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Optical Disks and CD-ROM: Publishing and Access

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INTRODUCTION

Laser disk technology is providing the media and methods for a far-reaching revolution in information storage that will, in concert with related advances in computer hardware and software technologies, usher in that portion of the information age wherein vast stores of useful knowledge become directly usable by the masses in a variety of forms and areas. As shown below, optical disk technology is rapidly maturing, and the burden of properly using it falls on those with the ingenuity and motivation who will develop and employ tools for information publishing and access. Presently, the most popular approach is to press roughly half a billion characters worth of data onto hundreds or thousands (and maybe soon millions) of CD-ROMs (compact disk read-only memory), the virtually indestructible 12-cm plastic disks that have become popular in recent years for distributing high-quality audio recordings.

Scope of This Report

Although MISCHO & LEE briefly discussed optical disk technology in last year's *ARIST* volume, the most recent detailed *ARIST* coverage was in the

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1984 volume, in which GOLDSTEIN reviewed storage technologies in general, especially those involving magnetic media, but also including optical approaches. In that same year, FUJITANI spoke of the coming revolution in storage with laser optical disks.

This chapter focuses on the beginnings of that revolution, including some historical discussions, but mainly emphasizing the years from 1984 through the spring of 1988. The aim is not only to explore the basic technology (second section of this chapter), but also to deal with publishing and access issues (third and fourth sections) that are crucial for making information available to those developing new application areas (fifth section). Current research efforts (sixth section) suggest future prospects (seventh section). Finally, some conclusions (last section) should help put the entire discussion into perspective.

While there is some coverage of most of the types of optical disks that have been or are being used, most of the discussion is on CD-ROM and related compact disk products and the role of standards in their commercialization. Only scant attention is given in this chapter to magnetic media since people are generally familiar with them. Similarly, other forms of storage, involving cards or tapes for example, are ignored. Our emphasis is on media and systems supporting random (i.e., fairly rapid direct location of any item regardless of its position) rather than sequential (i.e., in serial order as with a magnetic tape) access.

By considering both information publishing and access, a well-rounded picture should emerge of what types of information are being dealt with, what is involved in the publication process, and what can actually be seen by end users. This leads to discussions on hypertext and hypermedia (i.e., information collections of text or multiple media along with links between related points or items and software to allow rapid association and viewing—see also section on multimedia below), information-retrieval approaches, and a variety of issues relating to interactive education and optical information systems. Excluded in general are product descriptions or discussions of specific commercial applications.

Terminology. In a recent course at Virginia Polytechnic Institute and State University (VPI & SU) bearing the same title as this chapter, it became clear that understanding the literature in this field requires a familiarity with the relevant jargon. While many articles such as this define important terms as needed, the most accurate, complete, and clearest glossary on the subject appears in a 1988 book in this field by the company that has played a leading role in the development and propagation of optical disk and CD-ROM technology (see Appendix B in PHILIPS INTERNATIONAL).

Related Publications

Hundreds of relevant publications of all types have appeared in recent years that fall within the scope of this report. Many are articles in the popular press that are quickly superseded as new products and approaches gain

acceptance. Thus, the vast majority of the entries in the bibliography at the end of this chapter are from books, journals, conference papers, and some related periodicals. Although there is some repetitive coverage (e.g., of basics or historical background), the articles selected are generally free of major technical inaccuracies. The following subsections deal with some of the key publications in the field; later sections refer to these publications or to articles contained in them as well as to other sources.

Books and booklets. Perhaps we can tell that optical disks are indeed having a revolutionary impact; one of the COINT (Communication and Information Technology: A Multidisciplinary Approach) reports focuses on that theme (COINT REPORTS STAFF, 1986b). LAMPTON also suggests that CD-ROM will have a lasting effect since he has written an excellent book on it for young children. On the other hand Saffady has prepared two detailed books which cover the history, technology, products, and providers of media and equipment that are aimed at knowledgeable information professionals. The first covers turnkey systems for entering, storing, and retrieving very large stores of documents (SAFFADY, 1986). The second has less emphasis on turnkey systems but provides an update on the read-only and read/write technologies and is filled with useful facts and comments on current commercial offerings and trends (SAFFADY, 1987). Another pair of early works, giving a British perspective from someone involved in many CD-ROM developments, has been prepared by Hendley. The first book covers the early developments quite well, including videodisks (HENDLEY, 1985). The second, somewhat more professionally published, provides a moderate-length survey of many of the areas covered by this chapter (HENDLEY, 1987). The longest section is on applications, but there are also discussions on media, standards, production, workstations, and comparisons between CD-ROM and other optical and conventional publishing systems. Another early guide to CD-ROM has been prepared by ROTH (1986) and includes excellent diagrams, although the product and supplier information is rather dated. A longer and much more up-to-date publication is the guide by BUDDINE & YOUNG. Building on an excellent practical introduction in the first three chapters and good discussions of multimedia and disk production, the last third of the book covers technology and standards, making the key aspects of CD-ROM and newer technologies easily comprehensible.

