- From 2000 on: DVD-Audio, DVD-R, DVD+R, DVD-RW, DVD+RW, DVD-RAM

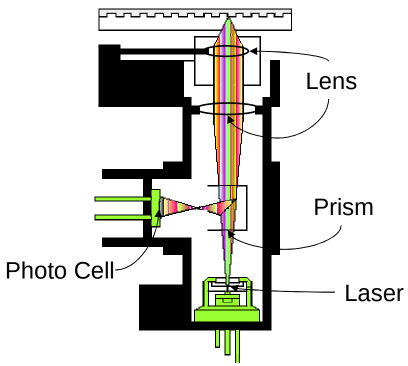




## Basic Technology

The Compact Disc Player Mechanism



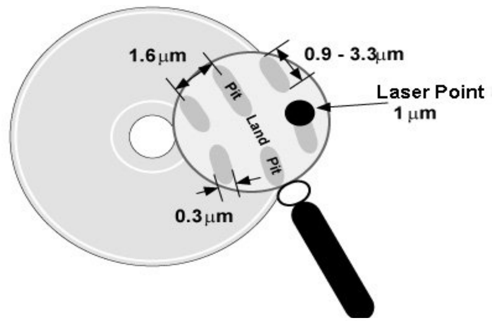

- A laser beam is reflected by the disc
- The prism diverts the reflected beam to the photo cell
- Wave length: approx. 780 nm (can be focused approx. 1µm)

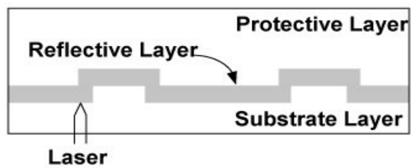




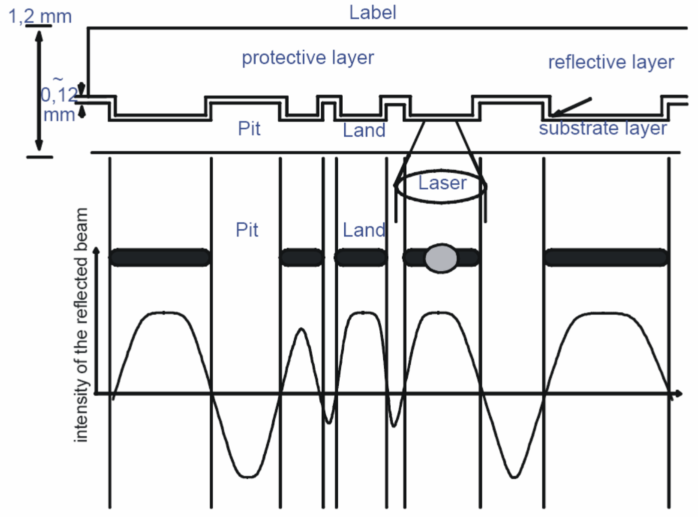
## Basic Technology of Compact Disc

- Information is stored in a spiral track (from inside to outside) of *pits* and *lands*, reflecting the laser beam with different intensity
- A CD consists of several layers, beginning from below
  1. *Substrate layer* (polycarbonate, with pits and lands, transparent for the laser beam)
  2. *Reflective layer* (aluminum, very thin)
  3. *Protective layer* (polycarbonate, used as carrier)
  4. *Label*



## Reading Data




Lands totally reflect the light, pits scatter the light





## Basic Technology of CD - Digital Audio

More information about a typical Compact Disc (CD-DA):

- Diameter 120 mm
- Thickness 1.2 mm
- Signal area 50 mm - 116 mm
- Playing time 74 minutes, 33 seconds
- Rotational speed 1.2 - 1.4 m/sec (constant linear velocity)
- Pit depth 0.12 µm

The spiral track of the CD…

- has approx. 20,000 windings
- is more than 5 km long





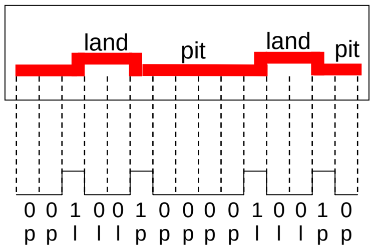
## CD-DA: Data Coding

Channel bits are stored as pits and lands on a CD where

- a change between pit and land (or vice versa) corresponds to a ”1”
- no change corresponds to a ”0”

