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ABSTRACT

This guide provides information on many aspects of CD-ROM development. Storage requirements of multimedia applications such as graphic images, audio, video, and animation are provided in section one. Storage capacity, transfer rate, and access time are the three criteria used to judge various storage media. In section two, specifications for these criteria are given for floppy disks, hard drives, network delivery, removable media, laser discs, and CD-ROMs. The following aspects of CD-ROM technology are discussed in section three: How do CD-ROMs work?, and How is data read from and organized on CD-ROMs? A discussion on constant angular velocity (CAV), constant linear velocity (CLV), and data layout of CD-ROMs is also included. Section four provides information on CD-ROM standards, including physical level standards (Red Book, Yellow Book, Green Book, Orange Book, and White Book) and logical level standards (High Sierra, ISO-9660). Hardware and software requirements for CD-recordability are outlined in section five. CD-recordable process steps include: (1) preparing the data and applications; (2) premastering; and (3) mastering. (MAS)

Developing CD-ROMs: Pitfalls and Detours On the Road to the Digital Village

Texas State Technical College
Waco

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I. STORAGE REQUIREMENTS OF MULTIMEDIA APPLICATIONS

A. Graphic images storage requirements

Realistic images are one of the best methods to illustrate the world around us. However, graphics can occupy a large amount of storage space. Listed below are the storage requirements of a typical graphic at various color resolutions:

256 Colors, 8-bit ---- 740 Kb

65,536 Colors, 16-bit ---- 1.1 Mb

16.7 million colors, 24-bits ---- 1.5 Mb

B. Audio storage requirements

Even using various compression algorithms, the demands for audio storage are high. Figure 1 is a listing of various storage rates for one minute of audio.

Various quality levels of ADPCM have been set. The following compares CD-ROM/XA compressed audio with CD-audio and .WAV files.

Quality Level	Sampling Frequency	Resolution	File Size Per 1 Min. Stereo Audio
CD-Audio	44.1kHz	16-bit	10.1MB
ADPCM Level A	37.8kHz	8-bit	4.3MB
ADPCM Level B	37.8kHz	4 bit	[illegible]
ADPCM Level C	18.9kHz	4-bit	1.1MB
.WAV File	22.05kHz	8-bit	2.5MB
.WAV File	11.025kHz	8-bit	1.3MB

Figure 2 Audio storage requirements

C. Video storage requirements

Video is the best method to show movement and the complex interrelationships between these motions. The storage rates for video, even compressed video, are very high. The size of the window, the frame rate, and the numbers of colors all add to these storage requirements. In Figure 2 are the storage requirements for 10 seconds of video.

Screen Area	Window Size	Frame Rate	Color Depth	Uncompressed File Size	Playback Data Rates
Quarter-Screen	160x120 Pixels	15 FPS	8-bit	2.88MB	2.88KB/Sec
Half-Screen	320x240 Pixels	15 FPS	8-bit	11.52MB	1.15MB/Sec
Half-Screen	320x240 Pixels	30 FPS	8-bit	23.04MB	2.3MB/Sec
Full-Screen	640x480 Pixels	30 FPS	8-bit	92.16MB	9.2MB/Sec

Figure 3 Video storage requirements

D. Animation storage requirements

Animation allows the user to visualize situations that would be difficult to demonstrate in any other manner. Animation's storage requirements, depending on number of colors, number of frames and window size, can vary from a few thousand bytes to many megabytes.

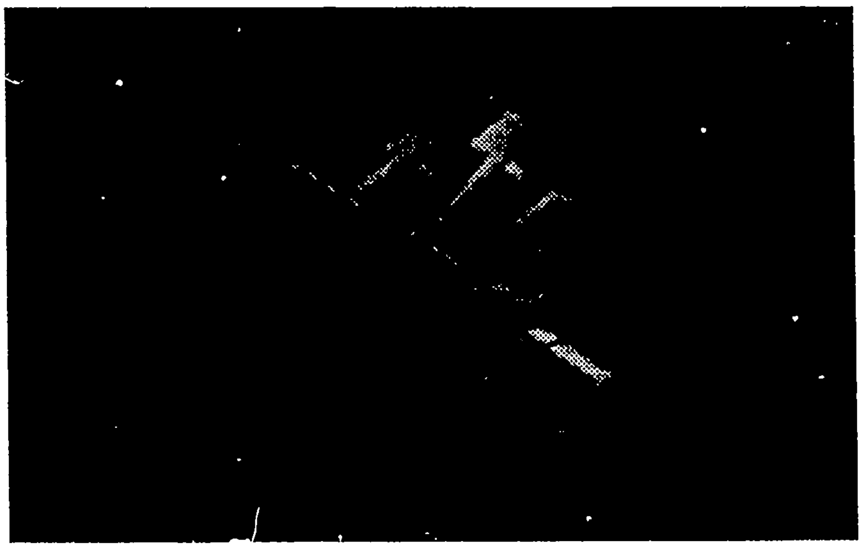

Figure 4 Animation frame

II. STORAGE CAPABILITIES OF VARIOUS MEDIA

A. There are three criteria to judge various storage media by:

1. *Storage Capacity* -- The storage capacity of a media. Usually measured in megabytes (MB). (Higher is Better)