Various survey reports, some with periodic updates, provide current perspective on the growth and development of the CD-ROM field. Thus, GALE (1987) gives profiles of companies, services, and products, including lengthy discussions of applications and their evolution. There are entries for standards organizations, information providers, venture capital sources, retrieval software, publications, hardware, manufacturers, etc. A companion report (GALE ET AL.) discusses the issues relating to textual retrieval, including systems, compatibility, software, databases, interfaces, and query languages.

Classics in the field are the three volumes prepared by Microsoft Press to coincide with their first three international CD-ROM conferences. *The New Papyrus* provides considerable insight and perspective, discusses CD-ROM systems, retrieval, and production; it covers the earliest applications of the

technology (LAMBERT & ROPIEQUET). The second volume continues these themes but avoids some of the redundancy and less informative articles and provides focused practical advice for publishing (ROPIEQUET ET AL.). Volume three (AMBRON & HOOPER) deals only indirectly with optical disks and CD-ROM since its theme is interactivity, but that is the key concept that most CD-ROM producers must appreciate if their products are to reach wider markets. Also discussing interactivity, but with how-to-do-it guidance and more details on lessons learned from working with videodisks, is the smaller collection of articles edited by LAMBERT & SALLIS.

Conferences. Technical details on research and development in media, optics, drives, and systems for handling optical information are discussed in conferences involving the optical societies; one of the best and most recent proceedings was edited by FREESE ET AL. Of historic interest especially is the report on the first CD-ROM conference sponsored in early 1986 by Microsoft (D.C. MILLER, 1986a). Although many of the now-frequent conferences on CD-ROM and optical disks do not publish their proceedings, there are at least a good number of focused (really, too short) papers in the recent book edited by ROTH (1987) from the Optical Information Systems '87 conference.

Newsletters and periodicals. The *OPTICAL INFORMATION SYSTEMS* journal has provided fairly good short articles about media, systems, and applications of CD-ROM for a number of years. *THE LASERDISK PROFESSIONAL*, a new periodical publication targeted at librarians and other professionals, may tread the middle ground between a scholarly journal and informative trade publications. For CD-ROM and related fields, *CD-ROM REVIEW* now serves as the trade periodical, and *CD DATA REPORT* acts as the most informative newsletter. Many other publications are emerging, but of particular interest to readers involved in government activities is the *CD-ROM APPLICATIONS FORUM* newsletter; it has grown out of the Special Interest Group on CD-ROM Applications and Technology (SIGCAT) group of U.S. government employees interested in CD-ROM publishing and access.

MEDIA AND STANDARDS

ISAILOVIC provides an excellent historical account of the development of optical memory systems and describes in great detail the various technologies involved. After reading the initial portion of his text, readers will be aware of the early research and developments, especially the emergence of videodisk systems that are still used today in much the same way as they were first shown a decade ago.

BOUWHUIS ET AL. supplement this information with a survey of the principles and practices involved in optical disk systems, including discussion of the optics, mechanics, recording, data encoding, and application of those schemes to common types of disks. Building on that background, it is productive to investigate this field by first studying the media along with the standards that have encouraged widespread use. After that the reader will be

better able to investigate the development of both recording and playback equipment and access software.

Magnetic Storage Approaches

As GOLDSTEIN has discussed, most of the information used by computers is stored in digital form on magnetic media. Because magnetic fields are used to store these data, these media are erasable (which reflects upon their reliability and longevity for archiving data) and reusable. Producers supply "blank" media, so publishing is done singly by users or by sequential copying, which requires time proportional to the amount of data involved.

Magnetic disks are high-performance devices, and the rapid improvement of that technology is expected to continue for some time (WAID). To provide some perspective, consider modern Winchester drives. Data are recorded in horizontally oriented regions, densely covering most of the surface. A common personal computer drive in 1988 might store 80 megabytes (MB) (million characters), while one for a large computer might store multiples of 300 MB. On average, data can be located in 15 to 150 milliseconds (ms) (i.e., access time) and can then be moved to a computer at the rate of 2 to 40 megabits per second (i.e., transfer rate). These disks are not removable and cost at least \$5 to \$40 per MB. They are mechanical devices, and the magnetic disks can be damaged if dust enters the drive since the "read" head lies within a few microns (μ) (millionths of an inch) from the disk surface. Newer drives have higher performance, and if recording can be done with the magnetization oriented vertically, significant further increases in the capacity of drives is expected.

