CD-ROMS, DVD-ROMS, AND COMPUTER SYSTEMS

Digital mass storage technology is rapidly growing because of the growing amount of data and documents (i.e., text, line diagrams, images, digital video, animation, sound files, virtual reality "walkthroughs," and others) that we create, store and archive. Until the arrival of the Compact Disc Read Only (CD-ROM) technology, the magnetic tape and then the hard disk, both capable of reading and writing data by using magnetic media, were the most obvious mass data storage solution, as they still are today for many applications.

As with many new technologies, cost, robustness, security, speed, and reliability of storing and retrieving data are of utmost interest to every direct or indirect computer user. Therefore CD-ROMs and Digital Variety Discs (DVD-ROMs), developed as a relatively low cost (i.e., byte per cent) optical alternative for magnetic mass data storage and retrieval.

Obviously during this development, the magnetic storage manufacturers were (and still are) fighting back by simultaneously lowering their prices on mass storage devices and increasing their data transfer rates and reliability. Simultaneously, the compact disc industry has researched and developed the alternative to the CD-ROM technology, often called DVD, or DVD-ROM, which stores several times that of the CD-ROM capacity (see the actual details later).

Data read/write/access speeds have also changed. Initially the CD-ROM drive, compared with the magnetic hard disk drive, was very slow, capable of transferring only approximately 150 kbytes/s (often called the 1×, or single-speed CD drive), whereas now, CD-ROM drives achieve up to 32× data transfer rates, approximately 4800 kbytes/s. This is close to a "reasonable" hard disk drive's read/write speed. (Obviously when analyzing the transfer rate, the interface and the entire computer hardware and software system integration quality are also important.)

To summarize this introduction, mass storage devices and the storage media employed are increasingly important. Thus technologies, such as optical CD-ROMs and DVDs, are thriving. But this is not to ignore other alternatives, most importantly the emerging and increasingly fast(er) intranets and the Internet, which in the long run will offer more acceptable data transfer rates and bandwidth, than we have now. This could take some of the burden of storing and archiving digital data and documents off the individual computer user, or office, or multimedia studio—obviously at a price in security and reliability that will ensure the future and viability of the CD-ROM and DVD technologies.

HISTORY OF DEVELOPMENT: CD-ROM AND DVD

To distribute massive amounts of digital audio data at reasonable cost and high quality, industry giants, such as Philips and Sony developed the CD-ROM optical storage technology in the early 1980s, when the digital "few" were taking over the analog stereo music industry.

The obvious attractive features of the audio CD versus the vinyl LP were the relatively low cost of production, duplication, and distribution, and also the robustness of the media and the significantly clearer and better (a feature, that is still disputed by some "artistically bent" ears) sound quality that the digital technology offers over that of the analog.

It is interesting to note that as with many new, revolutionary technologies, even in the USA, where society accepts technological change at a faster rate than in most other countries, it took approximately five years for the audio CD to supplant the vinyl phonograph record industry. (Based on this experience, one wonders how long it will take to replace the current combustion automobile engine with clean electric or other types of power.)

For the computer industry, the Compact Disc Digital Audio (CD-DA) became an exciting medium for storing any data (i.e., not just audio), including computer-controlled interactive multimedia, one of the most interesting technological innovations of the twentieth century. The approximately $1.00 cost of duplicating 650 Mbytes of data and then selling it for approximately $200.00 (in those days) created a new revolution that became the multimedia CD-ROM as we know it today.

Although there are not just read-only, but also read/write CD-ROMs (see CD-RW later), typically a CD-ROM is an optical read-only media, capable of storing approximately 650 Mbytes of uncompressed digital data (as an example, a Sony

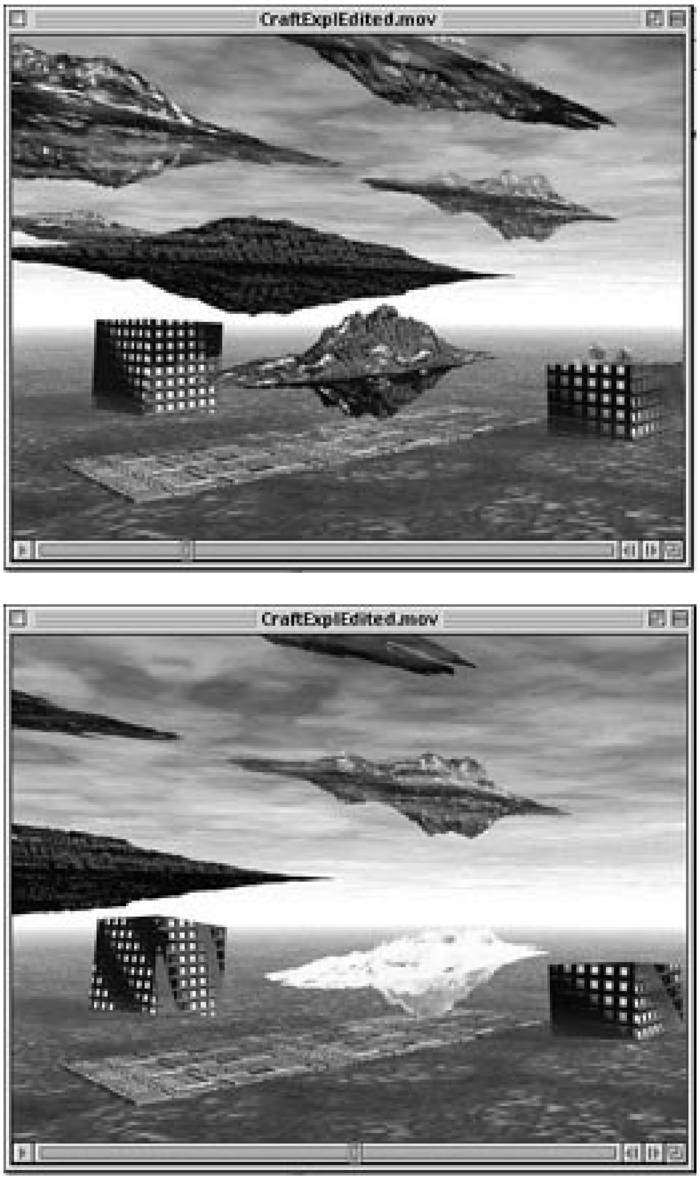

Figure 1. (top) and (bottom) A solid model animation sequence of a short battle created by Richard G. Ranky, illustrating two of hundreds of high-resolution frame-by-frame rendered complex images, integrated into a QuickTime digital, interactive movie and stored on CD-ROM. (For full color images please look up the website: http://www.cimwareukandusa.com).

CD-ROM stores 656.10 Mbytes in 335925 blocks, uncompressed), meaning any mix of text, digital video, voice, images, and others.

It is important to note that with the advancement of real-time compression and decompression methods and technologies, CD recording software packages can put more than 1.3 Gbytes of data on a CD-ROM, instead of the usual 650 Mbytes.

It is expected that with the increasing computer processor speeds and better integration (see what Apple's back-side cache can do to the overall speed of the machine), real-time compression and decompression will be an excellent solution for many applications that need more than 650 Mbytes on one CD. Obviously this also depends on the cost of the competing DVD technology! This makes the CD-ROM and the emerging higher capacity DVD technology essential to digitalizing and computerizing photography, to the animation and the video industry, and to the mass archival and document storage and retrieval business.

To illustrate the breadth and depth of the opportunities of electronic image capture, manipulation, storage, and retrieval, consider Fig. 1 (top) and 1 (bottom), and Fig. 2(a–d). (Note, that some of these images and sequences are available in full color at www.cimwareukandusa.com and that more interactive demonstrations are available in the electronic version of this Encyclopedia). Note the difference between the two figures in terms of the approach and methods used. The first set was created entirely by computer modeling and imaging, and it illustrates a totally artificial world, whereas the second first photographed real, physical objects and then the images were digitized, “pasted,” and integrated into an interactive QTVR (see later) movie (1–11).

CD-ROM TECHNOLOGY, MEDIUM, AND THE STORAGE DENSITY OF DATA

The most important differences between the magnetic (hard disk) and the optical (compact disc) technology include the storage density of data and the way data are coded and stored. CD-ROMs (and DVDs) use coherent light waves, or laser beams, versus magnetic fields that are spread much wider than laser beams, to encode information. The other major advantage is that the laser beam does not need to be that close to the surface of the media as is the case with the magnetic hard disk read/write heads. Magnetic read/write heads are as close as 16 μm, or 0.0016 mm, to the surface, increasing the opportunity for the jet-fighter shaped, literally flying, read/write head to crash into the magnetic surface. In most cases this causes catastrophic data loss to the user.

The principle of the optical technology is that binary data are encoded by creating a pattern of black and white splotches, just as on/off electrical signals do, or like the well-known bar code in the supermarket. Patterns of light and dark are read by a photo detector that changes its resistance depending on the brightness levels it senses through a reflected laser beam.

In terms of manufacturing, that is, printing/duplicating the compact disc, the major breakthrough came when engineers found that by altering the texture of a surface mechanically, its reflectivity is also changed. Dark pits do not reflect light as well as a bright mirror, meaning that the CD-ROM should be a reflective mirror dotted with dark pits to encode data by a laser beam traveling along a long spiral, just as with the vinyl audio LPs, where pits are accurately blasted onto the disc.

The CD is an 80 mm (the “minidisc”) or a 120 mm diameter (the “standard”) disc, 1.2 mm thick, and it spins, enabling direct data access, just as with the vinyl audio LP, when the needle was dropped to any of the songs in any order. (Note that the more obvious 100 mm diameter would have been too small to provide the approximately 150 Mbytes per square inch storage density of the optical technology of the 1980s, preferred by the classical music industry). This meant solving

Figure 2. (a–d) An interactively navigatable, pannable, QuickTime VR (QTVR) virtual reality movie by Mick F. Ranky of Budapest by night, allowing user controlled zoom-in/out and other hot-spot controlled interactivity. (For full color images please look up the website: http://www.cimwareukandusa.com).

the data access problem on a coated plastic disc, more simply compared with the magnetic hard disk.

To maximize the data storage capacity of the disc, the linear velocity recording of the compact disc is a constant 1.2 m/s. To achieve this at the inside and the outside tracks of the disc, the spin varies between 400 revolutions per minute (rpm) and 200 rpm (at the outside edge). In this way the same length of track appears to the read/write head in every second.