→ equals Differential NRZ coding in data communication

Example:




→ A land as well as a pit is given by a sequence ”10...0”





## CD-DA: Data Coding

*Not allowed*:

- Sequences of “1” (frequent changes “pit-land-pit-land...” are difficult to detect)
- Long sequences of “0” (synchronization problems)

*Therefore*:

1. There must be at least two “0” between two “1”
2. Sequences of “0” are limited to a length of 10

Generalization of “bit stuffing“ principle:

Insert a “0” after five successive “1” to avoid the occurrence of the starting flag (six “1”) in the data part

# CD-DA: Eight-to-Fourteen Modulation

- 8 data bits are coded onto 14 channel bits (similar to 4B/5B FDDI coding)
- $2^{14}$ possible code words, 267 meet the requirements 1. and 2.

Enough for the 256 combinations of 8 bits

- To achieve 1. and 2., between consecutive code words, three additional bits are used (depending on the code words, e.g. 01001000100000 **000** 10000100000000)
  **100**

"Efficiency" is rather poor:
8/(14+3)= 8/17 ≈ 50%

Two possible alternatives for the additional bits due to requirement 1 (in this example)





# Eight-to-Fourteen Modulation Example

| | | |
|---|---|---|
| Audio Bits | 00000000 | 00000001 |
| Modulation Bits | 01001000100000 | 10000100000000 |
| Filling Bits | 010 | 100 |
| Channel Bits | 01001001000100000 | 10010000100000000 |
| On the CD-DA | lppplllpppplllllll | |

Land Pit

Could also be "000"

$$\text{Audio data rate} = 16\ \frac{\text{bit}}{\text{sample}} \cdot 2\ \text{channel} \cdot 44100\ \frac{\text{sample}}{\text{s} \cdot \text{channel}} = 1{,}411{,}200\ \frac{\text{bit}}{\text{s}}$$

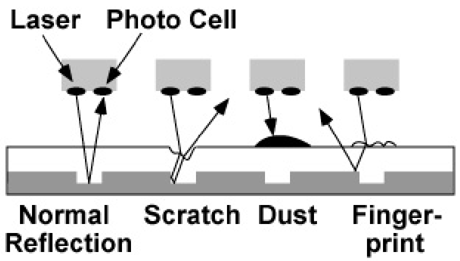
$$\text{Audio capacity} = 74\ \text{min} \cdot 1{,}411{,}200\ \frac{\text{bit}}{\text{s}} = 6{,}265{,}728{,}000\ \text{bit} \approx 747\ \text{Mbyte}$$





# CD-DA: Error Handling

Pollution and scratches may cause errors when reading a CD (burst errors most times)



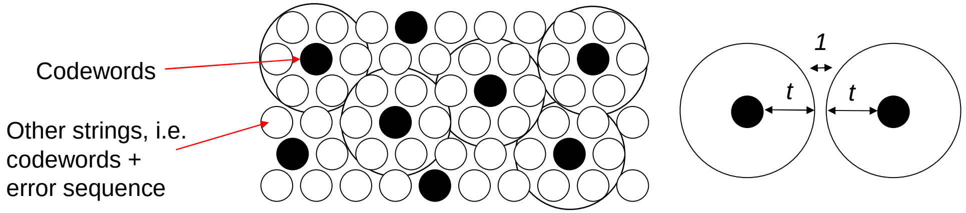

→ Methods for error detection and correction required
- Note: these methods are only suitable for audio and video; for computer data, which are more sensible against loss, these mechanisms have to be extended
- In general: the higher the redundancy (only 8 data bits within 17 transmitted bits, i.e. more than 50% redundancy), the better is the capability for error correction