2. *Transfer Rate* -- The number of bytes that can be transferred from the media in a set amount of time. Usually measured as kilobytes per second (KB/sec) or megabytes per second (MB/sec). (Higher is Better)

3. *Access Time* -- Access time is comprised of two measures: seek time and latency. Seek time measures how long the media takes to locate the data and latency is the amount of time before the data is ready to be read. Usually measured in milliseconds (ms). (Lower is Better)

B. **Floppy Disks**

1. Storage Capacity: 360 KB to 1.44 MB
Transfer Rate: 150 KB/sec
Access Time: 500 ms

2. *Advantages*
----Cheap
----Transportable

3. *Disadvantages*
----Transfer rate low
----Access time high
----Low storage capacity

C. **Hard Drives**

1. Storage Capacity: 80 MB to 2 GB
Transfer Rate: 1-4 MB/sec
Access Time: 9-30 ms

2. *Advantages*
----Fast transfer rates
----Low access times
----Large storage capacity

3. *Disadvantages*
----Not transportable

D. **Network Delivery**

1. Storage Capacity: Unlimited (subject to storage space on network)
   Transfer Rate: 1 - 16 MB/sec
   Access Time: Variable

2. *Advantages*
   ----Large storage capacity
   ----High transfer rates

3. *Disadvantages*
   ----Connection not always available
   ----File transfer does not synchronize multimedia (video, audio)

E. **Removable Media**

1. Storage Capacity: 250 MB to 1 GB
   Transfer Rate: 1 - 4 MB/sec
   Access Times: 15 - 30 ms

2. Types
   --Bernoulli boxes
   --Writable Optical disks
   --Magnetic-Optical (Floptical)

3. *Advantages*
   ----Large storage capacity
   ----High transfer rates
   ----Transportable

4. *Disadvantages*
   ----Not widely used
   ----Expensive (optical disks)

F. **Laser discs**

1. Storage Capacity: 30 minutes video per side or 54,000 frames
   Transfer Rate: direct pass through to video screen
   Access Time: ~250 - 400 ms

2. *Advantages*
   ----Large storage capacity
   ----No need to involve computer CPU in delivery to screen

3. *Disadvantages*
   ----Not widely used
   ----Mainly a video format

G. **CD-ROMs**

1. Storage Capacity: 680 MB
   Transfer Rate: 150, 300, 450, 600 KB/sec
   Access Time: 150 - 350 ms

2. *Advantages*
   ----Large storage capacity
   ----Widely in use

3. *Disadvantages*
   ----Transfer rates barely adequate
   ----High access times
   ----Need CD-Recordable technology to create

III. CD-ROM TECHNICAL ASPECTS

A. How Do CD-ROMs Work?

1. How is Data Read from a CD-ROM?

CD technology is based on the principle of measuring the reflection of a laser light beam from microscopic pits corresponding to "1"s and "0"s of digital data. See Figure 5.

The Compact disc begins with a transparent polycarbonate disc into which pits are physically formed. The pits and lands (the surface between the pits) run along a spiral data path that is equivalent to 16,000 tracks per inch.