Optical Storage Approaches

Optical storage units generally use lasers to access data, so durable removable media are common and can be accessed by heads that are on the order of 1 mm (millimeter) from the surface. Drives for CD-ROM cost \$400 to \$1,500 and allow access to roughly 600 MB of data; the plastic costs around \$2 to produce and is prepared in quantity by pressing, using a master. CD-ROM is thus very clearly a medium for publication. Transfer rates and access speeds are about an order of magnitude worse than for quality Winchesters. Other optical disks allow user recording, may hold more data, are more expensive but may have faster drives, and in some cases they closely parallel magnetic systems. However, the data are much more secure, even for archives that must last ten years or more.

Analog. Laser disks can store data in either analog or digital form (ISAILOVIC). Videodisks (sometimes called laser disks) commonly hold roughly 50,000 image frames recorded in analog form. While digital data and sound can be stored, the key strength of videodisks is their ability to handle large slide collections or video sequences. This is especially appropriate for

delivery of motion or still video in a vein similar to VCR (video cassette recorder) players although videodisks also allow random access to any point on the disk in about a second. Players typically cost at least \$1,000 but when they are used for interactive information delivery, they may be part of a computerized system costing \$5,000 to \$10,000. Thus, their appeal has been strongest for training and other shared-use situations.

Digital. Most optical disks store data using digital as opposed to analog technology. Thus, high quality digital audio equipment is gradually replacing the previously common analog devices, and virtually all of the sound recorded on optical disks is in digital form. Computer databases stored on optical disks are also almost all recorded in digital form. However, analog storage of video is still commonplace, since images take up a great deal of space when they are encoded in digital form—perhaps a megabyte each for a color TV image. Digital data can be easily manipulated by computer and can be copied indefinitely without any loss in quality. Building on the established base of expertise in videodisk production, efforts to store digital data on optical disks proceeded. The aim was to allow users to record on their own drives, thereby obtaining high-capacity removable archives (containing around a billion characters per disk) with performance almost comparable with magnetic disks (LABUDDE). Technical innovations regarding media, optics, drives, and systems have been required. Some are discussed at optical storage conferences (OPTICAL SOCIETY OF AMERICA, 1985; 1987).

Media and drives have become highly reliable, even compensating for dust or surface imperfections or vibrations, with error rates on the order of one per million. For digital computer stores containing around a billion characters, however, such error rates are not acceptable; error rates must be on the order of one in a million million or even one to five orders of magnitude better. This can be achieved with methods that allow computers or disk drives to detect and correct errors; SHIFMAN provides evidence regarding which of the various Reed Solomon code schemes is best able to give the necessary reduction in error rates. When roughly one third of the storage capacity on optical disks is devoted to error detection and correction (EDAC), desired levels of reliability can be achieved. Thus, standards groups have selected a particular combination of EDAC schemes for the various digital optical disk media (NUGENT). The error correction approaches used for CD-ROMs are clearly and carefully discussed by HARDWICK.

Write Once

Since the early 1980s, optical disks on which users can store roughly a billion characters (a gigabyte, GB) have been available. A blank 12-inch disk could be purchased, initially for hundreds of dollars, and users could create an archive by using a laser that would burn pits in the surface to store digital data. These units allowed the user to “write once” and later to read many times with a low-powered laser (i.e., write once, read many or WORM, sometimes also called DRAW, for direct read after write). HERTHER provides a

clear and concise overview of this methodology and its utility. ROSCH also discusses WORM drives, concentrating on capabilities and products as of the end of 1987. IBM markets a WORM drive (i.e., the 3363 unit) for their Personal System 2 line of computers (see discussion in ARCHER ET AL.) for archive and backup purposes, so the use of magnetic tapes for these purposes may decline. While the IBM 3363 costs around \$2,000 and will store 200 MB on a single side of a 5.25-inch, \$60 cartridge, other vendors market more advanced drives that operate more quickly and store 400 MB on each of their two sides (ROSCH).

Erasable

While read-only devices are suitable for publishing and write once devices are valuable for archiving data, it is nearly essential to be able to erase information for certain computer applications. Certain media with special magnetic and optical properties have been developed and studied for use in erasable optical disks (GARDNER ET AL., 1986; 1987); a magnetic field is applied to the entire surface but causes changes only in a micron-sized spot while a fairly high-powered laser causes the temperature to rise beyond the Curie point, thereby allowing the field to effect a change in that tiny region. The application of a different magnetic field allows the data to be "read" with a low-powered laser. While other erasable optical disk systems have been developed (e.g., in which lasers apply heat to force melting and subsequent phase shifts in spots on the media), the magneto-optical (M/O) scheme was sufficiently perfected in 1987 for several vendors to begin preparing commercially available products (SIMPSON). FREESE summarizes the methods and current status of this technology, suggesting that erasable disk drives would be commercially available in 5.25- and 3.5-inch sizes during 1988, albeit for prices slightly higher than for Winchester drives. Announcements by companies such as Tandy and Maxtor in the spring of 1988 were among the first official statements launching this serious competition for erasable optical disks that may challenge the supremacy of magnetic disks.

