# Multimedia Systems: Optical Storage Media

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# Contents

*Multimedia*
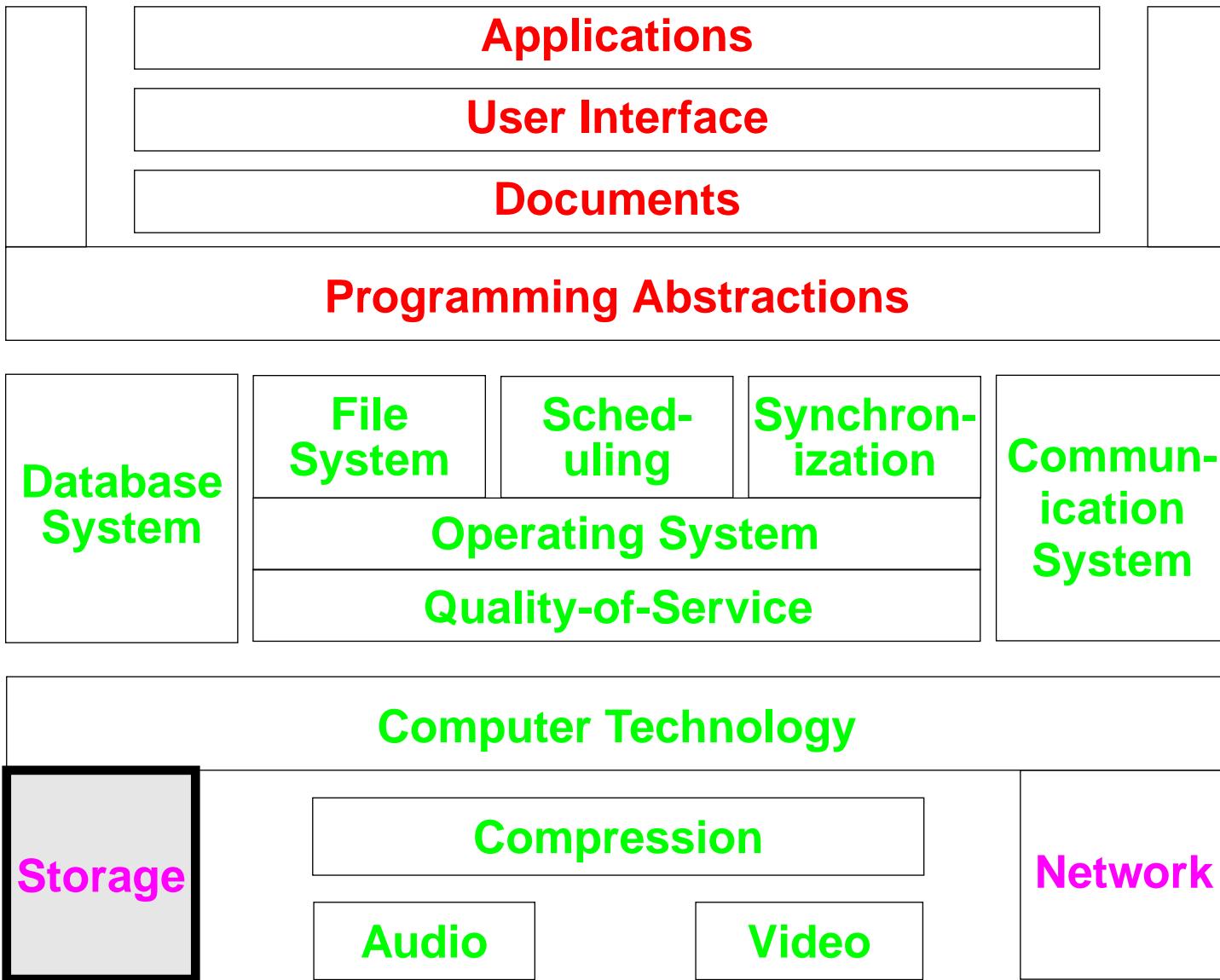
1. Overview

2. History

3. Fundamentals

4. Laser Vision

5. Compact Disc Digital Audio (CD-DA)

6. Compact Disc Read Only Memory (CD-ROM)

7. Further CD-ROM Based Developments

8. DVD: Digital Video Disk

9. Compact Disc Write Once (CD-WO)

10. Compact Disc Magneto Optical (CD-MO)I

11. Summary

# 1 Overview

## Compact Disc

```
   CD-MO                                              CD-WO

        ...                                      ...

              ISO      CD-ROM/XA
              9660

                    CD-ROM

                     CD-DA

   R/W              RO              WO

   magneto optical        optical basis
   basis
```
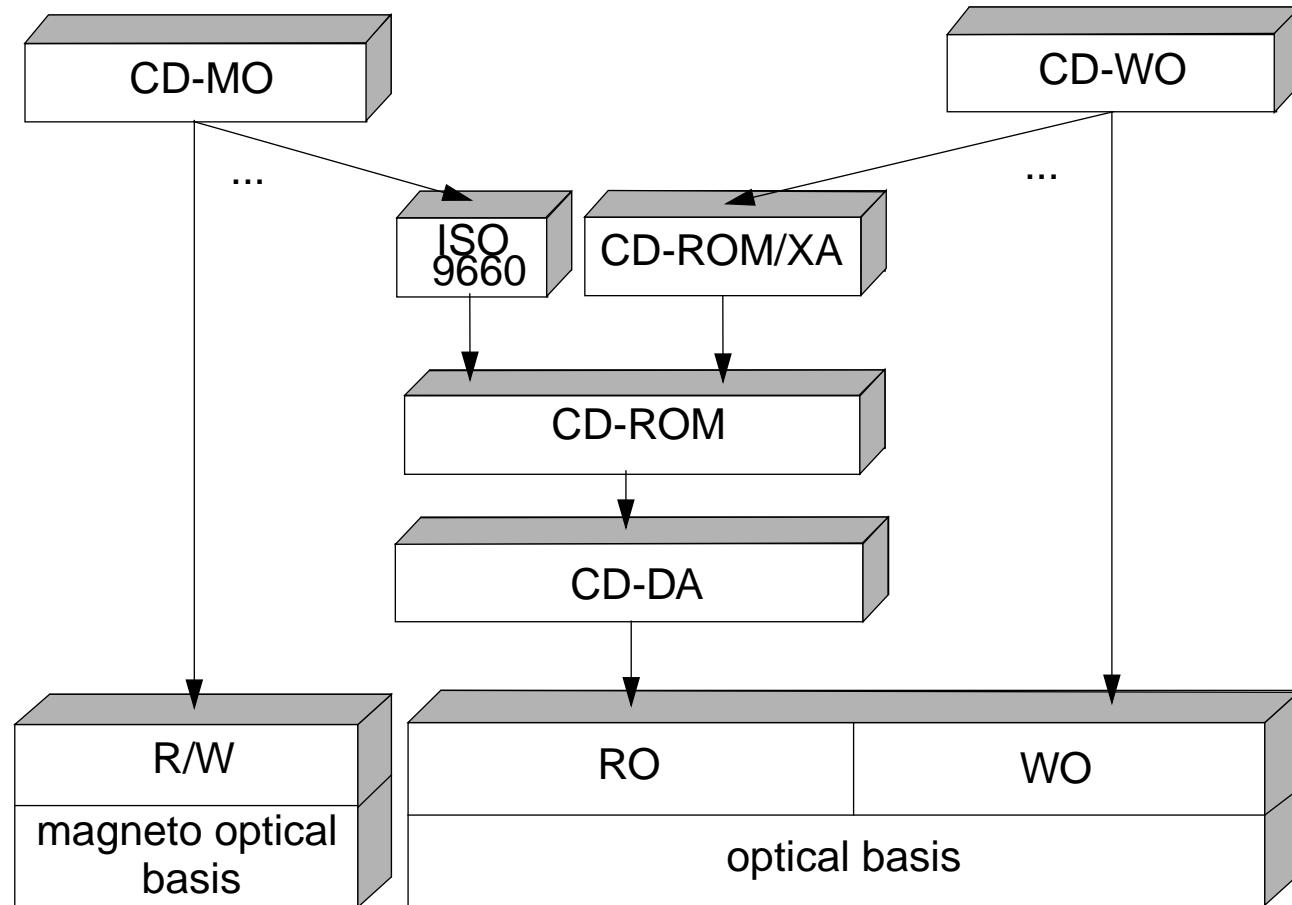
# 2    History

| 1973 | **Video Long Play (VLP) - published** |
|------|---------------------------------------|
| 1983 | **Compact Disc Digital Audio (CD-DA) - available:**<br>• Red Book Standard |
| 1985 | **Compact Disc Read Only Memory (CD-ROM):**<br>• Yellow Book Standard for physical format<br>• High Sierra Proposal<br>• ISO 9660 Standard for logical file format |
| 1986 | **Compact Disc Interactive (CD-I) - announcement:**<br>• Green Book |
| 1987 | **Digital Video Interactive (DVI) - first presentation** |
| 1988 | **CD-ROM Extended Architecture (CD-ROM-XA) announcement** |
| 1990 | **CD Write Once (CD-WO), CD Magneto Optical (CD-MO):**<br>• Orange Book |
| 1996 | **Digital Video Disk DVD** |