# CD-DA: Error Detection and Correction - FEC

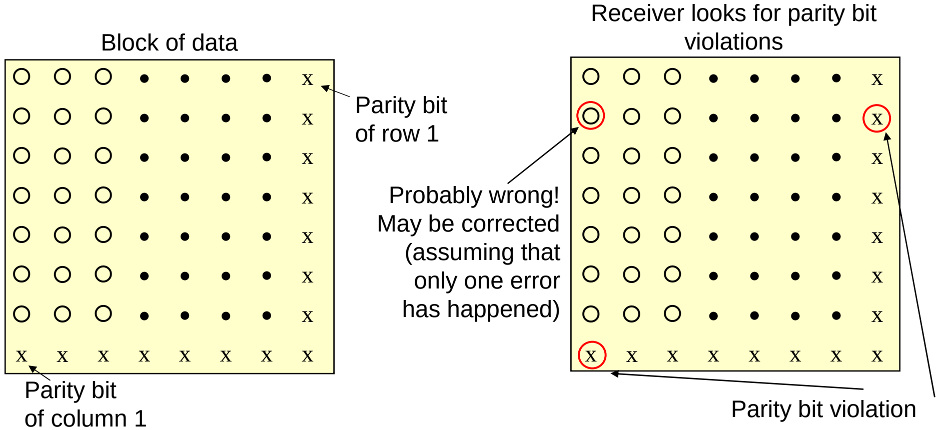
- Normally, after detection of an error the sender is informed and will retransmit
- ARQ - Automatic Repeat reQuest is obviously NOT viable for CDs!
- Therefore: FEC - Forward Error Correction
- The principle:




- Select very few codewords. The Hamming distance (differing positions) between codewords should be large ($x$, $y$ codewords, $x \neq y$, $A = min\ |x\text{-}y|$ = as large as possible)
- If $A = 2t + 1$, $t \in N$, then we can correct all errors of size $t$ or smaller (maximum likelihood principle)

## CD-DA: Error Detection and Correction – what could we do?

1. Transmit 3 times the same information and do "majority voting"
2. Hamming coding

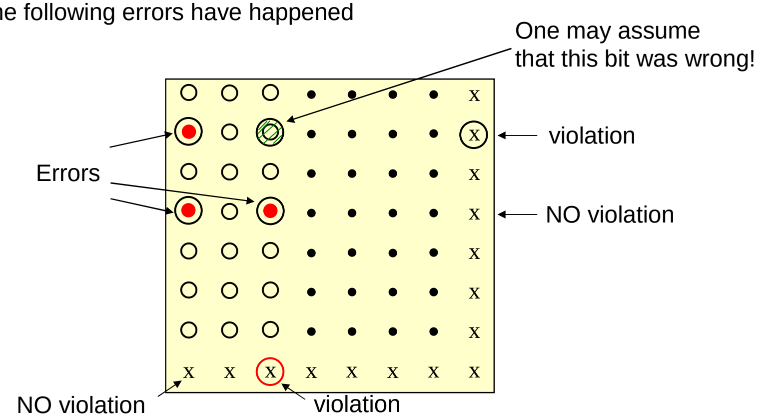







## CD-DA: Error Detection and Correction – what could we do?

- The risk: Wrong "corrections" possible!
- Assume the following errors have happened




No error correction but creation of one additional error!

→ *we need other techniques on CD, which can deal with burst errors*





## CD-DA: Cross Interleaved Reed-Solomon Code

Used on CD-DAs: *Cross Interleaved Reed-Solomon (R-S) Code*

Two parts of coding:

1. Error correction based on *Reed-Solomon Codes* (in two stages)
   - 24 data bytes are protected with 8 error correction bytes. Each byte is represented by 14+3 = 17 bits (this holds also for the correction bytes)
   - First stage: 4 error correction bytes are used by the R-S decoder to correct single-byte errors. Uncorrectable errors are marked.
   - Second stage: the remaining 24 + 4 bytes are passed through another R-S decoder, which uses the other 4 correction bytes for correcting double-byte errors and detecting some additional errors.
2. *Interleaved storage* of data
   - Consecutive bytes are distributed over multiple frames (one frame consists of 588 channel bits, corresponding to 24 bytes of audio)
   - By this, some distance is created between neighboring data – burst errors are damaging only parts of the data which can hopefully corrected by the R-S code





## CD-DA Frames

24 bytes of audio data are stored in frames which consist of:

- *Synchronization* – certain pattern, marks the beginning of a frame. Pattern: 12 × "1", followed by 12 × "0" plus three fill bits = 27 bits
- *Audio data* - two groups of 12 bytes (left and right channel) = 408 bits
- *Error correction bytes* - 8 bytes = 136 bits
- *Control and display byte* - 1 byte, each bit of it belongs to a different sub-channel = 17 bits
  - The bits of the Control and Display byte are named *P, Q, R, S, T, U, V*, and *W* (sub-channel bits)
  - The sub-channel bits of 98 consecutive frames are used together, giving 8 sub-channels of 98 bits each for additional information
  - These 98 frames are forming a *block*
  - Example of usage of sub-channels:
    - The *P* sub-channel distinguishes a CD-DA from CDs with data
    - The *Q* sub-channel stores in the first blocks the lead-in (the CD directory), in the other blocks absolute time on CD and relative time of a music track

# CD-DA: Data Rates

| Stream | Included bits | bits per frame | bit rate [bits/sec] |
|---|---|---|---|
| Audio bit stream | Sampled bits (audio bits only) | 192 | $1.4112*10^6$ |
| Data bit stream | Audio bit stream + error correction bits + control & display bits | 264 | $1.94*10^6$ |
| Channel bit stream | Data bit stream + modulation bits + filling bits + synchronization bits | 588 | $4.3216*10^6$ |

75 blocks are needed per second (for audio).
Thus a CD playing time is 333,000/75/60 = 74 minutes.





# CD-DA: Areas and Blocks

*CD-DA Areas*

- Lead-in area (directory of the CD-DA, identifies beginning of individual tracks)
- Program area (actual data of tracks are stored here)
- Lead-out area (helps the CD-player to leave the program area in a controlled way)

*CD-DA Tracks*

- Program area can consist of 1 - 99 tracks with different lengths; each track corresponds to a song or sentence of a symphony.
- Tracks contains several index points which are used for direct positioning of the laser. Two index points are mandatory:
  - Begin of the track
  - Begin of audio inside the track

*CD-DA Blocks*

- 98 frames form a block (block size: 7,203 channel byte or 2,352 (data) audio byte)
- Blocks do not have a special meaning for CD-DAs. Other CDs (like CD-ROMs) use this structure for additional control data.





# Compact Disc - Read Only Memory (CD-ROM)

CD-ROM Technology

- Developed for storage of general purpose data
- Beside computer data, a track of a CD-ROM may also contain audio data (conform to audio tracks of a CD-DA, distinguished by *P* sub-channel of frames)
- If both, computer and audio data are stored on a CD-ROM it is called Mixed Mode Disc (usually the computer data are stored first)





# CD-ROM: Blocks

Computer data in comparison to audio data:

- Much more sensitive to errors (no compensation by repetition, interpolation or dropping possible) → additional error correction methods have to be provided
- Need smaller data units for random access → use blocks instead of tracks for random access.
- Available bytes for data in each block: 2,352 byte (333,000 blocks fit on one CD)
- The CD storage capacity can be used in two ways (modes):
  - CD-ROM Mode 1 (usually used for computer data) and
  - CD-ROM Mode 2 (used for other media)

## CD-ROM Mode 1 (Data)

- 2,352 bytes are a block (75 blocks per second give a data rate of 1,411.200 Mbit/sec. This includes 2,048 data bytes + 304 overhead bytes)
- The bytes of a block are subdivided as follows
  - 12 bytes synchronization (marking of block beginning)
  - 4 bytes header (unambiguous identification: minute, second, block number, mode)
  - 2,048 bytes data
  - 4 bytes error detection code (EDC), used: CRC over header and data bytes
  - 8 unused bytes
  - 276 bytes error correction code (ECC), again Reed-Solomon coding

| Sync | Header | Data | EDC | Unused | ECC |
|---|---|---|---|---|---|
| 12 | 4 | 2048 | 4 | 8 | 276 |

**Remaining error rate (after correction): ≈ $10^{-12}$**

- Capacity: 333,000 blocks · 2,048 byte/block = 681,984,000 bytes ≈ 650 Mbytes
- Data rate: 2,048 byte/block · 75 blocks/sec = 153,600 byte/sec ≈ $1.2 \cdot 10^6$ bits/s