Furthermore, because of the access time in which the drive performs, it is important to note that the track pitch of the CD is 1.6 μm. This is the distance the head moves from the center toward the outside of the disc as it reads/writes data. The data bits are at least 0.83 μm long. (In other words, a CD-ROM and its drive are precision electromechanical and software instruments).

Because the distances between the tracks are so small, it is extremely important to properly cool CD writers as they cut master CD-ROMs in a professional studio, inside, or outside a PC or Mac on the desktop. Usually fan cooling is adequate. Nevertheless, air-conditioning even in a desktop environment is advisable on a warm summer day! Furthermore, such equipment should not be operated at all when the inside cooling fan breaks down!

For mass duplication, a master CD (often referred to as the "gold CD") is recorded first. Then this master is duplicated by a stamping equipment, in principle, similar to vinyl audio LP production or photocopying. A crucial aspect of this process is that the data pits are sealed within layers of the disc itself and are never reached mechanically, only optically by the laser beam. Therefore, theoretically quality mass produced ("silver") CDs never wear out, only when abused harshly leaving scratches on the surface of the disc or exposed to extreme temperatures (12–17).

CD-ROM Blocks and Sectors

The recordable part of the compact disc consists of at least three blocks. These are as follows:

- Lead-in-block, holding the directory information, located on the innermost 4 mm of the disc's recording surface
- Program block, holding the data or audio tracks that fills the next 33 mm of the disc
- Lead-out-block, that marks the end of the CD at the external 1 mm.

A compact disk is divided into sectors. The actual size available is 2352 bytes for each sector. Different CD formats use this 2352 bytes in different ways. As an example, an audio CD uses all 2352 bytes for audio data, whereas computer-oriented multimedia data formats need several bytes for error detection and correction.

Then each sector is divided further into logical blocks of 512, 1024, or 2048 bytes. These block sizes are part of the definition for each standardized compact disc format.

CD-ROM Standards

As is the case with any successful technology, everyone wants to use CD-ROMs, but in their own way, depending on the application. Therefore they have standardized both the hardware and the software to bring some order to this "chaos".

Compact disc standards include the following:

- **Red Book:** This is the original compact disc application standardized by the International Standards Organization (ISO 10149) for digital audio data storage that defines digitization and sampling data rates, data transfer rates, and the pulse code modulation used.

  As prescribed by the Red Book, the ISRC-Code holds the serial number for each track in a standardized format.

  Q-Codes contain extra information about sectors, such as the ISRC-Code, the Media Catalog Number and the indices. The Media Catalog Number is a unique identification number (UPC-EAN bar code, Universal Product Code) for the compact disc.

  If required, the ISRC and Q-Codes can be set in specialized CD writing/mastering software, such as in Adaptec's Jam (see later in the section on CD-ROM software packages).
- **Yellow Book:** Introduced in 1984, this first enabled multimedia, describes the data format standards for CD-ROM discs, and includes CD-XA that adds compressed audio data to other CD-ROM data. This is the most important format from a computing, interactive multimedia perspective.

  The Yellow Book [ISO 10149: 1989(E)] divides the compact disc into two modes: Mode 1 meant for ordinary computer data and Mode 2 for compressed audio and digital video data.

  Because the fact that Yellow-Book CD-ROMs have mixed audio, video, and ordinary computer data, they are often referred to as mixed mode CDs. (See also CD-ROM formats later).
- **The Green Book** is the elaborate extension of the Yellow Book and is a standard for Philips' CD-i, Compact Disc Interactive. It brings together text, video, and sound on a single disc in an interleaved mode and extends the amount of digital, stereo audio data that can be put onto a single CD to up to 120 min (versus 74 min).
- **The Orange Book,** developed jointly by Philips and Sony, defines the hardware and software aspects of the recordable CDs, often called Compact Disc Recordable (CD-R: see later in more detail). Introduced in 1992, the Orange Book enabled multisession technology.

  A session is a collection of one or more tracks. Each recording procedure on a CD-R generates a session that contains all tracks recorded within the same time period, hence the terminology, "session".

  A compact disc recorded in multiple recording sessions is called a multisession CD. In this case, each session has its own lead-in track and table of contents that is used by the software. The number of sessions should be minimized for efficient interactive multimedia playback and to save 13 Mbytes of overhead per session.

  Furthermore, the Orange Book defines the Program Area that holds the actual data on the disc, a Program Memory Area that records the track information for the entire disc, including all sessions it contains the Lead-in Area that holds the directory information, the Lead-out Area that marks the end of the CD, and the Power Calibration Area that calibrates the power of the recording laser beam.

- **The Blue-Book** standard was first published in 1995. It introduced stamped multisession compact discs in which the first track is a Red-Book audio track. This resolved the "track one compatibility problem". (Formerly this standard was known as CD-Extra. Microsoft calls it CD-Plus). The Blue-Book standard enables compact disc authors to put interactive multimedia data into the unused capacity of musical CDs.
- **The White Book** comprises the standards for video CDs. This format is based on CD-i (see the Green-Book standard). These CD products are meant to be played on CD-i players.

Proprietary CD-ROM Standards

There are also other proprietary compact disc standards. Most importantly the

- KODAK Photo CD, readable on Macs, PCs, SIGs (computers made by Silicon Graphics Inc.) and other machines is a standard for storing high-quality photographic images developed by the Eastman Kodak Company, and
- MMCD, a multimedia standard for hand-held CD players made by the Sony Corporation and
- others.

CD-ROM Transfer Rate

The transfer rate of a compact disc system is a direct function of the rpm at which the disc spins in the player.

Because of the different sizes of bocks and the error correction methods used by different formats, the exact transfer rate at a given spin rate varies from one type of CD to the other.

As an example, in audio mode the block size of 2362 bytes is transferred using a 1× drive at 176 kbytes per second. In Mode 1, where the block size is 2048 bytes, the 1× drive pushes through 153.6 kbyte/s.

As with a current CD-ROM drive at 32× speed in Mode 1, where the block size is 2048 bytes, the 32× drive pushes through $32 \times 153.6 = 4{,}915.2$ kbytes per second, a value close to a "reasonable" hard disk drive's transfer rate.

CD-ROM Access Time

Compared with the magnetic hard disk drives, the CD-ROM's access time is significantly higher because the optical read head is bulky, versus the elegant flyweight mechanism of the hard disk. The optical assembly that moves on a track carries more mass and that translates into longer times for the head to settle into place.

Besides the mass of the optical head, the constant linear velocity recording system of the CD further slows down the access to desired date. With music, for which the CD was originally designed, this is not a problem because it is (usually) played back sequentially. With computer data access, the CD must act as a random access storage device, and then the speed (access time plus read or write time) becomes crucial.

The typical access time for a modern CD drive is approximately 100 to 200 ms, about ten times longer than that of a modern magnetic hard disk's access time.

CD-ROM Formats

The Yellow-Book standard enables multimedia because it describes the data format standards for CD-ROM discs and includes CD-XA that adds compressed audio data to other CD-ROM data. However the Yellow Book does not define how to organize the data into files on the disc. Therefore the High Sierra Format (HSF) and later the ISO9660 format were developed and standardized.

The only difference between the HFS and the ISO9660 formats is that some CD drives read HFS CDs only (on old Macs), but the good news is that all recent drives on all platforms (i.e., MacOS, Windows/NT, Unix) read both.

ISO9660 strictly maintains the 8/3 DOS naming conventions, whereas the HFS format used on Macs from the very early days, allowed full length Mac file names. (Long file names are beneficial in particular when large number of multimedia objects/files have to be named and coded meaningfully.)

To fix this problem for Windows 95, Microsoft introduced a set of extensions to ISO9660, called the Joliet CD-ROM Recording Specification. These extensions support 128-character long filenames (not the max. 255) with a broad character set. Unfortunately, DOS systems prior to Windows 95 still read according to the 8/3 file naming convention. Thus even some of the latest multimedia CDs are still forced to use the short 8/3 filenames (e.g., for a video clip: 12345678.mov, instead of a more meaningful: JaguarTestDrive_1.mov), to maintain compatibility.

CD-RECORDABLE (CD-R)

The fact that the compact disc is a sequentially recorded but randomly playable system (versus the magnetic disk, which is randomly recordable as well as playable) making writing a CD-R a more complex operation than copying files to a (magnetic) hard disk.

Because CD recorders want to write data (i.e., "burn the CD-R") in a continuous stream, the data files to be recorded onto CD must first be put into a defragmented magnetic disk folder, often called "writing a virtual image" file. To ensure continuous space on a hard drive, the best practice is to reformat the drive or its partition before moving any files into it. This prevents any interruptions during CD recording (i.e., mastering) that are most likely to result in an error in recording. Normally, the folder created on the magnetic disk will be copied over/recorded exactly "as is" onto the CD-ROM.

Furthermore the number of sessions should also be minimized for efficient interactive multimedia playback (in particular in the case of several large video files) and to save space (i.e., 13 Mbytes per session).

For the laser beam to code data onto the CD-R, the CD-R media needs an extra layer of dye. To guide the process even better, in particular for a desktop, all CD-Rs have a formatting spiral permanently stamped into each disc.

Analyzing the cross section of a CD-R, the outside layer is a silk-screened label. Then as we move further inside, there is a protective layer, and then the reflective gold coating, with the photoreactive green layer embedded into a clear polycarbonate base.

As with all CDs, the CD-R has a bottom protective layer that gives its robustness. A thin reflective layer is plated on the polycarbonate to reflect the CD beam back so that it can be read by the compact disc drive. The dye layer, special to the CD-R, is between this reflective layer and the standard protective lacquer layer on the disc. It is photoreactive and therefore changes its reflectivity in response to the laser beam of the CD writer, enabling data coding.

CD-RW CD-ERASABLE

Ricoh pioneered the MP6200S CD-ReWritable (CD-RW) drive in May 1996. (CD-Erasable, or CD-E, was the original, confusing terminology). Then, it was the only compact disk drive that could read and write data onto a CD! Users today enjoy a vastly expanded range of choices, in terms of manufacturers and the variety of software bundles and interface options.