# 3  Fundamentals

## Pits and Lands



optical disc

$\lambda_1$

$\lambda_2$

e.g. CD:
$\lambda_1=1.6\mu m$
$\lambda_2=0.6\mu m$
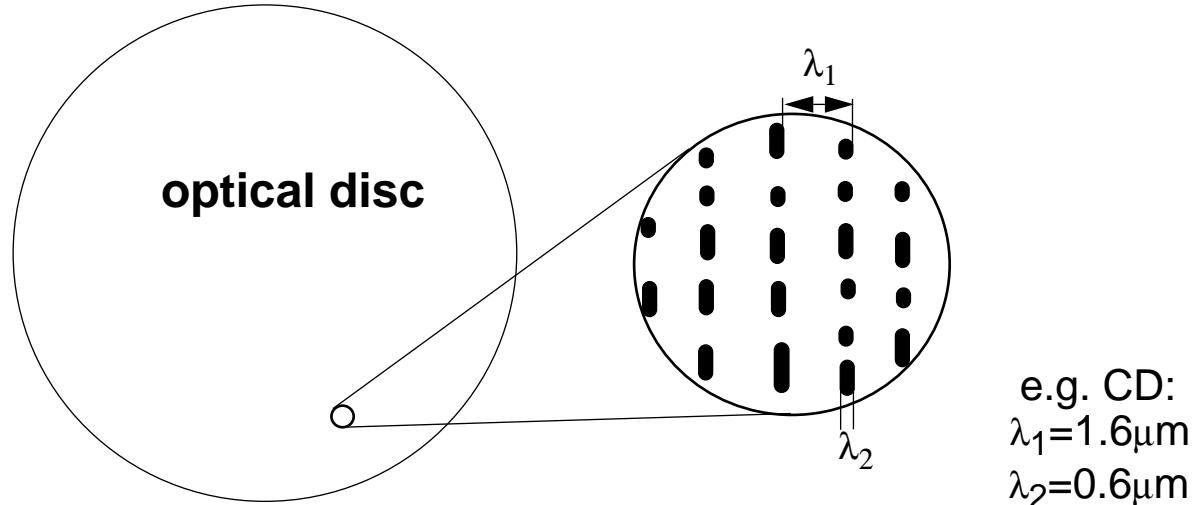
**Information is stored in a spiral-shaped track:**

- Series of pits and lands in substrate layer

- Transition from pit to land and from land to pit: '1'

- Between transitions: sequence of '0' s

- 16000 turns/inch (tpi)

# Fundamentals: Physical Structure

**Cross-section through disc in direction of spiral track:**
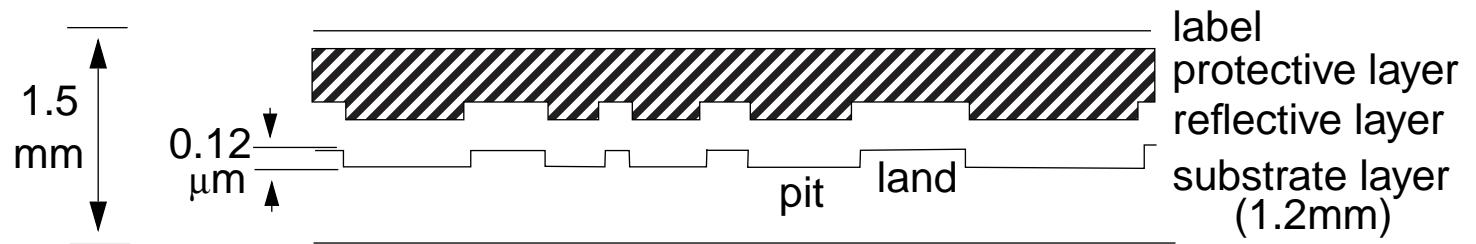


## 3 layers:

- Transparent substrate layer

- Reflective layer

- Protective layer

# Fundamentals: Read Data

land    pit

reflected light level
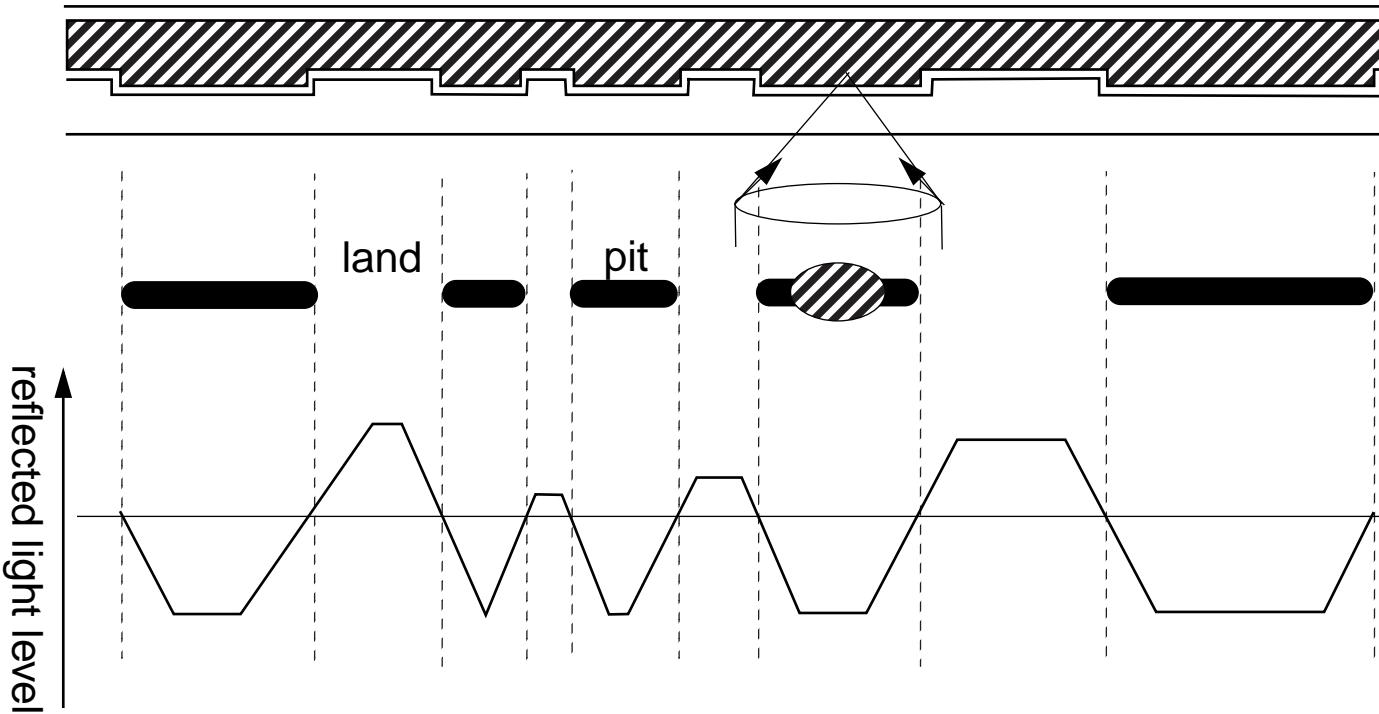
**Laser focused onto reflective layer:**

- Lands - almost totally reflecting

- Pits - scattering

# Advantages of Optical Storage Media

**High data density:**

- 1.66 data bits / $\mu$m of track

- 16000 tpi $\Leftrightarrow$ floppy disk: 96 tpi

**Long term storage:**

- Protection of data

- Surface out of focus $\Rightarrow$ insensitivity to dust, scratches

**Low probability of head crashes:**

- Distance between head and substrate surface > 1mm

**Adequate error correction**

**Each digital disc is equivalent to the master**

# 4    Laser Vision

## Characteristics:

- Storage of video and audio

- Analogue encoding

- High quality of reproduced data

- Diameter: ~ 30 cm

- Storage capacity: ~ 2.6 GByte

## History:

- Originally Video Long Play (VLP)