## CD-ROM Mode 2

- Mostly for audio but also for other data
- The block structure is very simple:
  - 12 byte synchronization
  - 4 byte header
  - 2,336 byte data

| Sync | Header | Data |
|---|---|---|
| 12 | 4 | 2336 |

→ Capacity: 333,000 block · 2,336 byte/block = 777,888,000 byte ≈ 742 Mbytes (vs. 650 Mbyte for Mode 1)

→ Data rate: 2,336 byte/block · 75 block/sec = 175,200 byte/sec ≈ $1.4 \cdot 10^6$ bits/s

- Note: These data rates correspond to a normal speed CD-ROM Player
- Today faster players are available, e.g. 40 x normal speed. Playing time is correspondingly reduced.





## Limitations of CD-ROM Technology

1. Higher access time than hard disks due to:

- *Synchronization Time*

  The internal clock must be synchronized to the signal. Some milliseconds needed.
- *Constant Linear Velocity playback*

  Reading of the inner part of a CD requires about 530 RPM (rotations per minute) whereas reading of the outer part needs 200 RPM. Adjustment is required.

  The rotation delay is the maximum duration to position the laser above the desired sector and to adjust the rotation speed. The rotation delay can be up to 200 milliseconds.
- *Seek Time*

  For random access with the laser beam the correct radius has to be adjusted and the block has to be found. Time needed: about 100 milliseconds.

2. No simultaneous playback of e.g. audio and data is possible

- Audio streams on a CD must be sequentially stored
- Thus many multimedia applications are impossible!





## Other CD Types: CD-I (Interactive)

- Designed for consumer electronics as an addition to a TV (CD-DA replacement)
- Specifies an entire system:
  - CD-ROM based format for different media
  - System software based on real-time operating system techniques
  - Decoder with Motorola chip (68000 family), video and audio chips

| Audio Encoding Type | CD-DA | CD-I Level A | CD-I Level B | CD-I Level C |
|---|---|---|---|---|
| Sampling Frequency | 44.1 | 37.8 | 37.8 | 18.9 |
| Bandwidth (kHZ) | 20 | 17 | 17 | 8.5 |
| Coding | 16 bit PCM | 8 bit ADPCM | 4 bit ADPCM | 4 bit ADPCM |
| Max. Recording Duration Stereo/Mono | 74 min / - | 2.4 h / 4.8 h | 4.8 h / 9.6 h | 9.6 h / 19.2 h |
| Quality | Audio CD | LP | FM Radio | AM Radio |

# Other CD Types: CD-I

CD-I can be used to encode images at different quality levels and resolutions

| **Image Encoding Type** | **YUV** | **RGB** | **Color Look-Up Table** |
|---|---|---|---|
| Image type | High quality natural pictures, many colors | High quality normal pictures | Simple pictures, requires preloaded color table |
| Standard resolution | 360×240 | 360×240 | 360×240 |
| Bits/pixel | 18 | 16 | 4 |
| Colors | 262,144 (=$2^{18}$) | 65,536 | 16 |
| Image size | 1,552,000 bit | 1,382,400 bit | 345,600 bit |

Animation Encoding:

- Motion pictures (few colors, run length coding, ~ 80,000 - 160,000 bit/image)
- MPEG





# Other CD Types: CD-ROM Extended Architecture

CD-ROM – Extended Architecture (CD-ROM/XA)

- Based on CD-ROM Mode 2 blocks
- Uses a sub-header of 8 byte in the 2,336 data byte (of CD-ROM Mode 2)
- Sub-header identifies the content of the block
- Therefore interleaving of separate data streams possible
- Special device is required

CD-ROM/XA allows two forms of blocks:

1. "Interleaved CD-ROM Mode 2 with improved error correction"

| Sync | Header | Sub-header | Data | EDC | ECC |
|---|---|---|---|---|---|
| 12 | 4 | 8 | 2048 | 4 | 276 |

2. "Interleaved CD-ROM Mode 2 for audio and video" (simple error handling)

| Sync | Header | Sub-header | Data | EDC |
|---|---|---|---|---|
| 12 | 4 | 8 | 2324 | 4 |



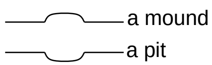


# Other CD Types: Recordable CDs

1. CD - Write Once (CD-WO)
   - ➢ Substrate layer has no pits and lands, but a pre-groove for laser adjustment
   - ➢ Aluminum reflective layer is replaced by a thin layer of organic dye
   - ➢ A thin layer of gold is located between dye and protective layer (highly reflective, does neither react to the dye nor corrode as do other metals).