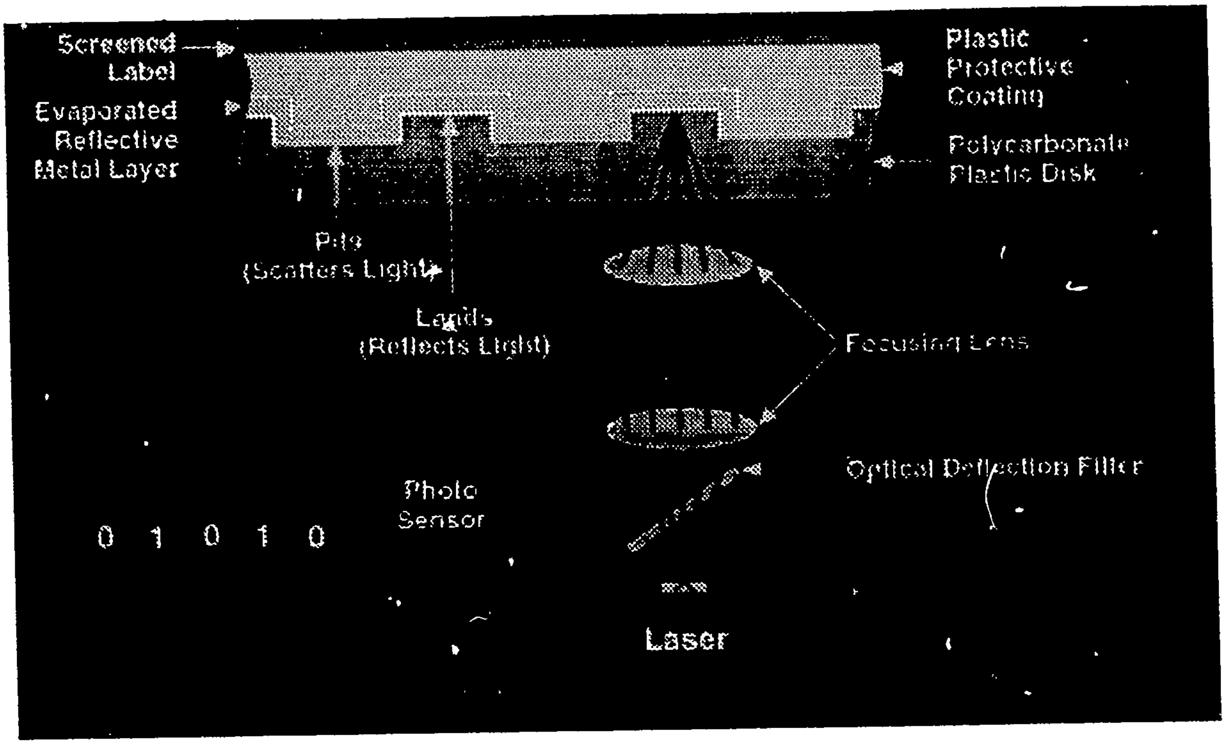

Figure 5 Laser reading CD-ROM

2. **How is the data on a CD-ROM organized?**

To understand the physical data structure of a CD-ROM, first you need to realize that there are two ways to spin a computer disk:

a. **Constant Angular Velocity (CAV)**

With CAV disks (Hard Drives, Optical Drives) the angular velocity of the disk remains constant (the RPM of the disk platter is constant). However, relative to the read/write head, the disk mo es faster on the outer tracks than the inner tracks. Therefore, the density of data is reduced on the outer tracks which results in less information stored on the disk. All magnetic drives use the CAV format with concentric tracks. See Figure 6.

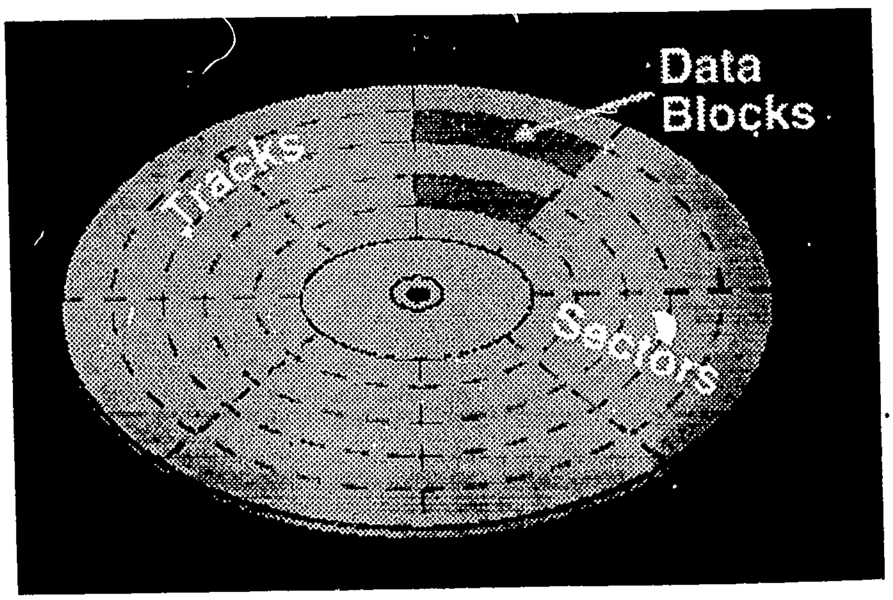

Figure 6 CAV disk

b. **Constant Angular Velocity (CAV)**

With CLV disks the linear velocity of the rotating disc relative to the read/write head remains the same (the disk platter's RPM changes). Therefore, the disc rotates faster when the read/write head is on the inner tracks than when its on the outer tracks. On the inner tracks the RPM is approximately 550 and drops to 200 as the read/write head moves to the outer tracks.