Compact Disks

Compact disks are 12-cm (4.72 inches) in diameter and are made of durable plastic. While computer systems most commonly accommodate 13-cm (5.25-inch) or 89-mm (3.5-inch) diskettes and disks, compact disks have become quite popular for a variety of optical disk products.

Compact disk digital audio (CD-DA). In the early 1980s, Philips International and Sony Corp. collaborated to develop a methodology for recording over an hour of very high-quality audio data in digital form on a compact disk. EDAC methods were specified to reduce the likelihood of error to well below that detectable by the human ear (see, e.g., HARDWICK), and, along with other technical specifications on producing and playing the disks, these

were recorded in the "Red Book" made available to licensees. An international standard formalizes the content of that book for digital audio disks (INTERNATIONAL ELECTROTECHNICAL COMMISSION). CDs and CD players have become successful consumer products in recent years, and so provide an economy of scale to help drive down the price of other CD-based products.

Compact disk read-only memory (CD-ROM). CD-ROMs were first perfected and publicly shown in 1985 (SAKO & SUZUKI). The technology was specified in the "Yellow Book" made available to licensees. Details are given in concise form by P. P. CHEN (1986) and by DAVIES. An international standard was submitted by ECMA (European Computer Manufacturers Association) to ISO (International Organization for Standardization) to formalize these specifications. In general the disks are the same as for CD-DA. However, disks recorded with a flag indicating Mode 2 contain digital audio, while those with a flag for Mode 1 need to have extra EDAC, bringing down the amount of usable data in a disk sector to 2,048 B (bytes) but increasing the reliability to beyond that of most magnetic disks. Since CD-ROM drives are generally improved versions of CD-DA players, prices are expected to drop significantly below the early 1988 lows of around \$500. The drives run at the same speeds as CD-DA players, so an entire disk with roughly 600 MB can be read (sequentially) in an hour, reflecting the transfer rate of 1.2 megabits per second.

CD-ROMs can be viewed simply as disks containing 300,000 or more consecutively numbered sectors of data. Since such a large amount of space is very difficult to use directly, widespread application of CD-ROM was not expected unless most computers could access data on CD-ROM through some standard directory structure. A group involved in early CD-ROM activities met in 1985 in the High Sierra casino to begin formulating a standard for volume and file structure (see history and other details in SCHWERIN ET AL.). A working draft standard was prepared in May 1986 (CDROM AD HOC ADVISORY COMMITTEE), and many CD-ROMs have been prepared according to those specifications. The 1986 draft is the basis for a national standard (NATIONAL INFORMATION STANDARDS ORGANIZATION) and a very similar international standard, ISO/DIS 9660 (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 1988). The national standard should be adjusted to conform to ISO/DIS 9660 so that it will be followed in almost all future CD-ROM productions. Ultimately, the directory and the contents of any CD-ROM should be readable on any CD-ROM drive and through most popular computer operating systems (e.g., MS-DOS). EINBERGER & ZOELLICK explain the important points in the High Sierra de facto standard in a concise but relatively complete form; those companies developing low-level device driver software should, however, refer to the above-mentioned ISO publication.

CD-ROM with digital video interactive (DVI). Since a CD-ROM stores digital data—either digital audio or other digital data—that information can represent anything that can be interpreted by computer hardware or software. Clearly, it is desirable to be able to record graphics, images, or motion video, but with straightforward approaches only 30 seconds of full motion video can be stored in digital form on a CD-ROM, and it would require one

hour to play it back! At the David Sarnoff Research Center (formerly owned by RCA and now owned by SRI International), a special set of VLSI (very large scale integration) chips were developed to support "digital video interactive" (DVI), wherein an hour of full motion video could be stored in compressed form on a CD-ROM and decompressed for real-time playback. A newsletter from the Sarnoff center describes ongoing progress in extending and applying this technology (*INTERACTIVITIES*). In March 1988 a total of four companies with significant involvement in CD-ROM development agreed to develop standards for DVI that would promote widespread use (REGIS MCKENNA INCORPORATED).