The CD-RW employs phase-change laser technology to code and decode data. From a user's viewpoint, the CD-RW is similar in operation to the magnetic hard disk. The drive updates the disk table of contents any time. Thus files and tracks are added without additional session overheads. (A session overhead is 13 Mbytes for a CD-R.)

Where CD-R drives in the past were limited to internal and external Small Computer System Interface (SCSI), today's range of CD-RW/CD-R multifunction drives come with parallel and IDE connections, in addition to SCSI.

Other important aspects of CD-RWs include the following:

- In comparison to the IDE or parallel-connected drives, SCSI drives are considerably faster, especially when using a PCI bus-mastering card.
- Most modern PC motherboards support four IDE devices. If there are already two hard drives and two CD-ROM drives installed, there is no room for additional IDE devices. Thus something has to be removed to install the CD-RW/CD-R drive.
- Now, the max. read-speed of CD-RW drives is 6×. Therefore a faster 12× to 32× CD-ROM drive should be installed in addition to the rewritable drive for fast multimedia playback.

Last, but not least, as with anything as complex as a CD-R or CD-RW, it is strongly advisable to determine the importance of toll-free technical support, technical support hours of accessibility and availability, and the cost of software, driver, and flash BIOS upgrades.

CD-ROM Care and Stability

In general, inside the optical disk is a data layer on a substrate, which is read by a laser. In the CD-ROM, the data layer consists of a reflective layer of aluminum with "pits and plateaus" that selectively reflect and scatter the incident laser beam.

Optical discs are generally constructed from polymers and metallics. The polymers are subject to deformation and degradation. Metallic films are subject to corrosion, delamination, and cracking. Metallic alloys are subjects to dealloying.

Optical discs consist of a data layer (pits, bumps, or regions of differing physical or magnetic properties) supported on a much thicker polycarbonate or glass substrate. A reflective layer is also required for CD-ROMs. The data layer/reflective layer is protected with an overcoat.

In optical media, there is a data "pit" that is responsible for reflecting/dispersing an incident laser beam. Anything that changes the reflectivity or other optical properties for the data "bits" results in a misread. According to the National Technology Alliance (USA), the optical clarity of the substrate is important in those systems where the laser must pass through this layer. Anything that interferes with the transmission of the beam, such as a scratch or reduced optical clarity of the substrate, results in a data error.

CD-ROM technology relies on the difference in reflectivity of "pits" stamped into a polycarbonate substrate and vapor coated with a reflective metallic layer, which is typically aluminum, hence the terminology for the mass produced CDs, "silver" CDs.

According to the National Technology Alliance (USA), a common cause of CD-ROM failure is a change in the reflectivity of the aluminum coating because of oxidation, corrosion, or delamination. Deterioration of the protective overcoat (acrylic or nitrocellulose lacquer) makes the aluminum layer more susceptible to oxidation and corrosion. Some manufacturers use a silver reflecting layer that is subject to tarnishing by sulfur compounds in the environment and CD-ROM packaging.

CD-ROMs also fail because the polycarbonate substrate deteriorates. Polycarbonate is subject to crazing, which reduces the optical clarity of the substrate locally. Oils in fingerprints and organic vapors in the environment contribute to crazing. Scratches in the substrate because of mishandling also cause disk failures.

The relative effectiveness of CD-Recordable media is an issue often bandied about in industry and business circles, where the technology is used and increasingly relied upon. Much of the controversy surrounds finding some useful way of evaluating the blank discs of various brands and types used in CD recorders today.

Several criteria go into evaluating disc usefulness: readability, compatibility with recorders and players, and expected life span. According to the National Technology Alliance (USA), results compiled in a series of tests performed by One-Off CD Shops International between early 1993 and mid-1995 on a variety of disc brands and types shed a great deal of light on the topic, even though the tests were done only to evaluate readability of recorded discs and not media longevity or suitability of specific brands or types for use on every system. But the methodological rigor of the narrow focus yielded considerable data that bodes well for the effectiveness of current disc-evaluating mechanisms.

Not every question has been answered by any means, but one finding, according to the National Technology Alliance (USA) is clear: "Worry about the quality of CD-R media seems largely unfounded" (18–21).

CD-RECORDABLE VERSUS MASS REPLICATED ("SILVER") COMPACT DISCS. AN ANALYSIS BY THE NATIONAL TECHNOLOGY ALLIANCE (USA)

Mass replicated ("silver") discs have their data encoded during injection molding. The pits and lands are pressed directly into the substrate. The data side of the transparent disc is metalized, usually by aluminum sputtered onto the bumpy surface, which is spincoated with lacquer to protect the metal from corrosion. Then it is usually labeled in some fashion, generally with a silk-screened or offset printed design.

One source of confusion and concern about CD-R discs is their notable physical differences (i.e., "gold/green shine") from normal, (i.e., "silver" shine) pressed compact discs.

Each CD-R blank is designed to meet standards regarding function, but the way each achieves the function of storing digital information so that it can be read by standard CD players and drives is quite distinct. The top sides and bottom sides of replicated discs are similar to those of CD-Rs. What comes between the polycarbonate substrate and the top's lacquer coating makes the difference.

CD-Rs are also polycarbonate underneath, but the substrate is molded with a spiral guide groove, not data pits and lands. Then this side is coated with an organic dye, and gold or silver (instead of aluminum as in the case of mass replicated discs) is layered on top of the dye as the reflective surface, which in turn is lacquered and sometimes labeled just as replicated discs are.

The dye forms the data layer when the disc is recorded and has a binary information image encoded by a laser controlled by a microcomputer using a premastering and recording program. Where the recording laser hits the dye, the equivalent of a molded "pit" is formed by the laser beam reacting with the photosensitive dye, causing it to become refractive rather than clear or translucent. When read by a CD player or CD-ROM drive, the affected area diffuses the reading laser's beam, preventing it from reflecting back onto the reader's light sensor. The alternations between the pickup laser's reflected light and refracted light make up the binary signal transmitted to the player's hardware for unencoding, error detection, correction, and further transmisison to the computer's processor or the audio player's digital/analog converter.

According to the National Technology Alliance (USA), the feature that really distinguishes recordable media from replicated discs is the dye layer. The polymer dye formulas used by manufacturers are proprietary or licensed and are one of the characteristics distinguishing among brands.

Now two types of dye formulas are in use, cyanine (and metal-stabilized cyanine) and phthalocyanine. Cyanine is green, and the other appears gold because the gold metalized reflective layer is seen through the clear dye.

Tenets of Readability Testing of CD-ROMs and CD-Rs

At least in theory, however, these differences should have little or no impact on readability, because CD-R and CD-ROM media share the "Red-Book" standard for Digital Audio (CD-DA). The Red Book specifies a number of testable measurements that collectively are supposed to determine whether a disc is readable as an audio CD media. The Yellow Book, or multimedia CD-ROM standard, requires some additional tests.

Because CD-Recordable discs, described in the Orange Book, are supposed to be functionally identical to mass replicated "silver" CD-ROMs, it is logical to assume that the same test equipment and standards should be applied to them as to Yellow-Book discs. So no new readability criteria were specified in the Orange Book. According to the National Technology Alliance (USA), several companies have built machines for testing discs during and after the manufacturing process based on these criteria, and only recently have new testing devices become available specifically for CD-Recordable.

Accelerated Test Methodology by the National Technology Alliance (USA)

Changes in a physical property involving chemical degradation can usually be modeled by an appropriate Arrhenius model. Error rates can be fit to an appropriate failure time distribution model. Once an appropriate model has been determined and fit to the experimental data, it can be used to estimate media properties or error rates at a future time for a given condition.

In performing accelerated tests, there is a trade-off between the accuracy and the timeliness of the results. It is impractical to age data storage media under "use" conditions because it would take several years to evaluate the product, by which time it would be obsolete. To obtain results in a timely manner, "use" temperatures and humidities are typically exceeded to accelerate the rates of material decomposition.

Severe temperature/humidity aging allow for a relatively rapid assessment of media stability, but results may not represent actual use conditions. Furthermore, samples treated in a laboratory environment may not be configured to represent typical use conditions.

To perform accelerated testing, several media samples are placed in several different temperature/humidity/pollutant environments. The media are removed at periodic intervals, and a key property is measured.

This key property could be a physical characteristic, such as magnetic remanence, or it could be data error rates, if the materials were prerecorded. After a sufficient number of key property versus time data have been collected at each condition, the data is fit to a predictive model (19,22–31).

ALTERNATIVE, INTERNET/INTRANET-BASED TECHNOLOGIES

Because of the rapid advancement of the Internet and local, typically much faster and more secure versions of it, often called intranets, mass storage, document archiving, interactive multimedia distribution and other services, mostly online, will become a reality and to some extent an alternative for data stored and distributed on CD-ROMs and DVDs.

The issue, nevertheless, is always the same: on-line accessible data over a very fast network under the "network's control," or at the desk on a CD-ROM, or DVD disc, under "the user's/creator's control." No doubt, there are reasons for both technologies to be viable for a long time. This does not ignore the point, that even if it comes on-line over a fast network, at some point in the system the servers are most likely to read the data from a CD-ROM, DVD juke box, or even from large capacity magnetic hard disks.

To understand the importance of the on-line, networked solution and the areas in which they could, and most likely will compete with the CD-ROM/DVD technologies, refer to

Table 1. Maximum Data Rates of Digital Telecommunications Standards

Standard	Connection Type	Downstream Rate	Upstream Rate
V.34	Analog	33.6 kbps	33.6 kbps
SDS 56	Digital	56 kbps	56 kbps
ISDN	Digital	128 kbps	128 kbps
SDSL	Digital	1.544 Mbps	1.544 Mbps
T1	Digital	1.544 Mbps	1.544 Mbps
E1	Digital	2.048 Mbps	2.048 Mbps
ADSL	Digital	9 Mbps	640 kbps
VDSL	Digital	52 Mbps	2 Mbps

Table 1 showing the Maximum Data Rates of Digital Telecommunications Standards. These are theoretical maximum data rates, and in practice, unless a direct hired line is used, the actual transfer rates are most likely to depend on the actual traffic.