The advantage of CLV is that more data can be stored on the outer track of the disk compared to CAV. The disadvantage is an increase in the random retrieval time due to the fact that when the head moves from the inner to outer tracks, the system has to wait until the rotating speed of the disc is reduced to maintain constant velocity. All compact discs use CLV. See Figure 7.

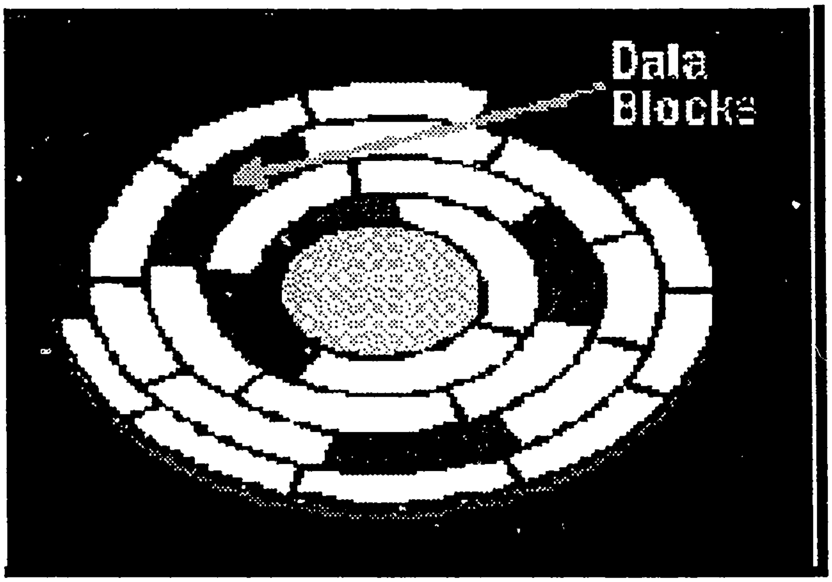

Figure 7 CLV disk

Compact discs read 75 blocks per second, since each block contains 2 KB of data, the transfer rate of a typical first generation CD-ROM reader was 150 KB per second. This rate is know as "1X" in CD-ROM terms. To reach this rate the disc must reach a linear velocity of 1.3 meters per second. The newer electronics can read a disc at a higher velocity in multiples of 1.3 meters per second. If a CD-ROM drive can reach a velocity of 2.6 meters per second, the transfer rate is 300 Kb per second, and the drive is known as "2X" reader. For a "3X" reader, the velocity is 3.9 m/sec and the transfer rate is 450 Kb/sec. For a "4X" reader, the velocity is 5.2 m/sec and the transfer rate is 600 Kb/sec.

The CLV format used by compact discs precludes using the "track and sector" addressing schemes used on magnetic disks. Instead, compact discs use a scheme that is clearly relative to its digital audio roots. If you "play" a disc from beginning to end, you find that there is room to record 74 minutes worth of data.

Each minute of recording can be divided into 60 seconds. In each second the drive can play or read 75 blocks. Each block consists of two kilobytes of data. The entire disk can hold 333,000 blocks or 681,984,000 bytes. The individual block is the smallest unit that can be addressed in terms of the minute of play, the second within the last minute and the block with the last second. The origin of the disk is specified as 0:0:0 (zero minute, zero second, zero block).

So, the data is stored in blocks in the spiral tracks of the CD-ROM and is referenced by its minute:second:block. All of this must be arranged in some organized fashion sc the CD-ROM reader can locate the desired information.

3. **Data Layout of CD-ROM**

A disc can be written in a single session or in multiple sessions (multisession). A session will contain a "Lead In" and a "Lead Out" area which are written before and after the data. The data area contains one or more tracks. A track is a complete file structure or audio segment written in one attempt. It is possible to have up to 99 tracks on a compact disc. There is also an index stored at the beginning of the disc that contains the physical addresses of all the tracks. The index is called the Table of Contents (TOC). See Figure 8.