Compact disk interactive (CD-I). Philips International and Sony Corp. announced in March 1986 their plans for CD-I development. Progress has been detailed in a newsletter (*CD-I NEWS*). This effort involves the development of a standard for storing interactive programs on a compact disk (specified in the "Green Book"), specification and construction of a packaged computer system capable of running those programs, and production of programs that follow the standard that can run on conforming computer systems (ISBOOTS). The definitive public document about CD-I (PHILIPS INTERNATIONAL) was released in early 1988 and provides introductory materials, technical details, discussion of possible applications, and an excellent glossary. In addition, Philips has developed a standard for exchanging information relating to interactive CD programming (BLUETHGEN) that should facilitate CD-I development and also aid in standardization of interactive CD-ROM programs. Ultimately, it is hoped that CD-I will reach the education and consumer market through the sale of Motorola 68000 family-based systems (scheduled for availability at a cost of roughly \$1,500 in 1988) with special CD-I (plus CD-ROM and CD-DA) capabilities, that can run interactive programs (perhaps costing \$40) including data, text, audio, graphics, images, animation, and limited motion video.

Other compact disk products. As discussed in the book by PHILIPS INTERNATIONAL, a number of other CD products have been or are being developed. CD-V (compact disk video) stores video images in analog form (in similar fashion to the scheme which was first introduced by Philips in 1972 and which was later called LaserVision; in addition at least one other competing scheme has been proposed) as well as digital audio. Eventually, CD-IV (compact disk interactive video) will evolve from CD-V and CD-I.

Other Size Disks

The original laser disks had 12-inch diameters and are still in widespread use. For applications where portability or economy of production was desired, 8-inch disks were used. Both sizes are suited for analog or digital storage, but with today's computer systems, economies of scale dictate use of much smaller disks.

5.25-inch products. In keeping with Winchester technology, most recent medium-scale WORM systems, beginning with the Optotech 5984 (LEE & CHEN), have been built to accommodate the 5.25-inch disk. However, other

options have been considered—various densities of data, use of one or both sides, storage organizations relating to playback methods (e.g., uniform pit sizes as in constant linear velocity (CLV) or variable pit sizes as in constant angular velocity (CAV) schemes), approaches to WORM or erasable methods, and alternative coding schemes. Various committees are actively working to establish a suite of standards for 5.25-inch products. It is likely that faster, higher-capacity digital disk drives will be available for read-only, write once, and erasable media. Emphasis, however, will be on optical digital data disks (OD³).

3.5-inch products. Even disks as small as 3.5 inches are being developed, and they parallel those for the 5.25-inch disk. CD-ROM products with limited storage requirements began to appear in 1988 also. Active work is continuing on M/O erasable drives for 3.5-inch media (SANDER & SLOVENKAI). Erasable disks with 50 to 100 MB capacity began to appear in 1988.

PUBLISHING

Publishing with optical disks such as CD-ROM can be viewed from various perspectives. First, there is the perspective of cost, which involves the media, equipment, and time needed to produce a disk with data. Here we can distinguish among the most expensive option, erasable, the next most expensive, WORM, and the inexpensive, read-only (especially CD-ROM). Second, there is the perspective of who does the publishing and when it is done. For erasables it is end users as the need arises, for WORM it is usually developers preparing limited-run products, and for read-only disks it is usually publishers.

Throughout the discussion below, the context is that of videodisk or CD-ROM publishing, although many points apply to other situations. In the most general case, however, the context is electronic publishing (see the excellent review of issues in that field by RAITT (1985a)). Data of all types, when made available electronically, can be copied or replicated on optical disks. BUTLER ET AL. explore when CD-ROM should be chosen as the appropriate medium for publication; after all, it is just one of many electronic publishing choices. MYERS focuses on the details of CD-ROM publishing. Regarding CD-I publishing, on the other hand, the reader is once again referred to the designer's guide by PHILIPS INTERNATIONAL.

Data Protection

One of the areas needing considerable attention in future years is in understanding data-protection issues and in the formulation and passage of appropriate legislation at all levels, especially since CD-ROM production involves the collection of large amounts of data. The current situation and concerns in this regard are thoroughly described by BREMNER, with the focus on copyright-related issues. In addition to discussing fair use and fair sale, registration and notice, rights of display and performance, he covers licensing arrangements, technology restrictions, and distribution approaches.

Negroponte makes clear the advantage of CD-ROM: "I marvel constantly at the industry's tendency to want to make read-only disks into write-once disks into read-write-erase disks—to make them like magnetic disks, failing to realize they are a publishing medium and that read-only is a virtue, not a liability. If you publish data, you want it inviolate. . . ." (BRAND, p. 23).

Authoring

Authoring involves collecting materials, reshaping/converting/reorganizing them, and creating an integrated whole. As in other electronic publishing ventures, authoring of optical disk products involves the use of a variety of special tools. Indeed, since some products such as CD-I involve a computer working in concert with all types of media, the authoring process involves expensive equipment, considerable technical knowledge, coordination of a large team of talented co-workers, and significant expense.