- 1973 first description in Philips Technical Review

# Laser Vision: Fundamentals

## Principles:

- Mix of audio and video

- Frequency modulation

- No quantization of pit length

## Cross section through a Laser Vision disc:



land

pit
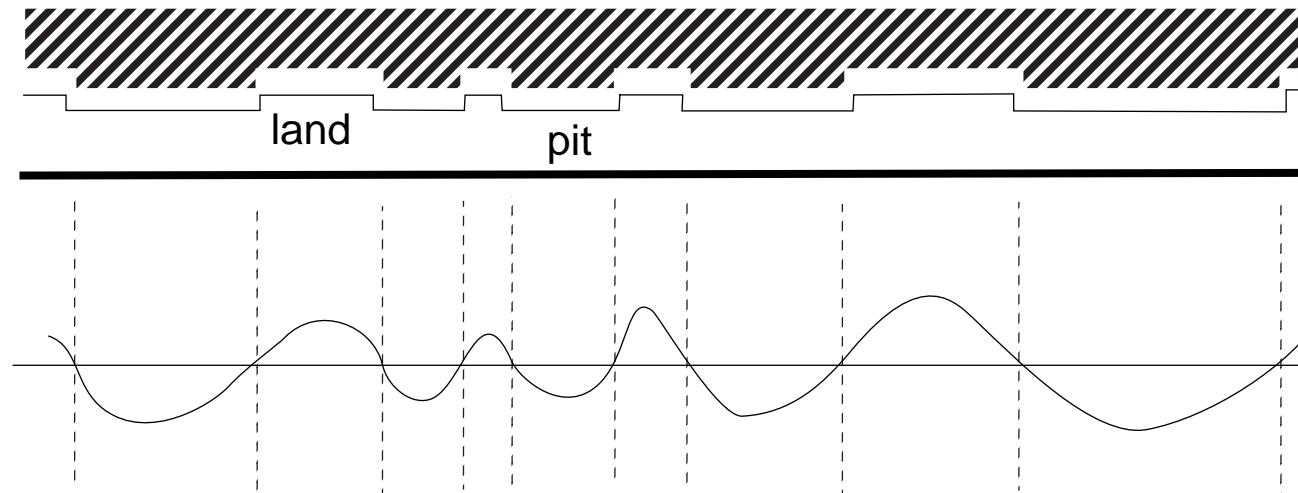
# 5    Compact Disc Digital Audio (CD-DA)

**Storage of audio data**

**History:**

- Development of basic technology by N. V. Philips

- Cooperation of N. V. Philips and Sony Corporation

- 1983 CD-DA available

**Physical characteristics:**

- Diameter: 120 mm

- Constant linear velocity (CLV),
  i.e. number of rotations/s depends on
  position of head relative to disc center

- Track shape:
  One spiral with appr. 20000 turns (LP: 850 turns)

# CD-DA: Characteristics

## Audio data rate:

- Sampling frequency: 44100Hz

- 16 bit quantization

- Pulse code modulation (PCM)

- Audio data rate = 1411200 bit/s = 176,4 Kbyte/s

## Quality:

- Signal to noise ratio (S/N):
  ~ 6dB/bit, 16 bit quantization ⇨ S/N exactly 98 dB

- LP, tape: S/N 50-60 dB

## Capacity: (without error correction data)

- Playback time: maximal 74 min

- Capacity =74 min ∗ 1411200 bit/s = 6265728000 bit ~ 747 MByte

# CD-DA: Pits and Lands



```
10000000 100000 1000 100  1000  100 1000000 10000000 10000000000
```

0.3μm
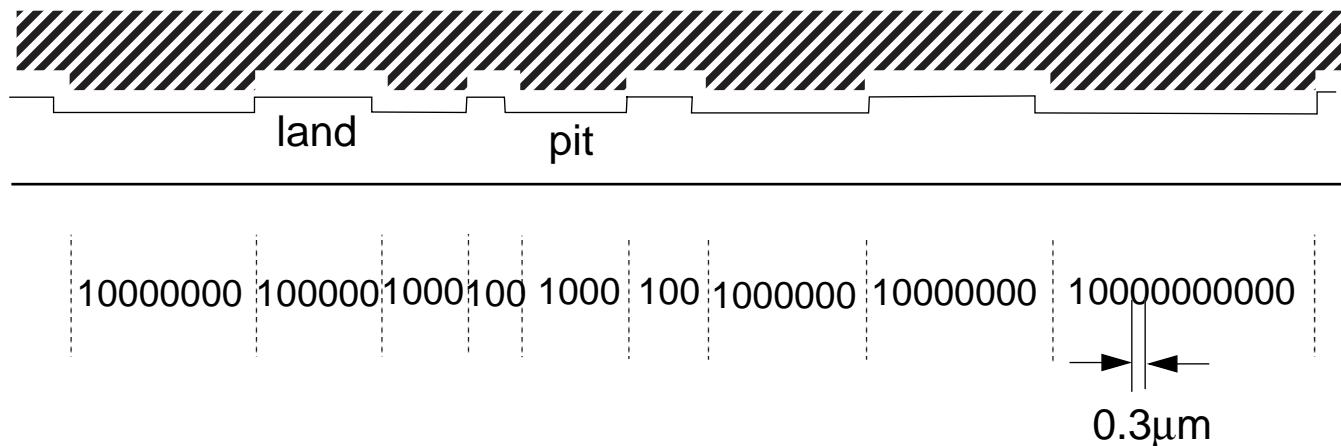
## Length of pits: multiples of 0.3μm

## Coding:

- Transition from pit to land / from land to pit: '1'
- Between transitions: sequence of '0's

# CD-DA: Eight-to-Fourteen Modulation

## Restricted laser resolution:

- Minimal distance between transitions (pit to land, land to pit)

- At least two "0" between two "1"

## Generation of clock signal:

- Maximal distance between transitions (pit to land, land to pit)

- Not more than 10 consecutive "0"

## ⇨ Eight-to-Fourteen Modulation:

- 8 bit value is encoded using 14 bits

- 267 combinations possible

- 256 are used
  (criterion: efficient implementation with small number of gates)

# CD-DA: Eight-to-Fourteen Modulation

**Example for a code conversion table:**

| data bits | channel bits |
|-----------|--------------|
| 00000000  | 01001000100000 |
| 00000001  | 10000100000000 |
| ...       | ... |

**Concatenation of independent 14 bit values**
**Í potential violation of:**

- Min. distance of 2 bits

- Max. distance of 10 bits

⇨ Three additional *merging bits*

# CD-DA:
# Eight-to-Fourteen Modulation
# Example

8 bit data                                    111101000 11100010

14 bit
modulated data                     00010010000010 10010001000010

merging bits                  010 00010010000010 000 10010001000010 001

sync. pattern
(part of 24 bit)