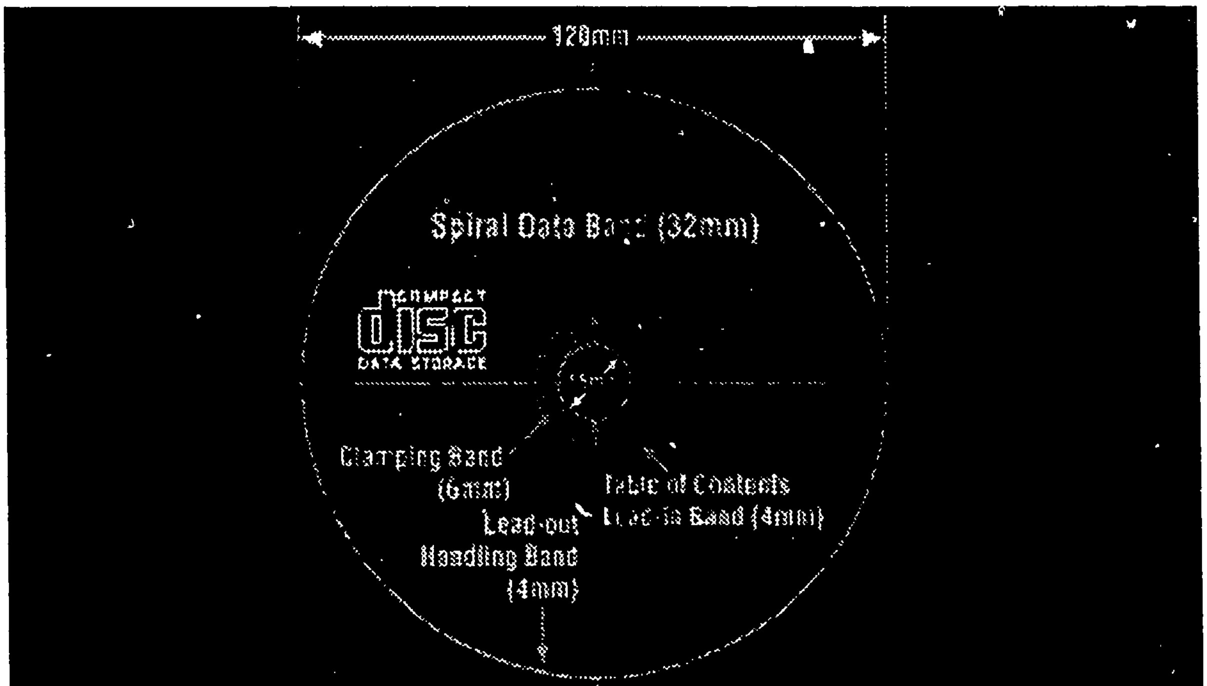

Figure **8** Disk Information

IV. CD-ROM STANDARDS

Without standards dealing with the physical placement of data and it's logical representation, everyone developing CD-ROM drives or software would have to develop their own proprietary system. If you had a drive from one manufacturer, a CD-ROM meant for another's drive couldn't be accessed.

Standards of data storage media consist of two levels: physical and logical.

For example, on a hard disk drive, the physical level is the tracks and sectors on the disk. The logical level defines the actual file structure consisting of directories, subdirectories, and files.

A. Physical Level Standards

Major compact disc formats are:

CD-AUDIO

CD-ROM (Compact Disc-Read Only Memory)

CD-I (Compact Disc Interactive)

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

Other (PHOTO-CD,VIDEO-CD)

The physical structures of CD's are based on the "book" standards. The book standards for compact discs break up the record tracks into sectors that are 1/75th of a second long and contain 2352 bytes of data plus 882 bytes for error control and correction. The 2352 bytes are also called a block which is organized into 90 frames of 24 bytes each.

Red Book Standard - CD-Audio

Yellow Book Standard - CD-ROM

Green Book Standard - CD-ROM/XA & CD-I

Orange Book - multisession & White Book - Video-CD

1. **The Red Book Standard**

The Red Book standard uses the entire 2352 bytes for audio data. It is also known as CD-DA (Compact Disc - Digital Audio). Red Book adds 794 bytes for error detection and correction (ECC) codes and 98 control bytes, making a total sector length of 3234 bytes. If the laser cannot read a damaged disc, the EDC/ECC is used to recreate the music. At 75 sectors/second, 60 minutes of audio is equal to 636 MB playing at 176.4 KB/second. See Figure 9.