Analyzing this table, it is obvious, that 128 kbit per second Integrated Services Digital Network (ISDN) lines and upwards, such as the T1 lines, representing the bandwidth of 24 voice channel telephone lines combined, provide viable on-line multimedia solutions. As with anything else though, simultaneously competing, supporting, and conflicting issues such as speed, ease of use, security, privacy of data, and reliability/robustness will ensure that both the on-line and in this sense, off-line CD-ROM, CD-R, and DVD technologies will be used for a very long time.

CD-ROM/DVD-ROM APPLICATIONS

The CD-ROM and DVD-ROM technology is applied in several different areas, but most importantly as audio CDs (that some rock stars have sold over 100 million CDs), for data and document archiving, for linear and nonlinear (i.e., interactive) video storage and playback, for image compression and storage, for interactive multimedia-based education, marketing, entertainment and many other fields of interest, where mass storage of data is important.

Besides the MPEG video standards, because Apple's multiplatform and Internet-friendly QuickTime and QTVR digital interactive video and virtual reality software tools became de facto interactive multimedia standards (delivered on CD-ROMs and DVDs, and streamed usually at lower quality due to the transfer rate and bandwidth over the Internet and intranets), as examples of applications, we introduce these technologies as they are embedded into engineering educational, or marketing, or game-oriented CD-ROM and DVD programs. In these examples, one should recognize the importance of accessing large amounts of data (e.g., 5 to 25 Mbyte digital, compressed video files), interactively and meaningfully, at the time and place the information is needed. (Many of these interactive examples can be found electronically at the website: http://www.cimwareukandusa.com).

Because the video-game industry is the prime source for computing and related CD-ROM R & D funding, we felt that we should demonstrate such new developments by showing Fig. 3(a–b).

As Apple Computer Inc. defines it, QuickTime (QT) itself is not an application, it is an enabling technology. QuickTime is comprised of pieces of software that extend the ability of a Mac's or PC's operating system to handle dynamic media.

Then applications use this technology and turn it into other applications. As an example, many educational titles, games, and reference titles have incorporated QuickTime into their development, including Myst by Broderbund, Microsoft Encarta by Microsoft, DOOM II by Id Software, Flexible Automation and Manufacturing, Concurrent Engineering, Total Quality Management by CIMware, and others.

QuickTime as a technology became the basis for many of the multimedia/computing industry's most respected digital media tools. QuickTime is much more then just video and

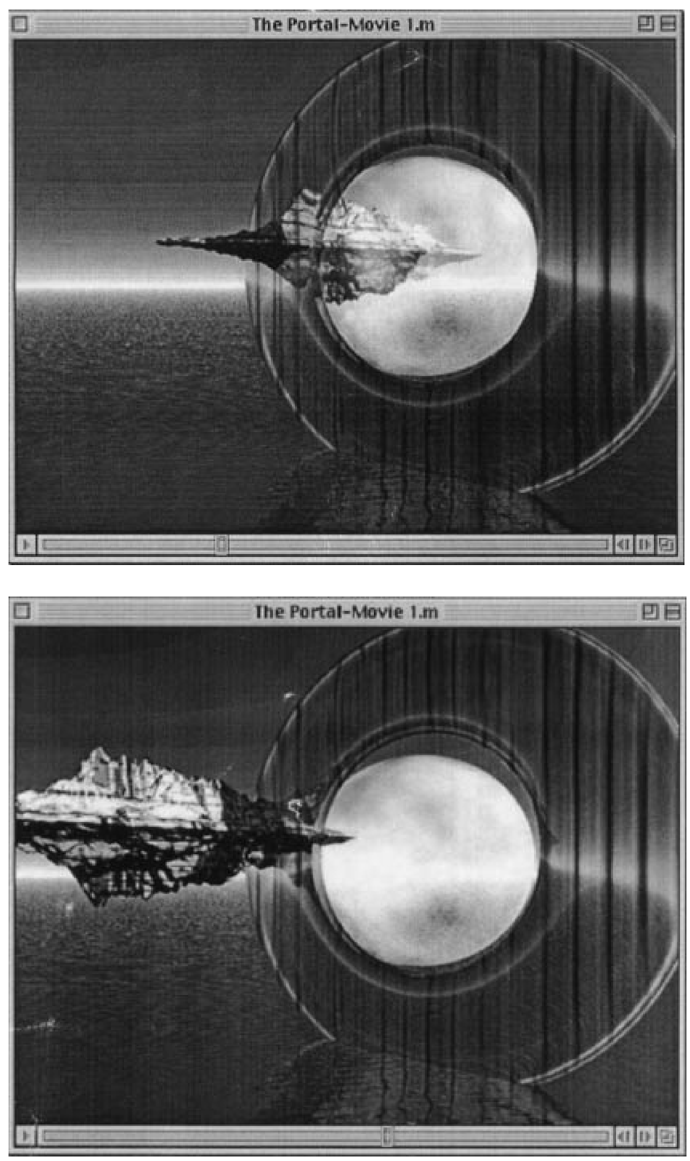

Figure 3. (a–b) These screenshots illustrate two frames of a longer animated space flight (by Gregory N. Ranky) as part of a video-game project on CD-ROM. The individual frames have been computer generated, then rendered, and integrated into an interactive QT movie.

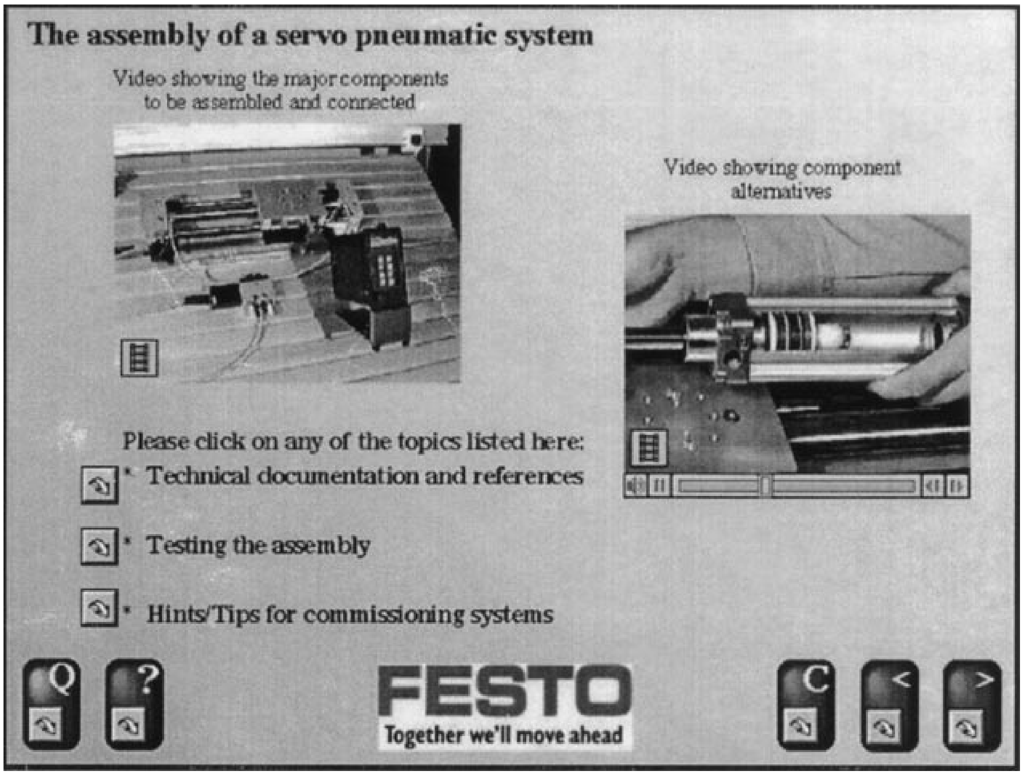

Figure 4. A screen of over 300 interactive screens of an industrial educational program on Servo Pneumatic Positioning.
(For full color images please look up the website: http://www.cimwareukandusa.com).

sound. It is a true multimedia architecture that allows integrating text, still graphics, video, animation, 3-D, VR, and sound into a cohesive platform. QuickTime, delivered either on CD-ROMs, DVDs, or in a somewhat less interactive mode "streamed" over the Internet/intranet makes it easy to bring all of these types of media together.

In February 1988, the International Standards Organization (ISO) adopted the QuickTime File Format as a starting point for developing the key component of the MPEG-4 digital video specification as the next generation standard. This format is supported by Apple Computer Inc., IBM, Netscape Corp., Oracle Corp., Silicon Graphics Inc., and Sun Microsystems Inc.

> MPEG's decision to utilize the QuickTime file format for the MPEG-4 specification has huge benefits for users and the industry," said Ralph Roges, principal analyst for Multimedia at Dataquest, San Jose. "This strategy will leverage the broad adoption of QuickTime in the professional media space, speed the creation of MPEG-4 tools and content while providing a common target for industry adoption.

At a broader level, interactive multimedia, stored on CD-ROMs, DVDs and the forthcoming fast internet and intranets, urge the development of anthropocentric systems in which humans and machines work in harmony, each playing the appropriate and affordable (i.e., the best possible) role to create intellectual and fiscal wealth. This means creating better educated engineers, managers, and workforce at all levels by building on existing skills, ingenuity, and expertise, using new science and technology-based methods and tools, such as interactive multimedia.

Today and in the forthcoming decade of our information technology revolution and eventually in the Knowledge Age, engineering, science, and technology combined can create an intellectually exciting environment that molds human creativity, enthusiasm, excitement, and the underlying curiosity and hunger to explore, create and learn. It is obvious that economic development is not a unidimensional process that can be measured by a narrow view of conventional accounting.

Consequently, there is a need to develop new creative and stimulative multimedia-based infrastructures, educational tools, products, and means of production that have the embedded intelligence to teach their users about "themselves" and that can meet challenges now faced by many companies and even countries as natural resources become more scarce, the environment becomes more polluted, and major demographic changes and movements of people are taking place.

The fundamental change that has to be recognized is that most existing hi-tech systems were designed so that with the human operator plays a passive role and a machine is the "clever" component in the system. This is because accountant driven management considers the workforce a major cost item instead of a major asset!

Anthropocentric technologies, such as flexible, interactive multimedia make the best use of science and technology,

Figure 5. A screen of more than 720 interactive screens of an educational multimedia program on Total Quality Control and Management and the ISO 9001 Quality Standard. (For full color images, please look up the website: http://www.cimwareukandusa.com).

driven by users at their pace and time, enabling the learners to explore and implement concepts broader than those of the accountant's order-bound fiscal view.