001000000000010 010 00010010000010 000 10010001000010 001
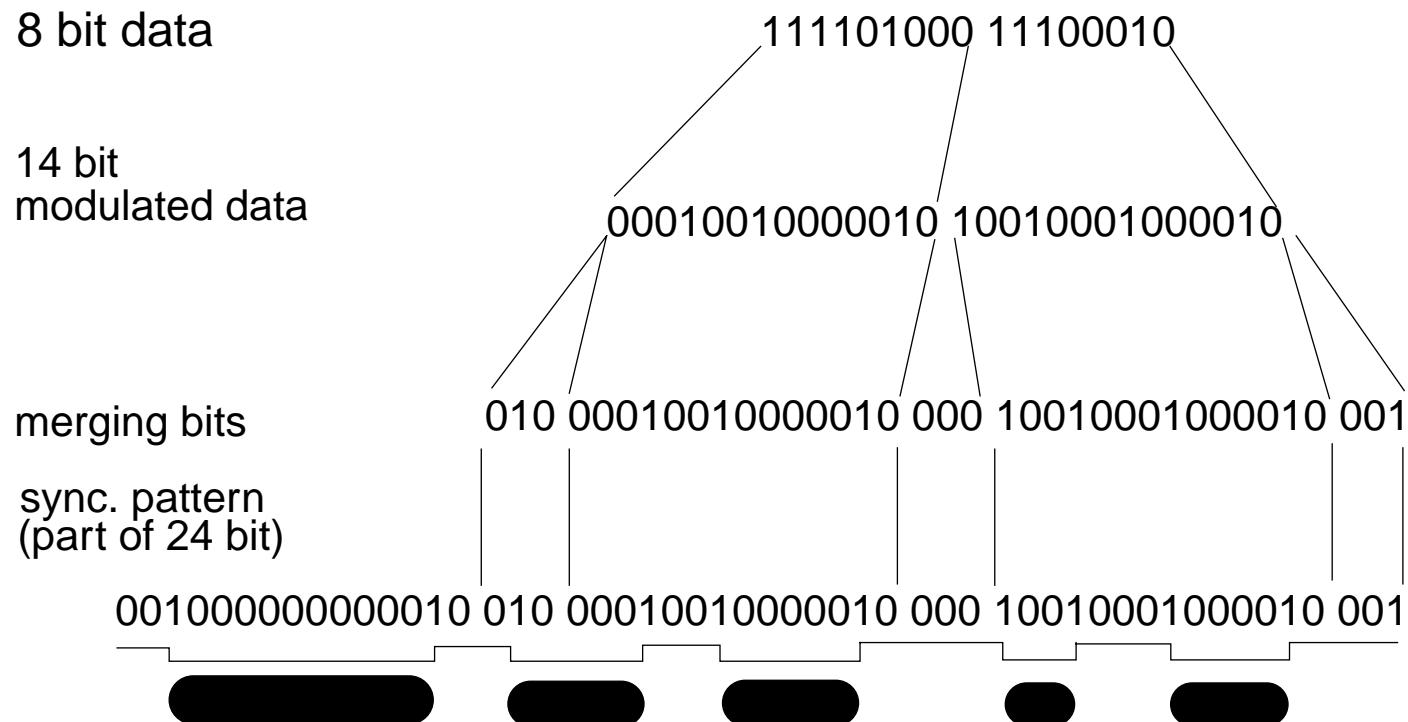
# CD-DA: Error Handling

**Typical Errors:**

- Scratches, dust, fingerprints

- „Burst errors"

- To be detected and corrected

**Two-level Reed-Solomon Code with frame interleaving:**

- First level: byte level, EDC and ECC
  - two groups: each with 4 correction bytes for 24 data bytes
  - first group: correction of single byte errors
  - second group: correction of double byte errors, detection of further errors
- Second level: Frame interleaving
  - frame: 588 channel bits = 24 audio data bytes
  - distribution of consecutive data bytes and corresponding ECC bytes over adjacent frames

# CD-DA: CIRC

**Cross Interleaved Reed Solomon Code**

**Error rate: $10^{-8}$ (~ 1bit/100 millions of bits)**

**Exact correction of 4000 data bits possible:**

- 4000 data bits * 0.3 $\mu$m/channel bit

- ~ 2.5 mm

- Hence: burst errors within 2.5 mm can be corrected

**Interpolation:**

- Up to 12,300 data bits (~ 7 mm)

- Hence: error within 7mm can be repaired

# CD-DA: Frames

**_Frame_ consists of:**

- Data:
  - 2 groups of 12 audio data bytes each (actual data)

- Error detection and correction code:
  - 2 groups of 4 parity bytes
  - According to Reed-Solomon

- Control & display byte:
  - Together with c&d bytes of other frames it forms subchannel stream
  - E.g., subchannel byte for track start identification

- Synchronization pattern:
  - Start of a frame
  - 12 x "1" + 12 x "0" + 3 merging bits = 27 bits

# CD-DA: Data Streams

**Audio bit stream ~ 1.41 x 10$^6$ bit/s:**

- 44,1 kHz sampling frequency~ 1411200 bit/s

- 16-bit stereo PCM

- Uniform quantization

**Data bit stream ~ 1.94 x 10$^6$ bit/s:**

- Audio bit stream
  + parity bytes
  + control & display byte

**Channel bit stream ~ 4.32 x 10$^6$ bit/s:**

- Data bit stream
  + EFM
  + merging bits
  + synchronization pattern

# CD-DA: Areas

**Areas:**

- Lead-in area:
  - List of contents
  - Indication to start of each track

- Program area:
  - Up to 99 tracks of different lengths
  - Typically one track relates to one song

- Lead-out area

**Random Access:**

- Tracks

- Index points:
  - $IP_0$: start of track
  - $IP_1$: start of audio data
  - Track pregap: part between $IP_0$ and $IP_1$

# CD-DA: Summary

## Provides:

- Suitable means for typical errors caused by damage, dust in audio data

- CD-DA specification is base for family of optical storage media

## But:

- Not conceived for:
  - video (different ECC, EDC scheme required)
  - discrete data (error rate too high)
- Desired: simultaneous play back of various media

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

**Storage of:**

- Data, audio, compressed audio and video

**Yellow Book CD-ROM Standard:**

- CD-ROM mode 1: for any data
- CD-ROM mode 2: for compressed audio and video data
- But can not be combined on single track

**Within single track:**

- Only CD-DA audio or only CD-ROM specific data

**Mixed Mode Disc:**

- Data tracks at the beginning
- Subsequent tracks for audio data

# CD-ROM: Structure

CD
*330 000* **blocks**

block
*2352 audio bytes*
*7203 channel bytes*

frame, channel bits
*588 bit, with*
*24 audio bytes*
$\approx 4{,}32 * 10^6$ *bit/s*

EFM
+
merging bits

synchroni--
zation

data bits
$\approx 1{,}94 * 10^6$ *bit/s*

control
&
display

CIRC

CIRC

L    L    R    R

audio bits
*1,411200 bit/s*
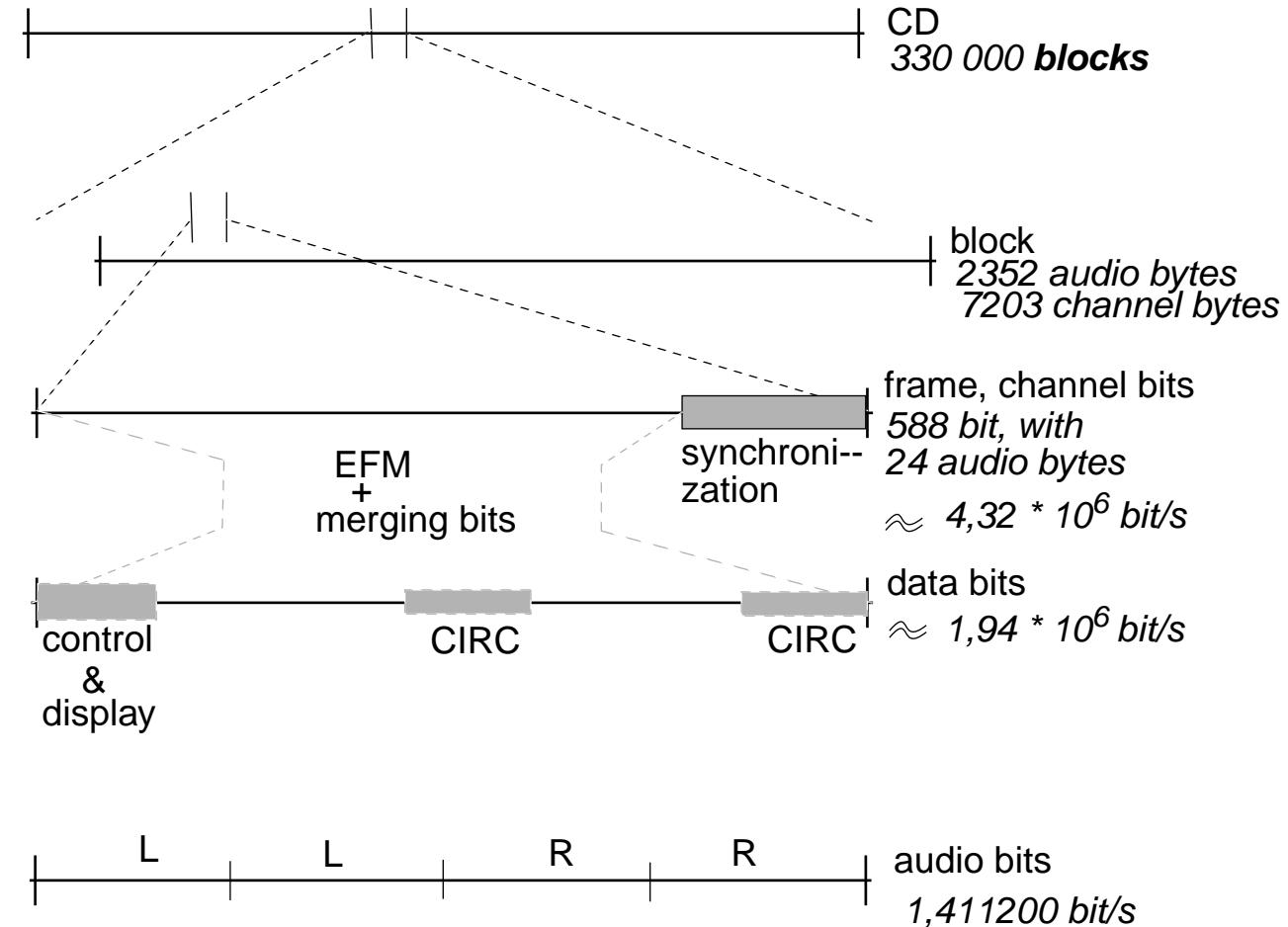
# CD-ROM: Structure