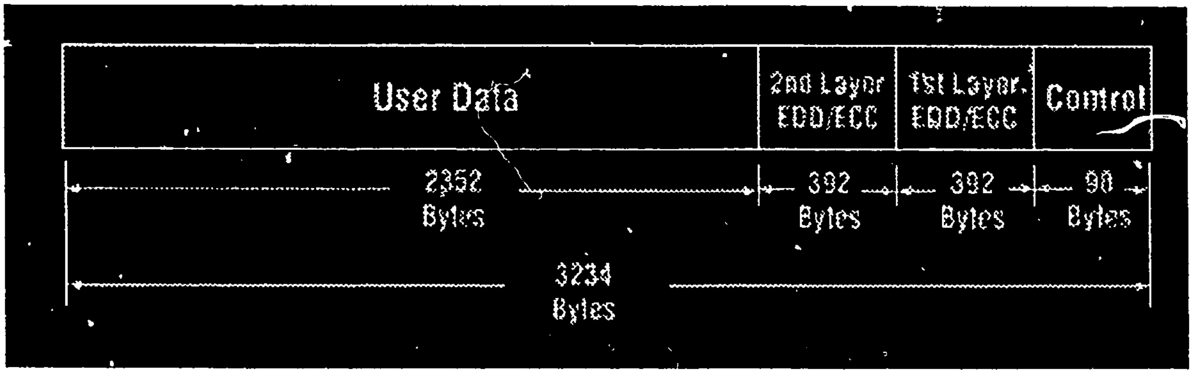

Figure **9** Red book block

2. The Yellow Book Standard

The Yellow Book mode 1 standard applies to CD-ROM and its use with computer data. Less bytes are allocated for user data, in order to add sync and header bytes to let the computer know what sector it is reading. EDC and ECC are also added to increase computer data reliability. At 75 sectors/second, a full CD-ROM disc would contain about 680 MB of computer data playing at 153.6 KB/second. See Figure 10.

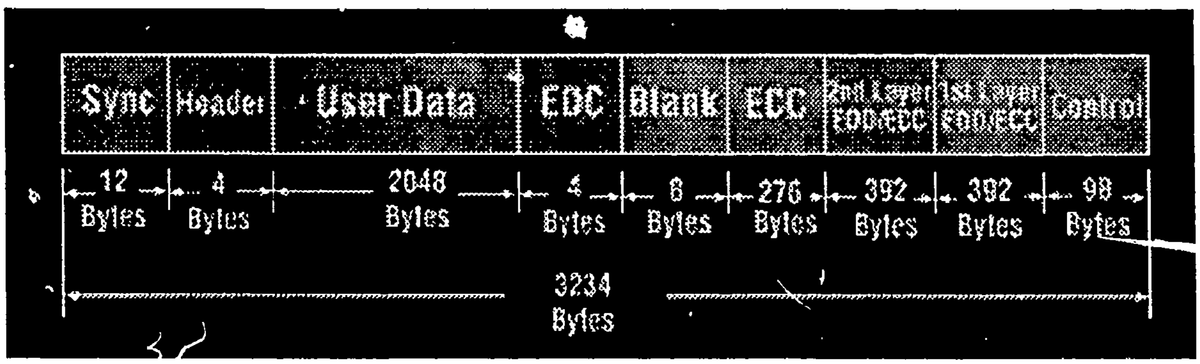

Figure **10** Yellow Book block

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3. The Green Book Standard

The Green Book standard applies to the Extended Architecture (XA). The Form 1 is used for computer data while Form 2 is used for compressed audio and video data. CD-ROM/XA allows Form 1 computer data to be interleaved on the same track with Form 2 audio/video data such that both appear to playback at the same time. In Form 2, if audio is compressed, the quality level is reduced from normal CD-Audio levels. The Green Book is also used for CD-I formats. See Figure 11.

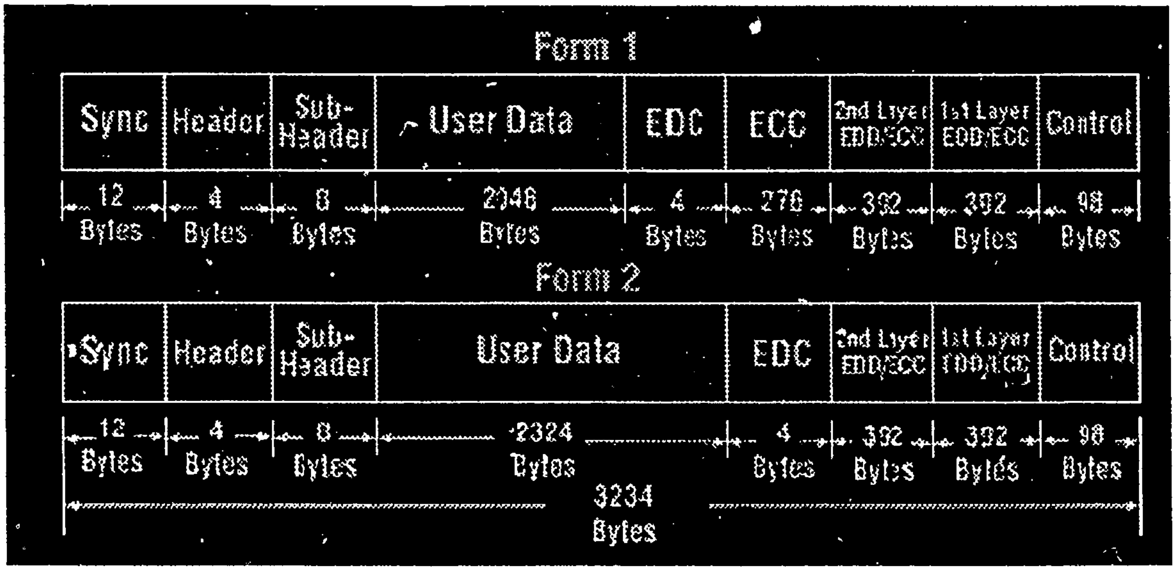

Figure 11 Green Book block

4. Other book standards are:

   a. The Orange book standard which deals with multi-session recording of CD-ROMs. Multi-session means that data can be added to the disc during different recording sessions. WORM (Write Once Read Many) optical drives are based on this standard.

   b. White book is an emerging standard that mainly deals with the delivery of full screen video. The Video-CD is based on this standard.