Consequently, the use of interactive multimedia is not war, but a new opportunity to put back humans into harmony with nature and "able" machines, by being better informed, educated, and happier contributors, rather than efficient long-term waste creators and destroyers of nature and society (32–40).

What Are Interactive Multimedia?

Interactive multimedia combine and integrate text, graphics, animation, video, and sound. They enable learners to extend and enhance their skills and knowledge working at a time, pace, and place to suit them as individuals and/or teams and to provide a range of choices about the way they are supported and assessed.

In other words

- The student has a choice and the freedom to learn
- The student is supported by the multimedia-based learning materials and technology
- The tutors create an effective, enjoyable learning environment and infrastructure

Figure 4 represents a screen of over 300 interactive screens of an industrial educational program on Servo Pneumatic Positioning, by Flaherty, et al. (40) on CD-ROM. The 650 Mbytes of data includes several hundred color photos and over 45 min of interactive digital videos explaining the various aspects of servo pneumatic components, systems, positioning, control, programming and applications.

Figure 5 is a screen of over 720 interactive screens of an educational multimedia program on Total Quality Control and Management and the ISO 9001 Quality Standard. Ranky and Ranky (41) on CD-ROM. The 650 Mbytes of data includes several hundred color photos and over 45 min of interactive digital videos explaining the various aspects of total quality control and the international quality control standard as applied to design, manufacturing and assembly in a variety of different industries.

Note, the many opportunities we have programmed into these screens to continuously motivate the learners to be responsive and be actively involved in the learning process. To maintain the continuous interactivity not just within the CD-ROM, but also "outside" the CD, Internet and email support is offered to learners. This enables them to interact with the author(s) and/or the subject area specialists of the particular CD-ROM via Email and to visit the designated WWW domain site for further technical and educational support (42).

(Some of these interactive multimedia examples will be available in electronic format as executable demo code when this Encyclopedia is published electronically. Some of the images and demos illustrated here can also be seen in full color at the website: http://www.cimwareukandusa.com.)

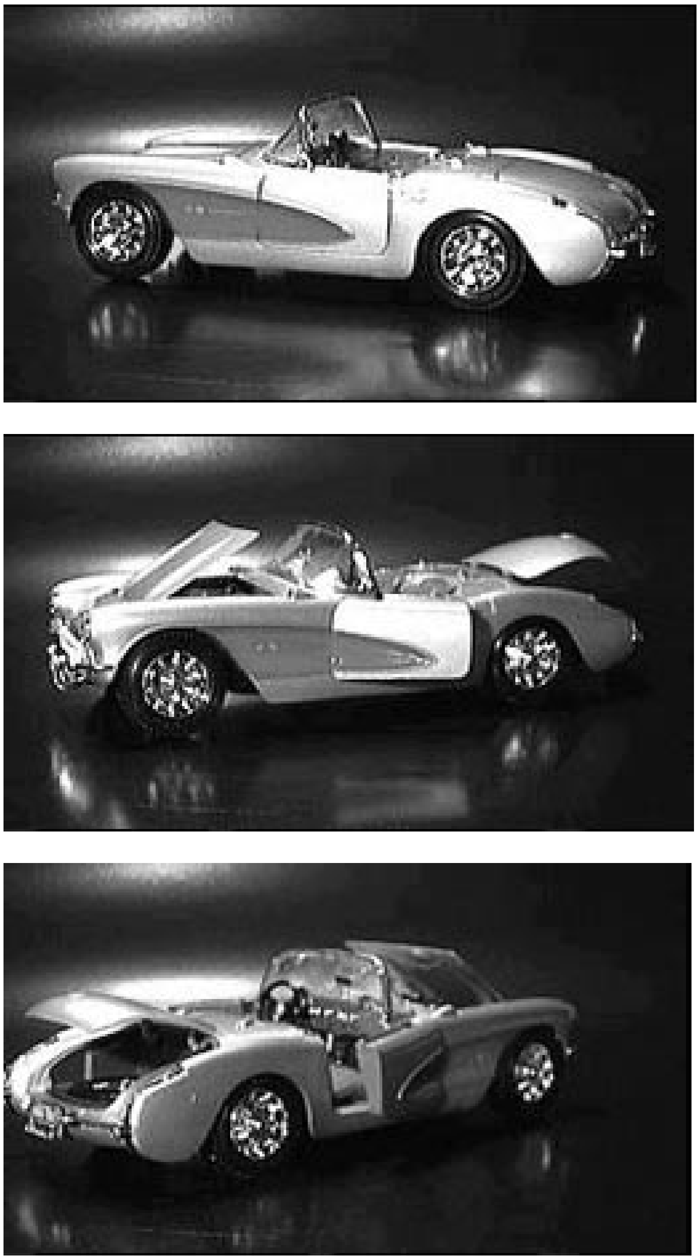

Figure 6. (a–c) A few frames of an interactively controllable (Chevy) automobile image, including opening and closing its doors under user control in QTVR on CD-ROM. (For full color images, please look up the website: http://www.cimwareukandusa.com).

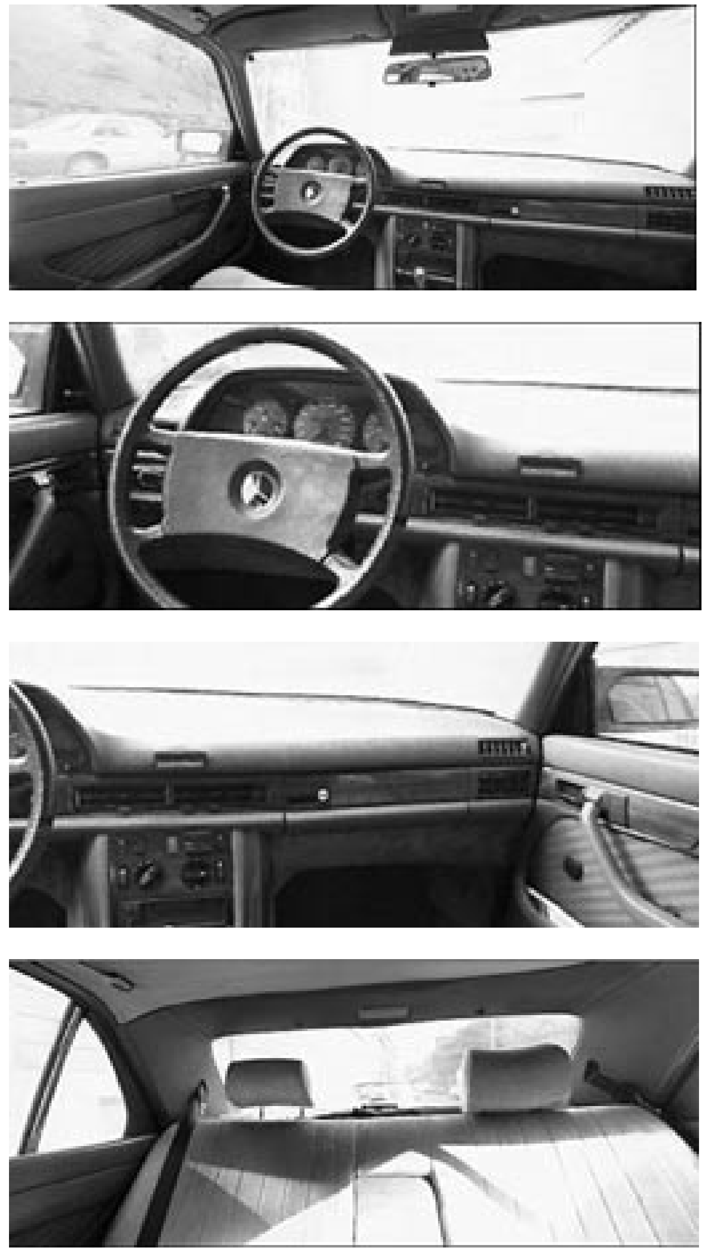

Figure 7. (a–d) A few frames of an interactively navigatable interior of a Mercedes automobile in QTVR on CD-ROM. (For full color images, please look up the website: http://www.cimwareukandusa.com).

WHAT IS QUICKTIME VR?

As Apple describes it, virtual reality (VR) describes a range of experiences that enable a person to interact with and explore a spatial environment through a computer. These environments typically are artistic renderings of simple or complex computer models. Until recently, most VR applications required specialized hardware or accessories, such as high-end graphics workstations, stereo displays, or 3-D goggles or gloves. QuickTime VR now does this in software with real photographic images versus rendered artificial models.

Now Apple's QuickTime VR is an integral part of QuickTime. It allows Macintosh and Windows users to experience these kinds of spatial interactions using only a personal computer. Furthermore, through an innovative use of 360° panoramic photography, QuickTime VR enables these interactions using real-world representations and computer simulations.

To illustrate the power of this technology when applied to interactive knowledge propagation on CD-ROMs, DVD-ROMs, and to some extent on the Internet, refer to Fig. 6(a–c), Fig. 7(a–d), and Fig. 8(a–b), again with all those great opportunities of interactive navigation, zoom/in and out and

Figure 8. (a–b) A traditional job shop. (For full color QTVR images, please look up the web-site: http://www.cimwareukandusa.com).

hot-spot controlled exploration of these hyperlinked images in QTVR on CD-ROM.

As can be recognized, the opportunities for interactivity, for learning by exploring under user (versus teacher control) is vast, not just in education, but also in marketing and general culture, in terms of showing and illustrating scenes, people, cultures, lifestyles, business practices, manufacturing, design and maintenance processes, and products even remotely, that have never been explored like this before.

(Some of these interactive multimedia examples will be available in electronic format as executable demo code when this Encyclopedia is published electronically. Some of the images and demos illustrated here can be seen in full color at the website: http://www.cimwareukandusa.com.)

SMARTDART: A SMART DIAGNOSTIC AND REPAIR TOOL IMPLEMENTED IN A VOICE I/O CONTROLLED, INTERACTIVE MULTIMEDIA, MOBILE-WEARABLE COMPUTER-BASED DEVICE FOR THE AUTOMOBILE (AND OTHER) INDUSTRIES

The co-principal Investigators of this R&D project at New Jersey Institute of Technology (NJIT) are Professors Paul G. Ranky and S. Tricamo Project partners in an R & D consortium include General Motors, Raytheon, the US National Guard and Interactive Solutions, Inc.