## Fine granularity for random access:

- Tracks, IP not sufficient

- Structure with a higher resolution: block

- Blocks with fixed number of frames

## Some numbers:

- 1 block = 32 frames

- 75 blocks/s  (for single-speed CD-ROM)

- 1411200 bit/s / 75 blocks/s / 8bit/byte = 2352 byte/block

## Allows for:

- Random access

- Better EDC, ECC

# CD-ROM Mode 1

| sync 12 | header 4 | user data 2048 | EDC 4 | blanks 8 | ECC 276 |
|---------|----------|----------------|-------|----------|---------|
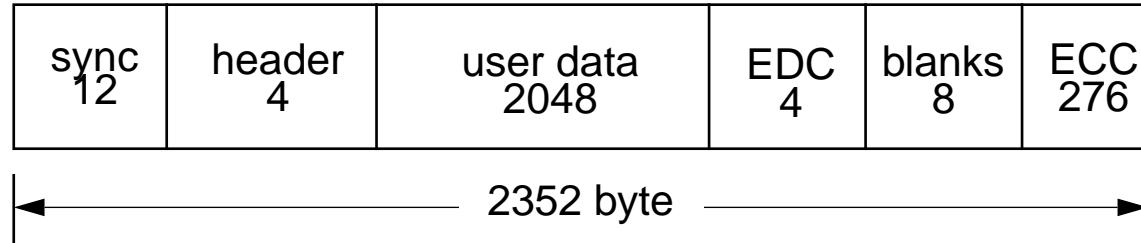
←———————————————— 2352 byte ————————————————→

## 1 block = 2352 byte:

- Header bytes include minutes, seconds, block number, mode
- Error rate = $10^{-12}$

## Capacity:

- Max. 74 min x 60 s/min x 75 block/s = 333000 blocks
- 333000 blocks/CD ~ 650 MByte (user data)

## Data rate:

- 2048 byte/block x 75 block/ s ~150 KByte/s (single-speed)

## Used by most CD-ROM applications

# CD-ROM Mode 2

| sync 12 | header 4 | user data 2336 |
|---|---|---|

|←——————————————— 2352 byte ———————————————→|
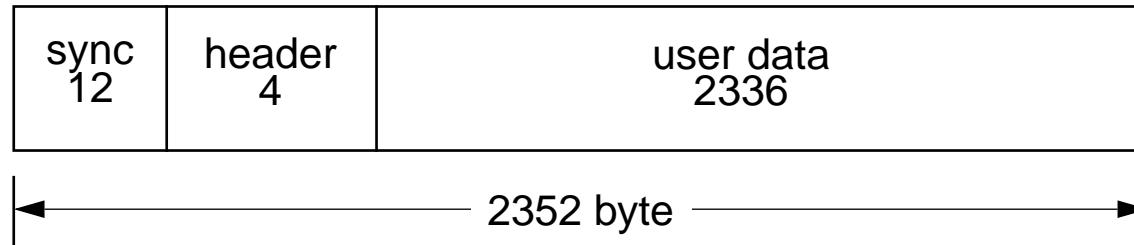
## Capacity:

- 333000 blocks x 2336 byte/block
  = 777888000 byte ~ 741.85 MByte

## Data rate:

- 2336 byte/block x 75 block/s = 171 KByte/s (single-speed)

## Problem: concatenation of mode 1 and mode 2 blocks

# CD-ROM: Average Access Time

**Time to position a block/sector:**

- Synchronization time:
  - Adapt internal clock to disc signal
  - Range of milliseconds

- Seek time:
  - Adaptation of laser to radius: max. 1s

- Rotation delay (for constant velocity time):
  - Find sector within 1 rotation
  - Adapt disk speed
  - ~ 300 ms

⇨ **Maximum access time > 1s**

⇨ **Average access time > 300ms (with data caching)**

- Simultaneous reading of audio and other data
  in CD-ROM mode 1 not possible

# CD-ROM: File System

## CD-ROM:

- No logical file format

- No directory specification

## High Sierra Proposal:

- Developed by group of industry representatives

- Initial file system leading to ISO 9660

## ISO 9660 file standard:

- Directory tree: information about files

- Path table:
  - List of all directories
  - Direct access to files of any level

- File interleaving

# CD-ROM: File System - Path Table
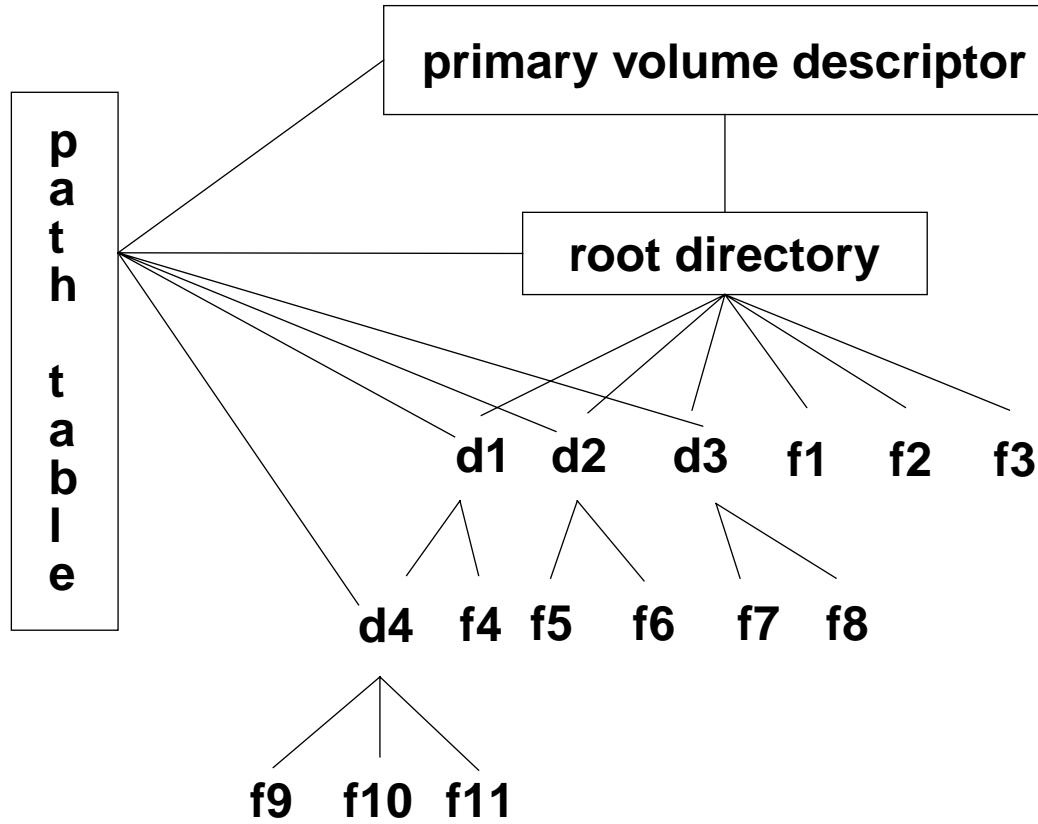
# ISO 9660 File System

**First track:**

- 16 blocks (sectors 0 to 15): system area

- Volume descriptors in subsequent blocks:
  - Primary descriptor:
    - Length of file system
    - Length and address of path table
  - Supplementary descriptors

- Volume descriptor terminator

**Logical block size:**

- Between 512 byte and 2048 byte (in steps of $2^i$)