Interactive design. To engage and maintain the interest of a user, it is most appropriate for many applications to view the end product as an interactive system, thereby calling for interactive program design. HON provides an overview of the parameters involved in interactive design, including those relating to the user, the equipment, and the system operation. In cases such as videodisk or CD-I design, there are many predetermined decisions, while for CD-ROM there are more options of all types. All media, however, provide flexibility about how and when the user is involved. HOLDER & DAYNES give a lengthy sequence of strategies for interactive feedback, aiming at simplifying the design process by breaking it down into a network of well-understood atomic interactions. BREWER (1986) describes the most important ways in which audio can be applied to promote interaction and provides an outline for design and development; he also explains hardware options and system interrelationships. More specific interaction modes are considered below for various types of systems or in connection with the discussion on data preparation.

CD-ROM. CANTER discusses a workstation-based authoring system for CD-ROM. Workstations may be needed for text entry, graphics, music or sound effects, and animation. "Scores" (as in music) must be developed, and all actions properly coded. General blocking of program components followed by specification of detailed timing, testing, and debugging are required.

Videodisk. Videodisks generally are prepared to support one or more levels of interactivity. Level 1 allows control with hand-held or remote controls. Level 2 involves programming of the videodisk player's built-in computer (KENT), which rarely has more than 7 kB of space for instructions and is thus too limited for complex interactive operation. Level 3 uses a separate computer to control the videodisk player. Various delivery systems are possible (HAUKOM & MALONE). There is considerable variation in graphic or audio interfaces and authoring languages and wide latitude in developing games, films, training programs, and other applications.

CD-I. Building on experience with level 3 videodisks, it is possible to engage in the very complex design process for CD-I. LOWE provides an overview of the standard and system, outlines possible classes of applications (e.g., talking books, activity simulations, video editing), discusses a low-level development methodology building on still-frame handling, and concludes by explaining authoring tools and production facilities. R. L. MILLER (1987) focuses on what was known about CD-I in early 1987 and provides general suggestions that are useful, but he includes other information that is dated. CANTER ET AL. propose an ideal CD-I authoring system involving domain editors for graphics, sound, text, and programs, with output controlled through an authoring language that supports description of interactions and specification of interleaving and formatting. An example illustrates the approach, and some systems under development for CD-I authoring are explained.

Data Preparation

Various types of information must be collected and put in proper form for subsequent processing and integration. The overall operation is summarized by ADKINS, along with pointers and estimates regarding approaches possible with varying budgets. COLVIN describes the organizational and indexing aspects involved in conventional databases (e.g., in columnar form). HAMILTON provides abbreviated guidelines regarding text handling, including aspects relating to fields within records and search capabilities, viewing them in contrast with those for online search systems.

Regarding text collections, BRIDGE & MORIN consider problems in obtaining data, whether by scanning and use of OCR (optical character recognition) or through conversion of tapes provided by a typesetter or after transformation of word-processor output. They summarize the steps involved but more importantly mention the importance of the AAP (Association of American Publishers) standard for document markup. This standard is based on ISO 8879 (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 1986). Standard Generalized Markup Language (SGML), which the U.S. Department of Defense and other organizations will require for many documents submitted in the future. The AAP standard is being moved toward international approval as a standard for markup of books, journal articles, and journals; it includes conventions for tables and equations and special characters as well as descriptions for document organization. As eloquently argued by COOMBS ET AL., this approach of "descriptive" (e.g., $\langle p \rangle$ to designate a paragraph) as opposed to "procedural" (e.g., ". in 5" to tell the computer to indent 5 spaces) markup is essential for future scholarly activities to flourish and allows information retrieval programs to be readily applied to text collections. Indeed, retrieval systems can then support even more precise requests, calling for some keyword appearing in a narrowly defined context (e.g., appearing with a specified type of emphasis in the title of a subsection).

N. M. NELSON (1987a) makes clear the value of the AAP standard for handling very large text collections.

Audio data preparation is the focus of the article by BREWER (1987). In addition to discussing delivery system options, he deals with tradeoffs of fidelity vs. storage (e.g., sampling, quantization, compression) and explores the distinction between audio prepared for CD-DA or for CD-I. He considers choices for audio sources and explains mastering (i.e., creating a "master disk" that facilitates mass replication) with audio.

D. C. MILLER (1986b) describes graphic images, explains the various types, discusses image processing, considers issues of storage and compression, and concludes with comments on motion and integration with audio. APPERSON & DOHERTY give a lengthier and more detailed survey of the issues and approaches involved. Beginning with the display environment, they consider presentation formats, image creation, and image format conversion. They also survey key points in image processing and conclude with discussions of CD-I and applications.

Updating. Not only must data be prepared originally, but some attempt must be made in most applications to deal with change in the data. ROUX considers the amount of information that can be handled through various distribution methods to supplement an initial collection on CD-ROM. He summarizes the relevant issues and practices and suggests update models for partial or full replacement of raw and index information. Incidentally, the standard ISO/DIS 9660 provides for logical deletion and updating of old disks in a multivolume set, but that requires users to switch among several disks using a single drive or to go to the extra expense of buying several drives.