SmartDART is a novel, computer-based prototype mentoring system with serious industrial applications in mind, implemented in a voice I/O controlled, interactive multimedia, mobile-wearable device for use by the automobile (and other) industries (see Fig. 9). SmartDART has the following features:

- Integrated to the computer diagnostic port of the automobile, or off-line, interacting with the technician, *can diagnose* a variety of problems and can communicate the results at the appropriate level, format, and mode, using various multimedia tools and solutions
- *Can self-tune* in terms of adjusting to the actual user needs and levels in an 'intelligent way'
- Has a *highly interactive* and user friendly multimedia-interface
- *Can update itself* (based on either the learned knowledge and/or by networked or plugged-in technical fact data)
- Is a *highly parallel, distributed and networked device*
- Has command-based *voice recognition*
- Has a *'hands-free' user-interface*
- Can work in *hazardous environments*
- *Can automatically generate diagnostic and maintenance reports* and can communicate these reports via its networked communications system to any receiving site or compatible computer
- To help to improve the next generation of products, the automated mentoring system can feed data and learned knowledge in a format and language that is appropriate and understandable to the design, manufacturing, quality control, etc. engineering community and their computer support and design systems (CAD/CAM)
- SmartDART *can diagnose itself* and report its own problems (and possible solutions) as they occur, therefore can help to improve the maintenance process, the design, and the overall quality of the automobile (or other complex product for which it is trained)

About the System Architecture

To achieve the previously listed and other functions, SmartDART is implemented as a small, rugged, networked mobile-wearable, or desktop networked computer-based device, that runs on a set of core processes, such as

- The Process Manager,
- The Information Manager
- The Interface Manager, and
- The Team coordinator.

SmartDART has a set of core modules linked to a fast knowledge bus, and through various smart cards, or modules

Figure 9. SmartDART is a novel, computer-based prototype mentoring system. (For full color images, please look up the website: http://www.cimwareukandusa.com).

it can execute various processes. These smart-cards have various domains of expertise embedded in them and are integrated following the object-linking methodology.

SmartDART has an open system architecture, meaning, that as the need arises, new smart cards can be developed and plugged-in to enhance its "field expertise." Because of the well-integrated, object-linked design architecture, these new modules, or smart cards, will automatically integrate with the rest of the system and follow the standard multimedia user-interface design, cutting the learning curve for using a new smart card to a minimum.

The Typical Application Scope of SmartDART

To explain the application scope of our system, let us list some broad application areas from the viewpoint of the maintenance technician or engineer, whose job is to diagnose or fix a problem. In general, SmartDART will answer the following questions and resolve the following problems:

- *How does the particular system under test work?* This is explained to a newcomer or to anybody that wishes to learn about the particular system by using highly interactive, multimedia tools and interfaces. A "system" in this sense is an automobile, a tank, or some other machine, such as a VCR or a medical instrument.
- *What are the subsystems, how do they work,* and *how do they interact?*

Furthermore, SmartDART can

- *diagnose the problem*
- *offer Go / No-go reporting*
- *provide end-to-end versus fault isolation*
- *Rehearse the repair / fix scenarios and procedures* by highly interactive and if required by the user, individualized interactive multimedia tools and techniques
- Be used as an *"expert" tutor,* supporting learners at various levels, following different educational scenarios and techniques best suited to the variety of users (i.e., maintenance technicians, design, manufacturing and quality engineers, students, managers, and others).

DIGITAL VERSATILITY DISC (DVD-ROM)

The DVD-ROM, or DVD technology, was created by merging two competing proposals, one by the CD-ROM inventors Philips and Sony and the other one by Toshiba. The purpose of the DVD is to create up-front a universal, digital storage and playback system, not just for audio, but for video, multimedia, archiving, and general digital mass data storage.

DVDs store significantly more data than CD-ROMs and come in different sizes and standards. The DVD medium resembles that of the CD-ROM technology. Even the size is the same, 120 mm diameter and 1.2 mm thick. Unlike the standard CD-ROMs, DVDs are made up of two platters cemented together to create the 1.2 mm thickness. Each of these layers are fully functional disks on both sides. Individual layers are distinguished (i.e., addressed) by the system by focusing the laser beam. The result is a sandwich that has two layers per side, four different recording surfaces, hence the significant data capacity increase.

As an example, DVD-5 with one side and one layer, offers 4.7 Gbytes storage capacity and 133 minutes of playing time. DVD-9 stores 8.5 Gbytes on 2 layers, DVD-10 stores 9.4 Gbytes, and DVD-18 massive 17.5 Gbytes and 480 min of equivalent playing time. These DVDs are the most likely be used in interactive multimedia and digital video applications.

Because optical technology has improved significantly since the 1980s when the CD-ROM was created, DVDs (standardized in December 1995) employ more closely spaced tracks and a better focused and high-wavelength laser beam (635 to 650 nm, medium red).

The DVD constant linear velocity is 3.49 meters per second, and the disc spins at between 600 rpm to 1200 rpm at the inner edge, much faster than the conventional CD-ROM.

DVD raw data transfer rates are also high, 11.08 Mbits per second raw and approximately 9.8 Mbits per second actual, approximately 7× or 8× more than CD-ROM, enabling full motion and full-screen video playback.

Besides the computing industry's need to store massive amounts of data, the real commercial driver behind the DVD technology is the video industry because DVDs can replace the old-fashioned, slow, linear, and relatively poor quality VHS and S-VHS video tape technology.

For videos, DVD uses MPEG-2 encoding that allows a relatively high-quality display with 480 lines of 720 pixels each to fit into a 4 Mbyte/s data stream. (With MPEG, the actual data rate depends on the complexity of the image, analyzed frame-by-frame at the compression stage).

DVD-Audio is also excellent too, allowing a 44.1 kHz sampling rate, and supporting 24 bit audio and several compressed multichannel formats that allow storing switchable, multiple language full length videos and playing them back with additional audio and interactive features.

To summarize this section, as with any new technology, DVDs have to break through the cost barrier in terms of individual DVD disc costs and also in terms of the entire recording, playback, and distribution infrastructure.

CD-ROM/DVD DRIVE MANUFACTURERS AND CURRENT DRIVES

Although companies manufacturing CD-ROM and DVD hardware and software change, this list is a reliable source of information and products.

DVS (Synchrome Technology)

Maestro CDR 4x12E,4X/12X, Windows 95, Windows NT, 200ms, SCSI.

Maestro CDR 4x12E,4X/12X, Macintosh, 200ms, SCSI.

Maestro CDR 4x121,4X/12X, Windows 95, Windows NT, 200ms, SCSI.

Japan Computer and Communication

JCD-64RW, 4X/2X/6X, Windows 95, Windows NT, 250ms, E-IDE.

MicroBoards Technology

Playwrite 4000RW, 4X2X/6X, Windows 95, Windows NT, Windows 3.1, UNIX, Macintosh, 250ms, SCSI-2.

Playwrite 400IRW, 4X/2X/6X, Windows 95, Windows NT, Windows 3.1, 250ms, E-IDE.

MicroNet Technology

MCDPLUS4X12, 4X/12X, Macintosh, 165ms, SCSI.

MCDPLUS4X12ADD, 4X/!2X, Windows 95, Windows NT, Windows 3.1, DOS, 165ms, SCSI.

MCDPLUS4X12PC, 4X/12X, Windows 95, Windows NT, Windows 3.1, DOS, 165ms, SCSI.

MCDPLUS4X121, 4X/12X, Windows 95, Windows NT, Windows 3.1, DOS, 165ms, SCSI.

MCDPLUS4X121PC, 4X/12X, Windows 95, Windows NT, Windows 3.1, DOS, 165ms, SCSI.

Microsynergy

CD-R4121, 4X/12X, Windows 95, Windows NT, Windows 3.1 Macintosh, 165ms, SCSI-2.

CD-R412E, 4X/12X, Windows 95, Windows NT, Windows 3.1 Macintosh, 165ms, SCSI-2.

CD-RW4261, 4X/2X/6X, Windows 95, Windows NT, Windows 3.1 Macintosh, 250ms, SCSI-2.

CD-RW426E, 4X/2X/6X, Windows 95, Windows NT, Windows 3.1 Macintosh, 250ms, SCSI-2.

Optima Technology Corp.

CDWriter, 4X/2X/6X, Windows 95, Windows NT, 250ms, SCSI-2.

Panasonic

CW-7502-B, 4X/8X, Windows 95, Windows NT, Windows 3.1 Macintosh, 175ms, SCSI-2.

Pinnacle Micro

RCD-4x12e, 4X/12X, Windows 95, Windows NT, Macintosh, 165ms, SCSI-2.

RCD-4x12i, 4X/12X, Windows 95, Windows NT, Macintosh, 165ms, SCSI-2.

Plexor

PX-R412Ce, 4X/12X, Windows 95, Windows NT, Macintosh, 190ms, SCSI.

PX-R412Ci, 4X/12X, Windows 95, Windows NT, Macintosh, 190ms, SCSI.

Smart and Friendly

CD-R 4006 Delux Ext (SAF781), 4X/6X, Windows 95, Windows NT, Macintosh, 250ms, SCSI-2.

CD-R 4006 Delux Int (SAF780), 4X/6X, Windows 95, Windows NT, Macintosh, 250ms, SCSI-2.

CD Speed/Writer Delux Ext (SAF785), 4X/6X, Windows 95, Windows NT, Macintosh, 165ms, SCSI-2.

CD Speed/Writer Int (SAF783), 4X/6X, Windows 95, Windows NT, 165ms, SCSI-2.

CD-RW 426 Delux Ext (SAF782), 4X/2X/6X, Windows 95, Windows NT, Macintosh, 250ms, SCSI-2.

CD-RW 426 Delux Int (SAF779), 4X/2X/6X, Windows 95, Windows NT, 250ms, E-IDE.

TEAC

CD-R555,4X/12X, Windows 95, Windows NT, Windows 3.1, 165ms, SCSI.