- Blocks of 512 byte, 1024 byte, and 2048 byte are used

- Files begin at logical block start

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

**History:**

- N.V. Philips, Sony and Microsoft (announcement in 1988)

**Goal:**

- Simultaneous transfer of various media data

**Characteristics:**

- Based on CD-ROM mode 2, ISO 9660, CD-I

- Extension of Yellow Book standard

- Interleaving of blocks of different media within the same track

- Definition of a new type of track used for:
  - compressed audio (ADPCM) and video data
  - images
  - text, programs

- Distinction between two block formats: „Form 1", „Form 2"

# CD-ROM / XA (Mode 2) Form 1

| sync 12 | header 4 | sub-header 8 | user data 2048 | EDC 4 | ECC 276 |
|---|---|---|---|---|---|

← 2352 byte →
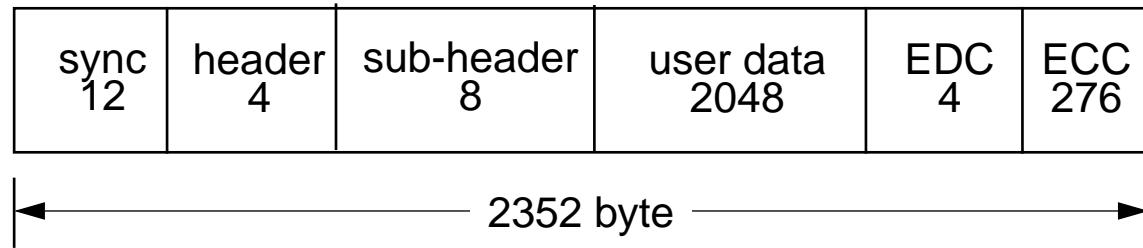
**Subheader:**

- Specification of CD-ROM Mode 2 XA-Format type

- 8 bytes

**Improved error handling for:**

- Text

- Program data

**By:**

- 4 byte for error detection

- 276 byte for error correction

# CD-ROM / XA (Mode 2) Form 2

| sync<br>12 | header<br>4 | sub-header<br>8 | user data<br>2324 | EDC<br>4 |
|---|---|---|---|---|

|← —————————————————— 2352 byte —————————————————— →|
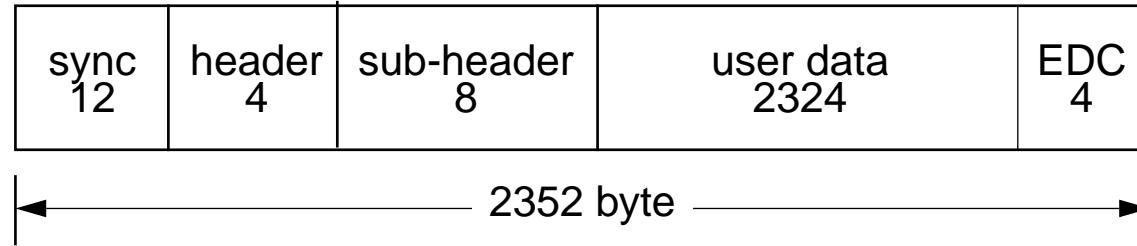
- Storage of compressed data (incl. audio, video)

- Only 4 bytes for error detection

- 13% more data bytes

# CD-ROM / XA: Audio

|  | CD audio | level B stereo | level B mono | level C stereo | level C mono |
|---|---|---|---|---|---|
| compr. ratio | 1 | 4:1 | 8:1 | 8:1 | 16:1 |
| coding techn. | PCM | ADPCM | ADPCM | ADPCM | ADPCM |
| sampling freq. | 44100 Hz | 37800 Hz | 37800 Hz | 18900 Hz | 18900 Hz |
| capacity | 74 min | 4 h 48 min | 9 h 36 min | 9 h 36 min | 19 h 12 min |
| data rate | 176 kByte/s | 43 Kbyte/s | 22 Kbyte/s | 22 Kbyte/s | 11 Kbyte/s |

# CD-ROM / XA: Drawbacks

## Compatibility to audio and video compression

- For some media only reference to standard
  - coding / decoding not part of CD technology

- MPEG audio not compatible (MPEG does not use ADPCM)

## Interleaved storage of data of different types in the same track:

- Requires special disc layout

- Requires effective interleaving with choice of suitable audio level

- Complex application development

# 7    Further CD-ROM Based Developments
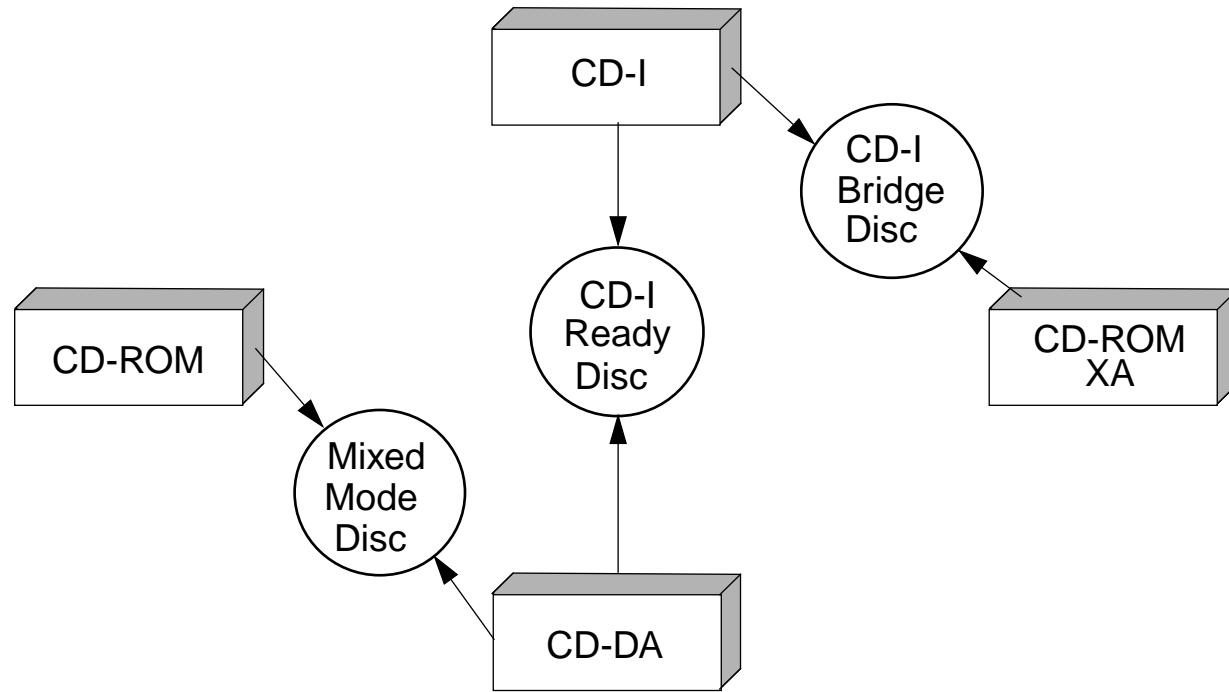
# CD-Interactive (CD-I)

## History:

- Developed by Philips and Sony

- 1986 CD-I announcement

- 1988 Green Book: CD-I extension based on Red and Yellow Book

- Originally for consumer market

## CD-I system:

- CD-ROM based format with interleaving of different media

- Compression algorithms

- Software (operating system)

- Hardware (decoder)

## Different quality levels

## Low data rates

# CD-I: Software and Hardware

**CD-I Software with CD-RTOS operating system:**

- CD-RTOS operating system is an extension of OS/9

- Real-time capabilities

**CD-I Hardware (decoder):**

- System board:
  - 680xx processor
  - Video-, audio -chips

- CD player with CD-DA components

- Mouse or joystick interface

- CD controller

- Connection to RGB monitor or TV

- Replacement of CD-DA

- Size of a video recorder

# CD-I: Audio

| | CD digital audio | CD-I 'A' hi-fi music | CD-I 'B' mid-fi music | CD-I 'C' speech |
|---|---|---|---|---|
| sampling rate | 44.1 kHz | 37.8 kHz | 37.8 kHz | 18.9 kHz |
| freq. range | 20 kHz | 17 kHz | 17 kHz | 8.5 kHz |
| encod. | 16 bit PCM | 8 bit ADPCM | 4 bit ADPCM | 4 bit ADPCM |
| s/n ratio | 98 dB | 90 dB | 60 dB | 60 dB |
| max. playing time | 74 min stereo | 2.4 h stereo 4.8 h mono | 4.8 h stereo 9.6 h mono | 9.6 h stereo 19.2 h mono |
| appr. fidelity equival. | CD | mono LP | mono FM | mono AM |

