

Chapter 2: Representation of Multimedia Data

Chapter 3: Multimedia Systems – Communication Aspects and Services

Chapter 4: Multimedia Systems
– Storage Aspects

- Optical Storage Media
- Multimedia File Systems

4.1: Optical Storage Media

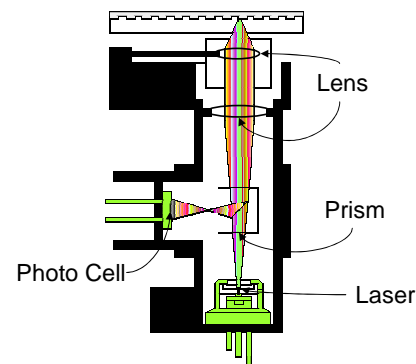
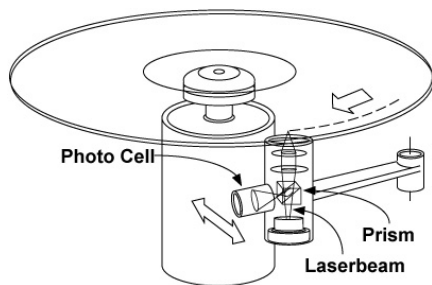
- Compact Disc Technology
- Digital Versatile Disc

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



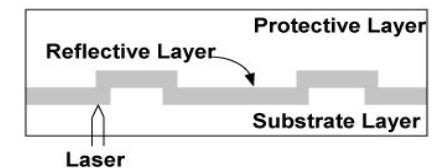
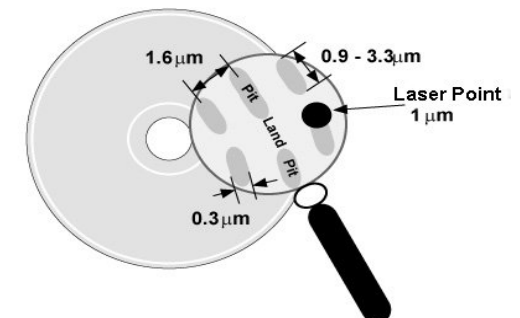
- A laser beam is reflected by the disc
- The prism diverts the reflected beam to the photo cell
- Wave length: approx. 780 nm (can be focused approx. 1µm)

Basic Technology of Compact Disc

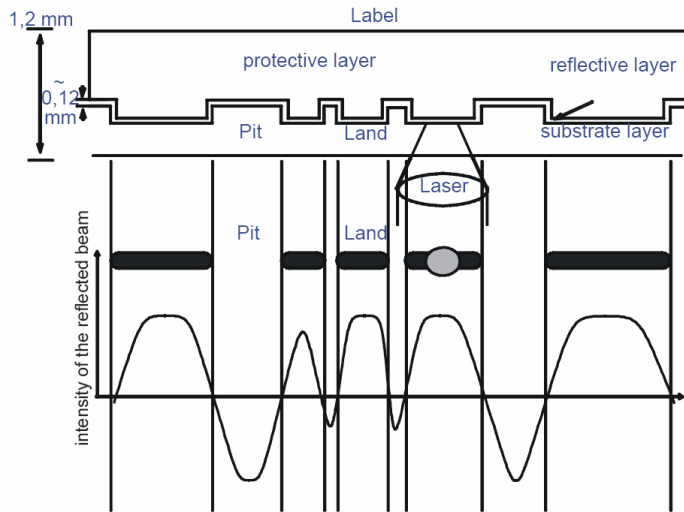
- Information is stored in a spiral track (from inside to outside) of *pits* and *lands*, reflecting the laser beam with different intensity

- 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

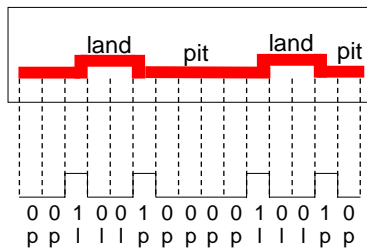
CD-DA: Data Coding

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)

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

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 | 0100100100010000 | 1001000010000000 |
| On the CD-DA | lppplllpppppllllll | |