5. CD-ROM Formats:

a. CD-I Format:

i. The Green Book standard also applies to the CD-I format

ii. CD-I is a product introduced by Phillips for the consumer market which permits text, graphics, audio, and video on a CD-I format disc to be played through to a conventional TV set. Interactivity for the user is the key feature.

iii. Like CD-ROM/XA, CD-I takes advantage of interleaving, compressed audio and various levels of video resolution and color depth.

iv. The future of CD-I might be limited by the relatively low number of titles and its ties to conventional TV.

b. Photo CD:

i. Eastman Kodak has developed the Photo CD process which requires the CD-ROM/XA standard for playback. The process enables users to transfer 35 mm photos to CD-ROMs for viewing through players connected to TV sets or computers.

ii. Photo CDs hold up to 100 photo images or more. Various firms now sell various photo collections through this format.

iii. CD-ROM/XA drives must have multisession capability to view additional groups of images that were added in later sessions to a partially filled disc.

c. CD-ROM/XA Format:

i. CD-ROM/XA offers enough advantages over CD-ROM, so that the CD-ROM Yellow Book will probably give way to the CD-ROM/XA Green Book standard. Some of these advantages are that the audio can be compressed to reduce storage file sizes and the audio can be interleaved with the text and graphics.

ii. CD-ROM/XA drives are needed for both Photo-CD and for CD-I.

iii. MPC Level 2 is recommending that CD-ROM drives be ready for upgrading to CD-ROM/XA.

6. CD-ROM Formats Review:

   a. Yellow Book standard is the standard that most current CD-ROM drives are based on.

   b. The built-in error detection and correction codes result in virtually zero errors in the digital data output.

   c. The time it takes to access data and the rate at which it is transferred are important parameters for CD-ROM drives.

B. **Logical Level**

The book standards deal with converting pits and lands into physical blocks of data. The logical structure deals with converting blocks of data into files, directories and volumes.

1. There are currently two major logical architectures for CD-ROMs:

   a. High Sierra

   After the announcement of the Yellow Book standard, in 1985, a consortium of major computer manufacturers and software developers assembled in Lake Tahoe, California to design a file format for CD-ROM. Since Lake Tahoe is in the Sierra mountains, the file format was named the High Sierra file format (HSF). This standard become the basis for the draft version of the International Standards Organization (ISO) 9660 standard. With minor modifications, the High Sierra format was adopted as ISO-9660 in 1987.

   b. ISO-9660

   In developing the ISO-9660 standard, there was a primary goal and a secondary goal:

      i. The primary goal was to build a file system that could be accessed across multiple platforms (i.e., DOS, Macintosh, UNIX, etc.).

      ii. The secondary goal was to develop a file system that could compensate for the slow seek performance of CD-ROM drives.

   There is a piece of software available for each platform that can read ISO-9660 file structure on a CD-ROM. On the DOS, platform, this software is called the Microsoft CD Extensions (MSCDEX) and on the Macintosh platform this software is called Foreign File Access.

c. In building a CD-ROM application, converting your application files into ISO-9660 is not mandatory. You can use ISO-9660, the native file structure of the host operating system, or a proprietary file format. There are several reasons to use the ISO-9660:

i. Since retrieval software can utilize MSCDEX to access the disc, most commercially available search software packages require to the disc to be in ISO-9660 file format.

ii. Other MS-DOS commands like DIR, TYPE, and COPY can be used with CD-ROM files. MS-DOS uses MSCDEX to access the disc.

iii. ISO-9660 is designed specifically for CD-ROM and compensates for the slow performance of the CD-ROM, making the application run faster.

iv. You can read files under different operating systems (e.g., UNIX, Macintosh, DOS). Although program files stored on the disk may not be executable under a different operating system, data files can be read.