# CD-I: Video

**Coding of still images at different qualities and resolutions:**

- Different amount of data

- Different data rates

**YUV mode:**

- Reproduction of natural images with many colors

- Encoding of changes of luminance and chominance values

- 360 x 240 pixel, 18 bit/pixel

- 262144 colors

- 360 * 240 * 18 bit/image = 194400 byte/image

**Animations with few colors:**

- Run-length encoding, about 10000 to 20000 Byte/image

**MPEG for video encoding**

# CD-I: Video

## Color Look-Up Table (CLUT):

- 4 bit/pixel (3.7 or 8 bit/pixel)

- For simple graphics fast data read-out

- Predefined color table

- 720 x 240 pixel, 16 colors

- 720 * 240 * 4 bit = 86400 Byte/image

## RGB mode:

- For very good graphics

- 5 bit/pixel for each component

- 15 bit/pixel + 1 additional bit/pixel = 16 bit/pixel

- 360 x 240 pixel/image, 65538 colors

- 360 * 240 pixel/image * 16 bit/pixel = 172800 Byte/image

# CD-I Ready Format

**CD that can be played in CD-DA and CD-I players:**

- Track pregap:
  - Contains CD-I specific information
  - Increased from 2-3 s to at least 182 s
- Audio players ignore the track pregap information and play only audio data part

**Three different modes of play:**

- Standard audio playback:
  - Track pregap information is ignored and only audio data played
- Reading, display and interpretation of the pregap data:
  - Audio data part is ignored
- Displaying pregap data as audio is played:
  - First step: loading CD-I information into player's RAM memory
  - Second step: start playing audio and information display

# CD-I Bridge Disc

```
                                    ┌──────────┐
                                    │  CD-I    │
                                    └──────────┘
                                        │        ╲
                                        │         ╲    ╭─────────╮
                                        │          ╲   │  CD-I   │
                                        ↓           ╲  │ Bridge  │
                                    ╭───────╮          │  Disc   │
      ┌──────────┐                  │ CD-I  │          ╰─────────╯
      │ CD-ROM   │                  │ Ready │               ↑
      └──────────┘                  │ Disc  │              ╱  ┌──────────┐
           ╲                        ╰───────╯             ╱   │ CD-ROM   │
            ╲     ╭───────╮             ↑                ╱    │   XA     │
             ╲    │ Mixed │             │               ╱     └──────────┘
              ↓   │ Mode  │             │
                  │ Disc  │             │
                  ╰───────╯             │
                       ↖        ┌──────────┐
                        ╲       │  CD-DA   │
                         ╲      └──────────┘
```
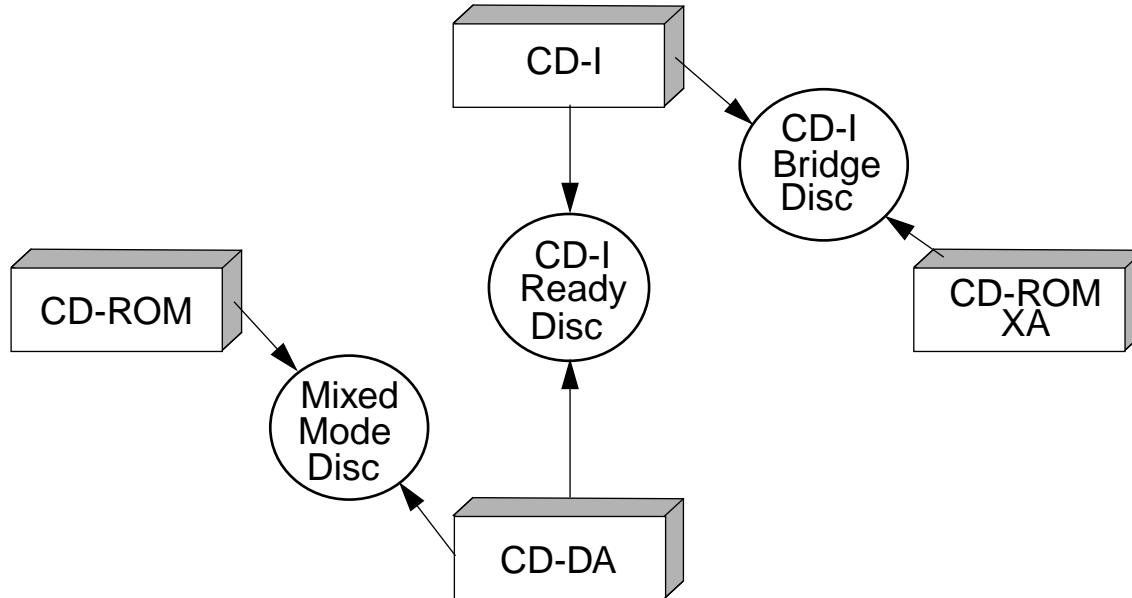
## Can be played at:

- CD-ROM players

- CD-I players

## All data tracks in CD-ROM Mode 2

## No CD-I disc tracks in the disc table of contents

# Photo Compact Disc

**Storage of photos of high quality**

**History:**

- Eastman Kodak and N.V. Philips Company

- 1990 announcement of Kodak Photo CD system

**Characteristics:**

- Example for a CD-Bridge Disc

- Based on CD Write Once (CD-WO)

- Readable with:
  - Photo CD players
  - CD-I players
  - CD-ROM / XA players

- Written by:
  - Special Photo CD players and CD-WO players

# Photo Compact Disc

## Production:

- Photos are taken with conventional cameras,

- Digitized with 8 bit for luminance component and 8 bit for each chrominance component, and

- Written on CD

## Per photo:

- ImagePac at five different resolutions: hierarchical coding

- About 3 to 6 MByte storage per ImagePac

## Capabilities:

- New professional and private application areas

- Simultaneous display of several images

- Image editing

- Integration in documents

# Photo Compact Disc: ImagePac

**Image resolution of a Photo CD:**

| type of image | compr./ uncompr. | number of lines | number of columns |
|---|---|---|---|
| base/16 | uncompressed | 128 | 192 |
| base/14 | uncompressed | 256 | 384 |
| base | uncompressed | 512 | 768 |
| 4base | compressed | 1024 | 1536 |
| 16base | compressed | 2048 | 3072 |

# 8    DVD: Digital Video Disk

**Also known as: „Digital Versatile Disk"**

**Goal:   Create a new optical media**
**to store an entire high-quality digital movie**
**on a single side of a disk**

## Technical overview of DVD:

- CD-like optical storage media
  - same size as CD $\Rightarrow$ allows for backward compatibility of reading devices
- Capacity considerably higher than CD
  - shorter pit/lands
  - tighter tracks
- EFM PLUS error correction scheme:  more robust than CD scheme
- 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

# CD versus DVD

| | CD | DVD |
|---|---|---|
| Disc diameter | 120 mm | 120 mm |
| Disc thickness | 1.2 mm | 1.2 mm |
| Laser wavelength | 780 nm (infrared) | 650 and 635 mm (red) |
| Track pitch | 1.6 µm | 0.74 µm |
| Min. pit/land length | 0.83 µm | 0.4 µm |
| Data layers | 1 | 1 or 2 |
| Sides | 1 | 1 or 2 |
| Data capacity | ~ 650 MB | Single-Layer: 4.7 GB Dual-Layer: 8.5 GB Double-Sided: 9.4 GB |

# CD versus DVD (cont.)

| | CD | DVD |
|---|---|---|
| Video data rate | ~ 1.5 Mbit/s | 1-10 Mbit/s (variable) |
| Video compression | MPEG-1 | MPEG-2 |
| Video capacity | ~ 1 hour | more than 4 hours (dual layer) |
| Sound tracks | 2-channel MPEG | 2-channel PCM 5.1-channel AC-3 optional: up to 8 data streams |
| Subtitles | - | up to 32 languages |

# DVD: Variants and Devices

**DVD variants:**

- DVD-ROM:    high-capacity data storage medium

- DVD-Video:    DVD application for motion pictures

- DVD-Audio:    DVD application for audio-only use

- DVD-R:    DVD variant allowing one-time recording of data

- DVD-RAM:    erasable and rewritable DVD variant

**DVD devices:**

- DVD Movie Player:    consumer appliance (similar to video player)