Land Pit

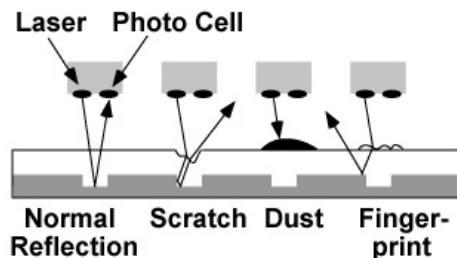
Could also be "000"

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

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

CD-DA: Error Handling

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

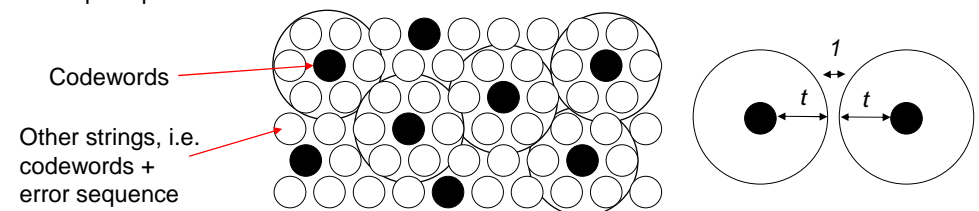


→ Methods for error detection and correction required

- 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, $x \neq y$, $A = \min |x-y|$ = as large as possible)
- If $A = 2t + 1$, $t \in \mathbb{N}$, then we can correct all errors of size t or smaller (maximum likelihood principle)

CD-DA: Cross Interleaved Reed-Solomon Code

Used on CD-DAs: *Cross Interleaved Reed-Solomon (R-S) Code* to deal with error bursts (as produced e.g. by scratches)

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: $12 \times "1"$, followed by $12 \times "0"$ 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 | $1.4112 \cdot 10^6$ |
| Data bit stream | Audio bit stream + error correction bits + control & display bits | 264 | $1.94 \cdot 10^6$ |
| Channel bit stream | Data bit stream + modulation bits + filling bits + synchronization bits | 588 | $4.3216 \cdot 10^6$ |

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 | } Remaining error rate (after correction): ≈ 10 ⁻¹² |
| 12 | 4 | 2048 | 4 | 8 | 276 | |

- 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 · 10⁶ 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 |

vs. 650 Mbyte
for Mode 1

- Capacity: 333,000 block · 2,336 byte/block = 777,888,000 byte ≈ 742 Mbytes
- Data rate: 2,336 byte/block · 75 block/sec = 175,200 byte/sec ≈ 1.4 · 10⁶ 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!

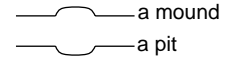
Recordable CDs

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: 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

Digital Versatile Disc (DVD)

Also known as: “Digital Video Disc”

Goal: 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

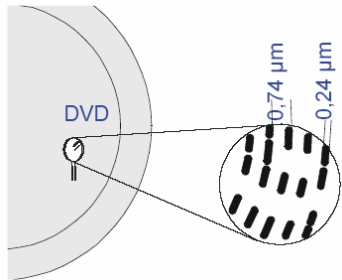
Under discussion: smaller DVDs

- 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

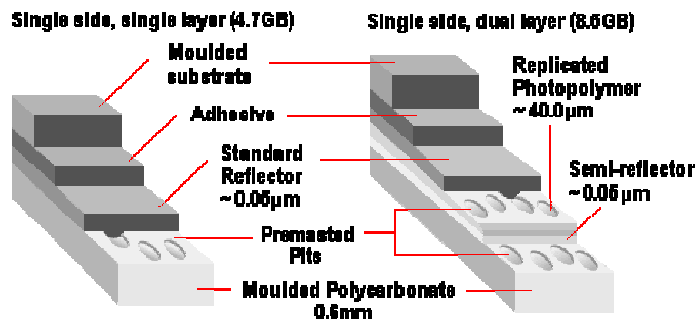
EFM+ error correction scheme

- 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) ca. 8.5 GB (DLSS) ca. 8.6 GB (SLDS) 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 (being 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