CD-RE555,4X/12X, Windows 95, Windows NT, Windows 3.1, 165ms, SCSI.

Yamaha

CDR400t, 4X/6X, Windows 95, Windows NT, Windows 3.1, UNIX, Macintosh, 250ms, SCSI-2.

CDR400tx, 4X/6X, Windows 95, Windows NT, Windows 3.1, UNIX, Macintosh, 250ms, SCSI-2.

CDRW4260t, 4X/2X/6X, Windows 95, Windows NT, Windows 3.1, UNIX, Macintosh, 250ms, SCSI-2.

CDRW4260tx, 4X/2X/6X, Windows 95, Windows NT, Windows 3.1, UNIX, Macintosh, 250ms, SCSI-2.

CD-ROM/DVD SOFTWARE WRITERS/VENDORS AND CURRENT CD-RECORDING SOFTWARE

Although companies manufacturing CD-ROM and DVD software and software version numbers change, this list is a reliable source of information and products.

Company	Software
Apple MacOS	
Adaptec	Jam 2.1
Adaptec	Toast 3.54
Adaptec	DirectCD 1.01
Astarte	CD-Copy 2.01
CeQuadrat	Vulkan 1.43
CharisMac Engineering	Backup Mastery 1.00
CharisMac Engineering	Discribe 2.13
Dantz	Retrospect 4.0
Dataware Technologies	CD Record 2.12
Digidesign	Masterlist CD 1.4
Electroson	Gear 3.34
JVC	Personal Archiver Plus 4.10a
Kodac	Build-It 1.5
Microboards	VideoCD Maker1.2.5E
OMI/Microtest	Audiotracer 1.0
OMI/Microtest	Disc-to-disk 1.8
OMI/Microtest	Quick TOPiX2.20
Optima Technology	CD-R Access Pro 3.0
Pinnacle Micro	CD Burner 2.21
Pinnacle Micro	RCD 1.58
Ricoh	CD Print 2.3.1
IBM OS/2	
Citrus Technology	Unite CD-Maker 3.0
Electroson	GEAR 3.3
Young Minds	Makedisc/CD Studio 1.20
Sun SunOS	
Creative Digital Research	CD Publisher HyCD 4.6.5.

Company	Software
Dataware Technologies	CD Record 2.2
Eletroson	GEAR 3.50
JVC	Personal RomMaker Plus UNIX 3.6
Young Minds	Makedisc/CD Studio 1.2
Sun Solaris	
Creative Digital Research	CDR Publisher HyCD 4.6.5
Dataware Technologies	CD Record 2.2
Electroson	GEAR 3.50
JVC	Personal RomMaker Plus UNI 3.6
Kodak	Built-It 1.2
Luminex	Fire Series 1.9
Smart Storage	SmartCD for integrated recording and access 2.00
Young Minds	Makedisc/CD Studio 1.2
HP HP/UX	
Electroson	Gear 3.50
Smart Storage	SmartCD for integrated recording and access 2.00
Young Minds	Makedisc/CD Studio 1.20
JVC	Personal RomMaker Plus UNIX 1.0
Luminex	Fire Series 1.9
SGI IRIX	
Creative Digital Research	CDR Publisher HyCD 4.6.5
Electroson	GEAR 3.50
JVC	Personal RomMaker Plus UNIX 1.0
Luminex	Fire Series 1.9
Young Minds	Makedisc/CD Studio 1.20
DEC OSF	
Electroson	Gear 3.50
Young Minds	Makedisc/CD Studio 1.20
IBM AIX	
Electroson	Gear 3.50
Luminex	Fire Series 1.9
Smart Storage	SmartCD for integrated recording and access 2.00
Young Minds	Makedisc/CD Studio 1.20
SCO SVR/ODT	
Young Minds	Makedisc/CD Studio 1.20
Novell NetWare	
Celerity systems	Virtual CD Writer 2.1
Smart Storage	SmartCD for recording 3.78
Smart Storage	Smart CD for integrated recording and access 3.78
Amiga	
Asimware Innovations	MasterISO 2.0

ACKNOWLEDGMENTS

We would like to express our thanks to NSF (USA), NJIT (in particular coprincipal investigators in major research grants, Professors Steven Tricamo, Don Sebastian, Richard Hatch, and the students), Professor T. Pato at ISBE, Switzerland, coprincipal investigator in our European research grants, and the students and faculty who have helped us a lot with their comments in the UK, USA, Switzerland, Sweden, Germany, Hungary, Austria, Hong Kong, China and Japan, DARPA in the USA, The US Department of Commerce, The National Council for Educational Technology (NCET, UK), The University of East London, the Enterprise Project team, the Ford Motor Company, General Motors, Hitachi Seiki (UK) Ltd., FESTO (UK and USA), Denford Machine Tools, Rolls-Royce Motor Cars, HP (UK) Ltd., Siemens Plessey, Marconi Instruments, and Apple Computers Inc. for their continuous support in our research and industrial and educational multimedia (and other) projects. Furthermore we would like to express our thanks to our families for their unconditional support and encouragement, including our sons, Gregory, Mick, Jr., and Richard for being our first test engineers and for their valuable contributions to our interactive multimedia projects.

BIBLIOGRAPHY

1. C. F. Quist, L. Lindegren, and S. Soderhjelm, Synthesis imaging, *Eur. Space Agency [Spec. Publ.] ESA SP* **ESA SP-402**: 1997, 257–262.
2. H. Schrijver, Hipparcos/Tycho ASCII CD-ROM and access software, *Eur. Space Agency [Spec. Publ.] ESA SP* **ESA SP-402**: 1997, pp. 69–72.
3. J. Zedler and M. Ramadan, I-Media: An integrated media server and media database as a basic component of a cross media publishing system, *Comput. Graphics* **21** (6): 693–702, 1997.
4. V. Madisetti et al., Darpa's digital system design curriculum and peer-reviewed educational infrastructure, *Proc. ASEE Annu. Conf.,* Milwaukee, WI, 1997, pp. 1–5.
5. T. F. Hess et al., Natural systems for wastewater treatment, *Course Mater. Cd-Rom Develop., ASEE Annu. Conf. Proc.,* Milwaukee, WI, 1997, pp. 1–8,.
6. R. Guensler, P. Chinowsky, and C. Conklin, Development of a web-based environmental, *Proc. ASEE Annu. Conf.,* Milwaukee, WI, 1997, pp. 1–11.
7. M. G. J. M. Gerritsen et al., Dicom CD-R, your guarantee to interchangeability? *Proc. 24th Annu. Meet. Comput. Cardiol.,* Lund, Sweden, 1997, pp. 175–178.
8. T. Yoshida et al., Robust control of CD-ROM drives using multirate disturbance observer, *Trans. Jpn. Soc. Mech. Eng., Part C,* **63** (615): 3919–3925, 1997.
9. J. Glanville and I. Smith, Evaluating the options for developing databases to support research-based medicine at the NHS center for reviews and dissemination, *Int. J. Med. Inf.,* **47** (1–2): 83–86, 1997.
10. J.-L. Malleron and A. Juin, Rhone-Poulenc Rorer database of palladium chemistry: Reactions, catalytic cycles and chemical parameters on CD-ROM Version 1.0, *J. Amer. Chem. Soc.,* **120** (6): 1347, 1998.
11. S. Myoung, Y. Chait, and M. Steinbuch, Inversion-free design algorithms for multivariable quantitative feedback theory: An application to robust control of a CD-ROM park, *Automatica,* **33** (5): 915–920, 1997.

12. J.-H. Zhang and L. Cai, Profilometry using an optical stylus with interferometric readout, *Proc. IEEE/ASME Int. Conf. Adv. Intell. Mechatron. (AIM'97),* Tokyo, 1997, p. 62.

13. E. W. Williams and T. Kubo, Cross-substitutional alloys of Insb. for write-once read-many optical media, *Jpn. J. Appl. Phys., Part 2: Lett.,* **37** (2A): L127–L128, 1998.

14. P. Nicholls, Apocalypse now or orderly withdrawal for CD-ROM? *Comput. Libr.,* **18** (4): 57, 1998.

15. N. Honda et al., Information services for greater driving enjoyment, *SAE Spec. Publ., Adv. Controls Veh. Navig. Syst., Proc. SAE Int. Congr. Expos.,* Detroit, MI, 1998, pp. 51–69.

16. J. K. Whitesell, *Merck Index,* 12th ed., CD-ROM (Macintosh): An encyclopedia of chemicals, drugs & biologicals, *J. Amer. Chem. Soc.,* **120** (9): 1998.

17. C. Van Nimwegen, C. Zeelenberg, and W. Cavens, Medical devices database on Cd, *Proc. 18th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.,* Amsterdam, Part 5 (of 5), 1996, pp. 1973–1974.

18. S. G. Stan et al., Look-ahead seek correction in high-performance CD-ROM drives, *IEEE Trans. Consum. Electron.,* **44** (1): 178–186, 1998.

19. W. P. Murray, CD-ROM archivability, *NML Bits—Newslett. Natl. Media Lab.,* **2** (2): 4, 1992.

20. W. P. Murray, Archival life expectancy of 3M magneto-optic media, *Proc. Magneto-Optical Recording Int. Symp. '92 , J. Magn. Soc. Jpn.,* **17** (S1): 309, 1993.

21. F. L. Podio, Research on methods for determining optical disc media life expectancy estimates, *Proc. SPIE—Int. Soc. Opt. Eng.—Opt. Data Storage,* **1663**: 1992, pp. 447.

22. On CD-ROMs that set a new standard, *Technol. Rev.,* **101** (2): 63, 1998.

23. National Geographic publishes 108 years on CD-ROM, *Imag. Mag.,* **7** (3): 1998.

24. Shareware boosts CD-ROM performance, tells time, *EDN,* **43** (4): 14, 1998.

25. Ford standardizes training with CD-ROMs, *Ind. Paint Powder,* **74** (2): 32, 1998.

26. O. Widell, Esrange Geophysical Information Services, *Eur. Space Agency [Spec. Publ.] ESA SP,* **ESA SP-397**: 1997, 331.

27. J. Tillinghast and G. Beretta, Structure and navigation for electronic publishing, *HP Laboratories Technical Report,* No. 97-162, Palo Alto, CA: Hwelett Packard Lab, Technical Publ Dept., 1997, pp. 1–13.