- DVD-ROM drive:    computer peripheral

# 9     Compact Disc Write Once (CD-WO)

**Cross-section through disc in direction of spiral track:**



- protective layer
- reflective layer
- absorption layer
- pit / land
- substrate layer
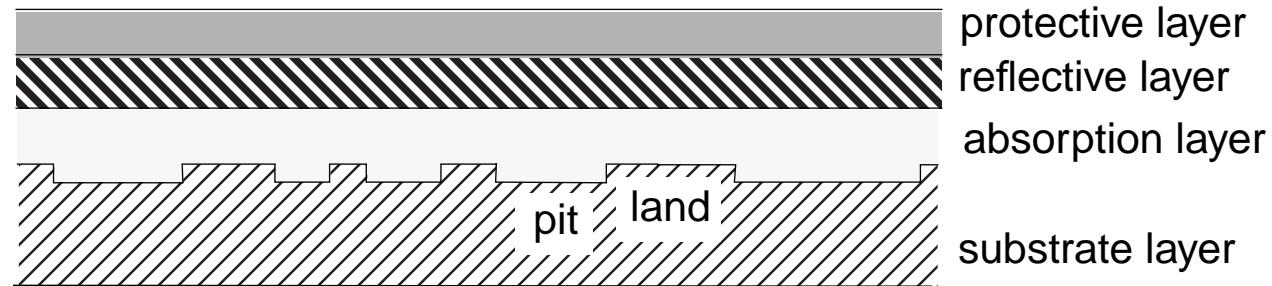
**Defined in Orange Book Standard Part II**

# CD-WO

## Principles:

- Pre-grooven track

- Absorption layer between substrate and reflective layer

- Irreversible change of the reflection characteristics by:
  - Heating up the absorption layer

- CD-WO can be played in CD-DA players

## Sessions:

- CD player needs table of content

- Several sessions each with:
  - Lead-in part
  - Data part
  - Lead-out part

- New sessions can be added

- Maximum of 99 sessions

# CD-WO

**Disc layout with several sessions:**

| lead in | information | lead out | lead in | information | lead out | ... |
|---------|-------------|----------|---------|-------------|----------|-----|

|←——————— session 1 ———————→|←——————— session 2 ———————→|
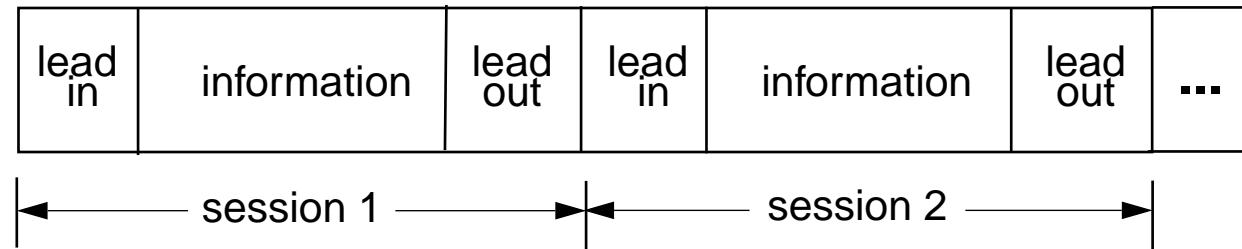
- CD players before 1992 can only read first session
- Regular CD-WO: only one session
- Hybrid CD-WO: several sessions

# 10 Compact Disc Magneto Optical (CD-MO)
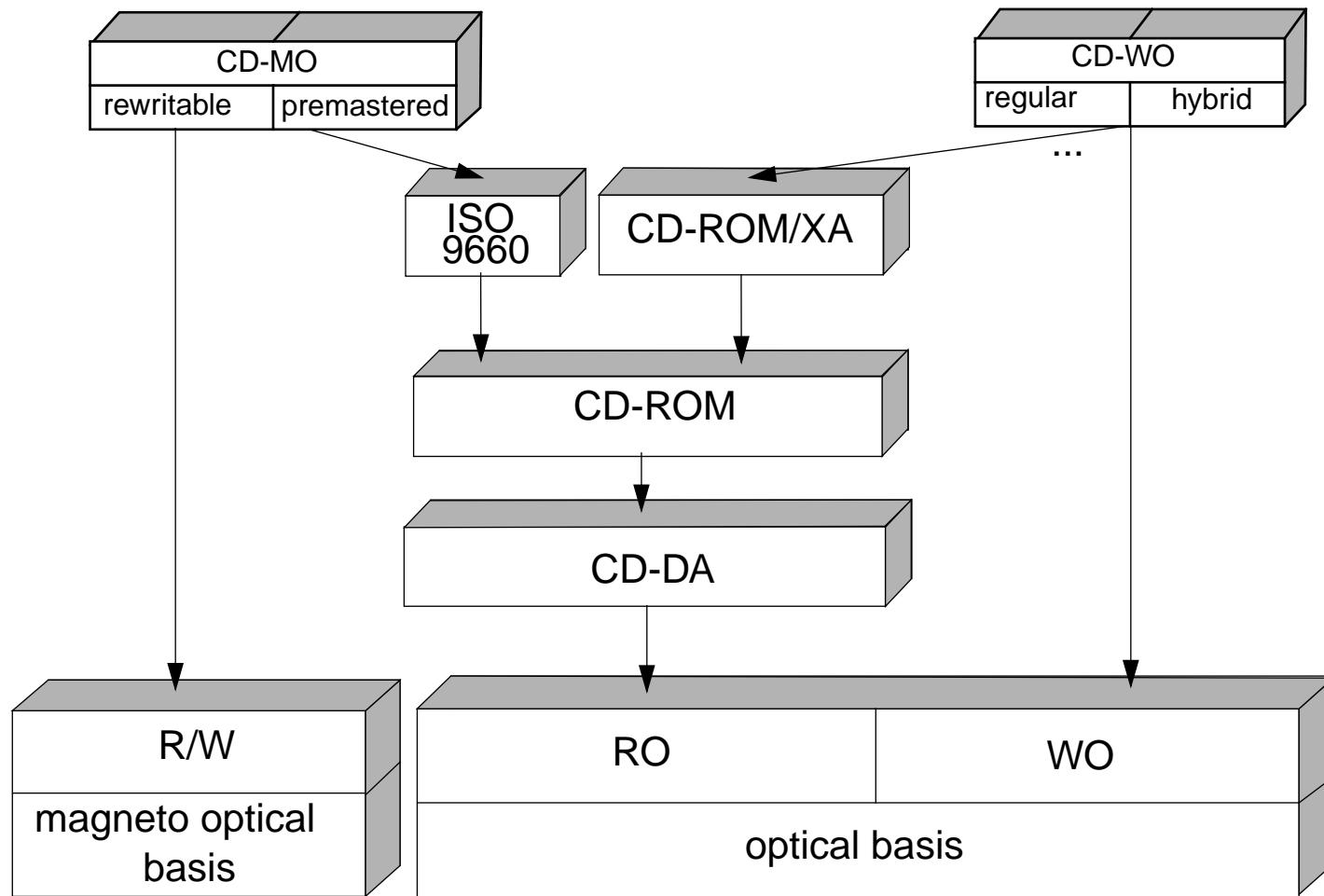
# CD-MO: Features

**Write, read, erase, and rewrite data**

**Definition in Orange Book Standard Part I:**

- High capacity (double-sided): about 650 MByte

- Data transfer rate: about 1.2 Mbit/s

**Principles of magneto optical technique:**

- Write:
  - Heating up of blocks
  - Apply about 10 x earth magnetic field
  - Polarization of single elements

- Discard:
  - Use constant magnetic field
  - Simultaneous heating up of block

- Read:
  - Polarization of light is influenced by magnetic characteristics

# CD-MO: Premastered and Rewriteable

**Optional premastered area:**

- Read-only

- Readable on any CD-player

- Using Red, Yellow and Green Book specifications

**Rewriteable area:**

- Use of different magneto-optical encoding techniques
  ⇨ incompatible to other CDs

- Cannot be read by standard CD-players

# 11   Summary

**Features of Compact Disc Technologies:**

- Can be used for all kind of storage

- Wide application area

- Large capacity

- Base is CD-DA technology (except CD-MO)

- Sequential specification of the different CD technologies

**Disadvantages:**

- Long average access time

- Incompatibility of CD-MO

**Future:**

- CD with enhanced storage space and data retrieval rate

- Smaller optical disc with similar capacity