Production

A number of plants can press compact disks (see, for example, STRUKHOFF, 1987), and this capability worldwide has recently grown to the point where plants are seeking to develop long-term arrangements for CD-ROM production to supplement the CD-DA work. Production typically includes both premastering (i.e., preparing for mastering) and mastering (ARMSTRONG).

The first step in disk production involves simulation and premastering. Data are loaded into a system with adequate storage and are organized into the proper directories (MERIDIAN DATA). ISO/DIS 9660 requires that special files be created to handle volume and directory descriptions. The layout of all data on the disk can then be fully specified. Next, simulation involves testing with special software that prohibits writing and adds delays so timings are close to those of the final disk. In the last phase of premastering, EDAC codes are computed and an analog tape may be produced. During mastering, the premastering output is used to drive the laser mastering system. Later, stampers are derived from the master, and multiple copies are produced, all with the same "imprinted" collection of data.

ACCESS

While considerable attention has been given to the problems of publishing on optical media, smaller investments have been made in efforts aimed at improving the accessibility of information recorded on CD-ROM and related types of disks. Better, smaller hardware is becoming available, and operating system interfaces that follow established standards have been developed. Nevertheless, despite pleas encouraging the use of more advanced retrieval models (FOX, 1986), most retrieval software shows little improvement beyond that common to online systems. Now that the benefits of hardware standardization have become abundantly clear and some gains from software standardization have been achieved (e.g., in terms of volume and file formats), focus should shift to the development of software architectures that will, on the one hand, promote interchangeability (as encouraged by ZOELLICK) and, on the other hand, encourage experimentation and innovation.

Drives and Interfaces

To access data stored on optical disks, a laser beam is focused on micron-sized spots on the surface, and a digital readout results from analysis of the (usually reflected) light that results. KUTTNER provides a detailed description of the optics involved and considers the various approaches to designing the lenses, plates, and other components.

BRAAT explains the principles involved in this type of scanning spot microscopy, provides a mathematical model of the readout process, and discusses signal and system issues. The key to the performance of optical drives is the behavior of the access mechanism, that part of the drive that moves in connection with computer requests to access data at varying positions on the surface. LAVENDER explains the servo systems involved in CD-ROM playback units, describing how, despite the incredibly high density of information (e.g., 20,000 separate tracks of data per inch) and the three-dimensional motion of the disk platter, the laser beam can be kept in focus during sequential reads and refocused after "seeking" a new location.

VAN ROSMALEN gives a lengthy but clear explanation of the basic control mechanics issues involved in various kinds of optical disks, complete with plots and curves of the underlying optical, magnetic, and mechanical characteristics; diagrams and photographs of components; comparisons of approaches for satisfying various performance requirements; and block diagrams of subsystems. While price competition puts pressure on reducing drive costs, performance competition keeps prices up as systems with lighter heads and higher quality optics are developed to decrease access time. FOX & WEAVER discuss the organization of CD-ROM drives, survey current offerings, and present empirically derived timings for a first-generation CD-ROM drive, wherein an access time of several seconds is common (as opposed to an average of less than half-a-second on newer drives). SEITHER considers the new half-height drives, which are smaller and can be less expensive since they

can share computer power and cabinetry with the processor. Unfortunately, despite standards in many other areas, the cartridges required for loading a CD-ROM into these drives are not standardized, thus creating further confusion and burden for users. In any case, CD-ROM drive sales have been and should continue to rise, especially as vendors offer discounts and a wide variety of retail outlets for these products (e.g., see STRUKHOFF (1988)).

To connect optical drives to computers, some type of disk controller or interface is required. WARREN (1986a) makes a strong case for SCSI (small computer system interface) drives, so that by changing only a software driver, the disk can be connected to a variety of systems. Since the SCSI standard and CD-ROM performance are fairly well matched, this seems the wisest course even though there are special interface cards available for IBM and related personal computers. More complex, however, is the problem of connecting and using many disk drives on a single computer for network access or of effectively using jukebox devices that store scores or hundreds of optical disks. ZELINGER surveys the field of optical jukeboxes, which are now most commonly used as part of large document archive systems. Recent efforts by Meridian Data, Inc. hold promise of allowing hardware support for accessing multiple CD-ROM drives attached to a server through local networks, a particularly important development for libraries and offices. However, related software support is also needed for this to be truly effective.

Operating and File System Support

With the recent approval of ISO/DIS 9660 for CD-ROM volume and file access, drivers have been extended so that popular operating systems will view properly published disks as just another hard disk drive (ZEICHICK). WARREN (1986b) argues that in addition to providing drivers, it is essential for tools to be developed allowing access to data files in a fashion that takes advantage of the attributes of the media and drives. His argument is sound and is considered later in the section on research.