28. J. Fry, A cornerstone of tomorrow's entertainment economy, *Proc. WESCON Conf.,* 1997, pp. 65–73.

29. M. Kageyama et al., Free time-shift Dvd video recorder, *IEEE Trans. Consum. Electron.,* **43** (3): 469–474, 1997.

30. S. P. Schreiner et al., Exposure models of library and integrated model evaluation system: A modeling information system on a CD-ROM with World-Wide Web links, *Proc. 4th IAWQ Int. Symp. Syst. Anal. Comput. Water Qual. Manage.,* Quebec, Can., Vol. 36, No. 5, 1997, pp. 243–249.

31. Anonymous, Software review, *Control Eng.,* **44** (15): 139, 1997.

32. M. William, Using multimedia and cooperative learning in and out of class, *Proc. 27th Annu. Conf. Front. Educ.,* Pittsburgh, PA, Part 1 (of 3), Vol. 1, 1997, pp. 48–52.

33. P. G. Ranky, A methodology for supporting the product innovation process, *USA/Jpn. Int. IEEE Conf. Factory Autom.,* Kobe, Japan, 1994, pp. 234–239.

34. P. Ashton and P. G. Ranky, The development and application of an advanced concurrent engineering research tool set at Rolls-Royce Motor Cars Limited, UK, *USA/Jpn. Int. IEEE Conf. Factory Autom.,* Kobe, Japan, 1994, pp. 186–190.

35. K. L. Ho and P. G. Ranky, The design and operation control of a reconfigurable flexible material handling system, *USA/Jpn. Int. IEEE Conf. Factory Autom.,* Kobe, Japan, 1994, pp. 324–328.

36. P. G. Ranky, The principles, application and research of interactive multimedia and open/distance learning in advanced manufacturing technology, *Invited Keynote Presentation, Fourth International Conference on Modern Industrial Training, Xi'an, China,* Hong Kong: Sci-tech Enterprise Department, Xi'an Jiaotong University and the Industrial Centre, 1994, pp. 16–28.

37. D. A. Norman and J. C. Spohner, Learner-centered education, *Commun. ACM,* **39** (4): 24–27, 1996.

38. R. C. Schank and A. Kass, A goal-based scenario for high school students, *Commun. ACM,* **39** (4): 28–29, 1996.

39. B. Woolf, Intelligent multimedia tutoring systems, *Commun. ACM,* **39** (4): 30–31, 1996.

40. M. Flaherty et al., FESTO: Servo pneumatic positioning, an interactive multimedia CD-ROM with off-line and on-line Internet support, over 330 interactive screens, CIMware & FESTO automation joint development, *Design & Programming* by P. G. Ranky and M. F. Ranky, CIMware Ltd., UK: 1995–1996. Web-site: http://www.cimwareukandusa.com

41. P. G. Ranky, An introduction to total quality (including ISO9000x), an interactive multimedia CD-ROM with off-line and on-line Internet support, over 700 interactive screens following an Interactive Multimedia Talking Book format, *Design & Programming* by P. G. Ranky and M. F. Ranky, CIMware USA, Inc., 1997. Web-site: http://www.cimwareukandusa.com

42. P. G. Ranky, An introduction to flexible manufacturing, automation and assembly, an interactive multimedia CD-ROM with off-line and on-line Internet support, over 700 interactive screens following an Interactive Multimedia Talking Book format, *Design & Programming* by P. G. Ranky and M. F. Ranky, CIMware USA, Inc., 1997. Web-site: http://www.cimwareukandusa.com

Reading List

W. H. Abbott, Corrosion of electrical contacts: Review of flowing mixed gas test developments, *Br. Corros. J.,* **24** (2): 153, 1989.

Anonymous, Trenchless technology research in the UK water industry, *Tunnell. Underground Space Technol.,* **11** (Suppl. 2): 61–66, 1996.

B. K. Das and A. C. Rastogi, Thin films for secondary data storage IETE, *J. Res.,* **43** (2–3): 221–232, 1997.

J. Deponte et al., Design and implementation of a system for multimedial distributed teaching and scientific conferences, *Proc. 3rd Annu. Conf. Virtual Syst. Multimedia (VSMM'97),* Geneva, pp. 156–165, 1997.

B. J. Dutson, Outlook for interactivity via digital satellite, *IEE Conf. Publ. Proc. Int. Broadcast. Conv.,* Amsterdam, No. 447, pp. 1–5, 1997.

M. Elphick, Rapid progress seen in chips for optical drives, *Comput. Des.,* **36** (9): 46, 48–50, 1997.

A. Gorodetsky et al., Effective use of multimedia for presentations, *Proc. IEEE Int. Conf. Syst., Man, Cybernet.,* Orlando, FL, Part 3 (of 5), Vol. 3, 1997, pp. 2375–2379.

J. Hohle, Computer-assisted teaching and learning in photogrammetry, *ISPRS J. Photogramm. Remote Sens.,* **52** (6): 266–276, 1997.

K. Holtz and E. Holtz, Carom: A solid-state replacement for the CD-ROM, *Rec. Proc. WESCON Conf.,* San Jose, CA, 1997, pp. 478–483.

M. F. Iskander et al., Interactive multimedia CD-ROM for engineering electromagnetics, *Proc. IEEE Antennas Propag. Soc. Int. Symp.,* Montreal, Can., Part 4 (of 4), Vol. 4, 1997, pp. 2486–2489.

H. Iwamoto, H. Kawabe, and N. Mutoh, Telephone directory retrieval technology for CD-ROM, *Telecommun. Res. Lab Source: NTT R&D,* **46** (7): 639–646, 1997.

P. Jacso, CD-ROM databases with full-page images, *Comput. Libr.,* **18** (2): 33, 1998.

A. Kleijhorst et al., Secure and cost-effective exchange of cardiac images over the electronic highway in the Netherlands, computers in cardiology, *Proc. 24th Annu. Meet. Comput. Cardiol.,* Lund, Sweden, 1997, pp. 191–194.

P. Laguna et al., Database for evaluation of algorithms for measurement of Qt and other waveform intervals in the Ecg, *Proc. 24th Annu. Meet. Comput. Cardiol.,* Lund, Sweden, 1997, pp. 673–676.

B. C. Lamartine, R. A. Stutz, and J. B. Alexander, Long, long-term storage, *IEEE Potentials,* **16** (5): 17–19, 1997–1998.

J. Lamont, Latest federal information on CD-ROMs, *Comput. Libr.,* **17**: 64, 1997.

J. Larish, IMAGEGATE: Making web image marketing work for the individual photographer, *Adv. Imag.,* **13** (1): 73–75, 1998.

M. Parker et al., Magnetic and magneto-photoellipsometric evaluation of corrosion in metal-particle media, *IEEE Trans. Magn.,* **28** (5): 2368, 1992.

R. T. Parkhurst, Pollution prevention in the laboratory, *Proc. Air & Waste Manage. Assoc. 90th Annu. Meet. Exhib.,* Toronto, 1997, pp. 1–10.

J. Phillips, Roamable imaging gets professional: Putting immersive images to work, *Adv. Imag.,* **12** (10): 47–50, 1997.

Physical Properties of Polymers Handbook, CD-ROM, *J. Am. Chem. Soc.,* **119** (46): 11355, 1997.

P. G. Ranky, An introduction to concurrent engineering, an interactive multimedia CD-ROM with off-line and on-line Internet support, over 700 interactive screens following an Interactive Multimedia Talking Book format, *Design & Programming* by P. G. Ranky and M. F. Ranky, CIMware USA, Inc. 1996, 1997. Website: http://www.cimwareukandusa.com

P. G. Ranky, An introduction to computer networks, an interactive multimedia CD-ROM with off-line and on-line Internet support, over 700 interactive screens following an Interactive Multimedia Talking Book format, *Design & Programming* by P. G. Ranky and M. F. Ranky, CIMware USA, Inc., 1998. Web-site: http://www.cimwareukandusa.com

K. Sakamoto and H. Urabe, Standard High Precision Pictures: SHIPP, *Proc. 5th Color Imag. Conf.: Color Sci., Syst., Appl.,* Scottsdale, AZ, 1997, pp. 240–244.

P. C. Searson and K. Sieradzki, Corrosion chemistry of magneto-optic data storage media, *Proc. SPIE—Int. Soc. Opt. Eng.—Opt. Data Storage,* **1663**: 1992, p. 397.

V. W. Sparrow and V. S. Williams, CD-ROM Development for a certificate program in acoustics, *Eng. Proc. Natl. Conf. Noise Control Eng.,* (*NOISE-CON*), Part 2 (of 2), Vol. 1, 1997, pp. 369–374.

D. E. Speliotis and K. J. Peter, Corrosion study of metal particle, metal film, and Ba-ferrite tape, *IEEE Trans. Magn.,* **27**: 4724–4726, 1991.

A. D. Stuart and A. W. Mayers, Two examples of asynchronous learning programs for professional development, *Conf. Proc. 27th Annu. Conf. Front. Educ.,* Part 1 (of 3), Vol. 1, Pittsburgh, PA, 1997, pp. 256–260.

J. VanBogart et al., Understanding the Battelle Lab accelerated tests, *NML Bits—Newslett. Natl. Media Lab.,* **2** (4): 2, 1992.

H. Yamauchi et al., 24×-Speec circ decoder for a Cd-Dsp/CD-ROM decoder LSI Sanyo Electric Co., Ltd., *Dig. Tech. Pap., Proc. IEEE 16th Int. Conf. Consum. Electron.,* Rosemont, IL, 1997, pp. 122–123.

Y. Zhao et al., Laser-induced temperature field distribution in multilayers of CDs and its effect on the stability of the organic recordlayer, *Chin. J. Lasers,* **24** (6): 546–550, 1997.

S. M. Zhu et al., Servo system control in digital video disc, *Proc. IEEE Int. Symp. Consum. Electron. (ISCE'97),* Singapore, 1997, pp. 114–117.

PAUL G. RANKY
New Jersey Institute of Technology
MICK F. RANKY
CIMware Ltd. UK and CIMware USA, Inc.

CD-ROMS FOR CONSUMER ELECTRONICS.

See OPTICAL CD-ROMS FOR CONSUMER ELECTRONICS.