Writing to a CD-WO

- ➢ When writing a laser beam heats the dye, resulting in tiny mounds
- ➢ Mounds alter the reflection of the reading laser at the gold layer and appear to the CD-ROM drive as pits




Sessions

- ➢ Writing of data to a disc (session) includes the lead-in, data and lead-out area
- ➢ Regular CD-WOs require all data to be written in one session
- ➢ Hybrid CD-WOs support multiple sessions to be written at several times





# Other CD Types: Recordable CDs

2. CD - Magneto Optical (CD-MO)
   - ➢ Can be (over-)written multiple times
   - ➢ Cannot be read by normal CD-ROM drives
   - ➢ An optical head and contact magnetic head are located opposite to each other, "sandwiching" the disc

Writing

- ➢ The laser beam heats the surface of the recording layer (approx. 150°C)
- ➢ At the same time the magnetic head polarizes the recording material ("direction" N or S, requires fast inversion of the magnetic field)
- ➢ Due to the fast reduction of the temperature when the laser passes on, the polarization can be realized at a fine granularity

Reading

- ➢ The polarization of the laser beam's light changes corresponding to the magnetization

Deleting

- ➢ The entire block is heated and polarized with a constant magnetic field

# Other CD-Types: CD-R and CD-RW

*CD – Recordable (CD-R)*

- Like CD-WO
- When writing, the laser has 4 times the temperature like for reading
- Allows for multiple sessions

*CD – Read/Write (CD-RW)*

- CD-MO can be overwritten several times – but needs special devices to be played!
- Thus, CD-RW uses a crystalline compound of silver, indium, antimony, and tellurium. This compound shows the effect of becoming absorptive when highly heated (and then cooled) and becoming reflective when medium heated (and then cooled)
- Laser has three temperatures: high power creates absorptive places (write), low power for reflection (read), medium power for conversion to reflective state (erase)
- Problem with CD-RW in some players: reflectivity is much lower than for "conventional" CD-ROMs and CD-DAs, making the reading harder





# Other CD Types: Photo-CD

- Based on CD-WO principle
- Reading possible on CD-I or CD-ROM/XA devices
- Developed films are digitalized with 8-bit luminance and 2 x 8-bit chrominance resolution
- 5 image resolutions possible

| Picture Name | Compressed/Uncompressed | Line Number | Column Number |
|---|---|---|---|
| Base/16 | Uncompressed | 128 | 192 |
| Base/4 | Uncompressed | 256 | 384 |
| Base | Uncompressed | 512 | 768 |
| 4 Base | Compressed | 1024 | 1536 |
| 16 Base | Compressed | 2048 | 3072 |

xbase = x times more resolution than base
base/y = y times less resolution than base





# Other CD Types

Multimedia Compact Disc (MMCD)

- Developed by 3M, Philips and Sony
- Single sided
- Dual layer with 7.4 GB capacity (3.7 per layer)

Super Density (SD)

- Developed by Toshiba and Time Warner
- Disc with 5 GB (single layer) or 9 GB (dual layer) per side
- Two of such discs can be glued (hot melt) together, giving 10 GB or 18 GB per disc
- Also: Recordable 6.4 GB disc and rewritable 5.2 GB disc

→ leads to the concept of DVD





# Digital Versatile Disc (DVD)

Also known as: "Digital Video Disc"

*Goal*: to create a new optical medium to store an entire high-quality digital movie on a disk

*Formats*

- Single-sided single-layer
- Single-sided double-layer: laser must switch focus to read both layers
- Double-sided: disk must be flipped over to read both sides