V. CD-RECORDABLE

A. Hardware and Software Required

1. Personal Computer:

a. The platform utilized for disc recording devices can be any personal computer - Intel-compatible, Macintosh or Unix workstation. The critical component is a fast hard drive.

b. CD recorders require a steady flow of information. A hard disk that can transfer at least 1,000 KB/s is recommended for writing a CD-ROM image (ISO-9660) to a double-speed CD recorder.

c. If an image (ISO-9660) is being built while data is written to the recorder (image-on-the-fly), the data transfer rate of the hard disk should be at least 1,500 KB/s.

d. The success of mastering process depends not only on the transfer rate of the hard disk, but also on the physical location and the fragmentation of the files.

2. CD-Recorders:

a. The first compact disc recorders appeared in 1989 and cost from $25,000 to $50,000. The latest generation costs from $2,500 to $10,000. Some points to keep in mind when choosing a CD recorder:

b. All CD recorders use the SCSI (Small Computer System Interface) interface. You must have a SCSI controller card installed in the personal computer (the Macintosh line has on board SCSI).

c. CD recorders write in multiples of 150 KBs. Most current generation recorders are 2X drives, in other words, record at 300 KBs. The faster the drive, the less time it takes to record a disc. Some of the newest recorders with 4X and even 6X drives can record a 680 Mb disc in as little as 10-15 minutes.

d. All recorders can write the four formats; CD-Audio, CD-ROM, CD-I and CD-ROM/XA. Some can also support multisession recording, such as Photo CD.

3. Premastering/Mastering Software

Premastering/mastering software provides the link between the personal computer and the CD recorder. The difficulty and quality of the CD-R process depends greatly on the premastering mastering software. There are several points to keep in mind when selecting a software package:

a. Which CD recorders are supported (Kodak, Phillips, Sony, Yamaha)?

b. What platforms is the application targeted at (DOS, Windows, Mac, etc.)?

c. What recording formats does the software support (IS0-9660, HFS, CD-Audio, CD-ROM/XA. CD-I, Mixed Mode, Video CD)?

4. CD-R Media

Current blank CD-R discs cost from $15 to $40. There are some similarities and differences between the normal CD-ROM discs produced in a manufacturing facility and a CD-R disc:

a. Both use a polycarbonate substrate and both have a protective lacquer coating.

b. In the traditional CD-ROM, a aluminum layer is used as a reflective layer. The disc is stamped with the information creating the pits and lands.

c. The CD-R disc has grooves stamped in it. An organic dye layer covers the grooves. The organic dye layer is deformed by a powerful laser in the CD recorder to form the pits and lands. Covering and protecting the dye is a layer of gold. Once the deformations have occurred; they are permanent.

B. The CD-Recordable Process

The basic steps for developing a compact disc are the same for both the CD-R process and for the traditional facility manufacturing process, with the exception of some changes at the point of mastering and replicating the disc. A CD-R can be sent to a replication facility for mass production. The basic steps are:

1. Preparing the data and applications

Distributing data and applications to users is the purpose of the CD-R process. You can create these data files and applications utilizing the best software for the particular type. You can use paint programs to create the graphics, capture/editing software for video clips, sound manipulation applications for the music and sound and, finally, a programming or authoring language to build the user interface to your data. There are a few points to remember:

a. If your application is designed to offer a large searchable index of information to the user, consider using specialized authoring software that lets you create databases and indexes for the data.

b. Identify the files you want on the CD-ROM. Include both the data files and any user interface applications that you have developed.

   Thoroughly test the completed application from your hard disk. If there are problems with the application before copying to the CD-ROM, there will be problems afterward.

2. Premastering

Premastering can also be called logical formatting. You select the file structure for the disk (IS0-9660, HFS, etc). You choose the physical placement of files on the disc and finally you may simulate the application from hard disk.

a. Since the retrieval performance of CD-ROM is slow relative to hard drives, the geographical location on files on the disc is important. Most frequently accessed files should be stored on the inner tracks to improve retrieval performance. The premastering software will allow you to control the exact placement of the file in terms of logical block address or physical block (min:sec:block) address.

b. After the data has been converted into the logical file format, the application can be simulated on the hard disk.

3. Mastering

After the files have been converted into the file format in the premastering process, the volume partition (or the CD-ROM image) can be transferred to the CD-R media using the CD recorder and mastering software.

a. If you wish your CD-ROM to be mass produced, the disc produced by the CD recorder can be sent to a replication facility for production. The CD-R, however, cannot be used as a master. The facility will read the data from the disc and create a metal stamper.

b. You can also send the disc image to the replication facility on DAT tape.

Reading List:

New Media magazine, Special Issue, 1995 Multimedia Tool Guide

The CD-Recordable Bible, Pahwa, Ash. Eight Bit Books, 1994

"Doing it Yourself: Archiving and Desktop Publishing with CD-Recordable" CD-ROM Professional magazine, Jan. 1994

"Premastering and CD-WO Software for the PC - Evaluations of Top In-House Publishing Software", CD-ROM Professional, May, 1993