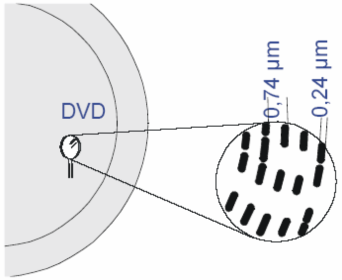
*Under discussion: smaller DVDs*

- Diameter of 8 cm (instead of 12 cm)

*Video quality*

- Resolution: 720 x 480 (NTSC), 720 x 576 (PAL)
- MPEG-2 compression used

# DVD Technology




*CD-like optical storage medium*
- Same physical size as CD → allows for backward compatibility of reading devices

*Capacity considerably higher than CD*
- Pits and lands shorter
- Tracks narrower
- Laser of shorter wavelength makes this possible
- Basic capacity: 4.3 GB

*EFM+ error correction scheme*
- Eight-to-Fourteen+ Modulation
- Maps 8 bits of data to 16 bits of encoded signal
- More robust than the CD scheme, no filler bits needed, simpler decoding mechanisms possible





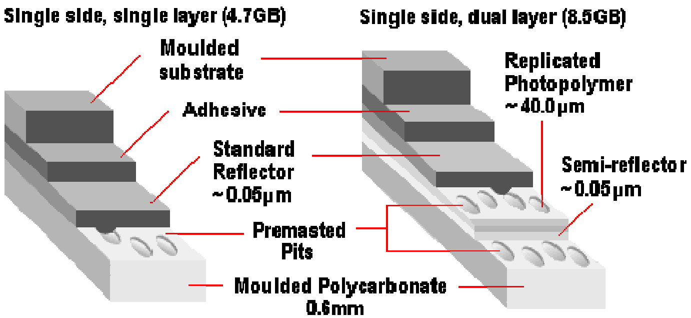
# CD/DVD Comparison

| | CD | DVD |
|---|---|---|
| Wavelength of laser light | 780 nm (infrared) | 650 and 635 nm (red) |
| Track distance | 1,6 µm | 0,74 µm |
| Minimal pit/land length | 0,83 µm | 0,4 µm |
| Data layers | 1 (single layer, SL) | 1 or 2 (double layer, DL) |
| Sides | 1 (single sided, SS) | 1 or 2 (double sided, DS) |
| Capacity | 650 – 800 MB | ca. 4.3 GB (SLSS)<br>ca. 8.5 GB (DLSS)<br>ca. 8.6 GB (SLDS)<br>ca. 17.2 GB (DLDS) |
| Video Data Rate | ca. 1.5 Mbit/s | 1 – 10 MBit/s |
| Video compression standard | MPEG-1 | MPEG-2 |
| Video capacity | ca. 1 h | 2 – 8 h |





# Single Layer and Dual Layer




- A second “data layer” is inserted between the reflective layer and the substrate, which is semi-reflective
- The laser has to change focus to be reflected at the semi-reflective layer (thus reading the basic layer), or to go through that layer (beeing reflected at the reflective layer, thus reading the additional layer)





# DVD Variants

*DVD-ROM: DVD Read Only Memory*
- Basic DVD specification
- Read-only mode for commercial video/audio

*Application formats*
- Specification of how to place audio and video on a DVD

  *DVD Video*
  - MPEG-2, resolution: 720 x 480 (NTSC), 720 x 576 (PAL)
  - Audio: MPEG-2 multi-channel audio or linear PCM

  *DVD Audio*
  - Multi-channel audio
  - Higher quality PCM audio

# DVD: Recordable Types

*Write Once*

- DVD-R and DVD+R
  - -R uses constant linear velocity (CLV): spins slower in outer region than in inner
  - +R also allows for constant angular velocity (CAV): write data less dense in outer region

*Write Many*

- DVD-RW DVD Recordable (should be “DVD Rewritable”)
  Uses CLV, appr. 1.000 rewrites
- DVD-RAM DVD Rewritable (should be “DVD Random Access Memory”)
  Uses CAV, appr. 1.000.000 rewrites
- DVD+RW DVD
  Uses CLV or CAV, appr. 1.000 rewrites

*Read only and write once*

- DVD PROM
  Part is ´”read only”, rest may be written once