Methods and Implementations

For a CD-ROM product to achieve extensive market penetration, it is essential that the human-computer interface be tailored to direct and easy access by the end user. This means helping people who are familiar and at ease with paper-based information systems become comfortable in using video screens (KERR). The surface design, the interface design, and the tools needed for them to find their way to the information they seek are crucial aspects. While CD-ROMs can contain data that are accessible from spreadsheets or other well-established interfaces, many are searched with the aid of a retrieval system.

Retrieval systems. Most retrieval systems for CD-ROM use conventional Boolean logic methods for carrying out complex searches. There is little

fundamental variation among the systems available, and comparisons such as that by HELGERSON (1986), while saving time in accumulating reliable system comparison data, lack criteria that would distinguish a conventional from an innovative system. Many important distinctions relate to the quality of the user interface, as has been carefully explained by KAHN (1988). He assesses the interfaces in six popular systems along five functional lines: browsing, using menus, refining a search, accessing a related online version, or printing/saving results. Unfortunately, he is forced to conclude that little real change has been made in the way online searches are carried out and that much better interfaces could be developed if human-computer interaction principles were conscientiously applied.

Better performance and more efficient retrieval are also possible if application software is tuned to media like CD-ROM. OREN & KILDALL propose prestoring the results of join operations in relational databases, give suggestions on useful compression methods, recommend improving access time by having multiple copies of data on CD-ROM and copies of the CD-ROM itself, and outline approaches to accommodate multimedia and new hardware capabilities. CICHOCKI & ZIEMER likewise make recommendations on minimizing "seeks," transferring large amounts of data (as opposed to frequent seeking) through the use of extra RAM, and preprocessing/replicating/clustering. For single-key searches they encourage tuning the hashing methods, while for multiple-key searches they suggest using hashing on each of the keys (and storing data redundantly) to locate single records or index buckets. For inverted files, they advocate B-tree dictionaries (with large buckets, good cache management, shallow flattened trees). For long searches, they recommend status reports to impatient users and for very large files, they encourage compression.

Hypertext and hypermedia. In a seminal 1945 paper, BUSH elaborated on his vision of a desktop portal to the world's store of recorded knowledge that would build on and give expression to the manifold associations among information items. Engelbart demonstrated in 1968 a first implementation of some of these capabilities (e.g., using a mouse and special keypad to directly manipulate and display structured documents that were accessed collaboratively by multiple individuals in remote locations) and has since extended those results to the realm of cooperative systems for augmenting human reasoning and information processing (ENGELBART & HOOPER). In the early 1970s T. NELSON coined the term "hypertext" to describe systems in which associations (links) between parts of text files are easily built and followed; at the same time he predicted that computers would become nearly universal tools with hypertext systems profoundly affecting the way we record, disseminate, and access information. YANKELOVICH provides a comprehensive bibliography to the related field of hypermedia, wherein text, audio, video, animation, and so forth may all be interlinked for true multimedia information access. YANKELOVICH ET AL. (1985) provide a vision of the "electronic book," in which computers become our primary method for accessing information and in which authoring and reading are much more closely connected than they are at present. They consider the tools required,

the efforts undertaken at Brown University and elsewhere, and research problems yet to be solved. The first issue of *HYPERMEDIA*, a new popular magazine first appearing in summer 1988, not only includes a short glossary, but also relates this burgeoning field to CD-ROM activities.

BROWN describes the first CD-ROM implementation of hypertext, CD Guide, and demonstrates how easily text and graphics can be accessed with a CD-ROM and a Macintosh. Recently, with the rapid growth in the use of the Apple hypermedia product, HyperCard (see discussion and examples provided by MARKMAN), publication of HyperCard "stacks" on CD-ROM should blossom. Other collections of hypertext and hypermedia are being produced on CD-ROM and generally should have well-designed user interfaces; they should be integrated with retrieval functions to provide a flexible and comprehensive information-storage and -access environment.

APPLICATIONS

By the end of 1987 there were roughly 200 different CD-ROM products, providing evidence of an emerging market but also challenging the user who is deciding whether and what to buy (D.C. MILLER, 1987b). While those products should ultimately be evaluated as they relate to user needs, they are most often evaluated according to content, price, support and documentation, search software, user interface, hardware, operating system, and standards followed (D.C. MILLER, 1987b).

While several CD-ROM products include demonstrations of a range of sub-products, several printed directories are available for a nominal charge. BOWERS' directory covers mostly CD-ROM but includes a small number of videodisk products, devoting a full page to each title. N. M. NELSON (1987b), in conventional book form, gives shorter descriptions of each product and includes a simple introduction as well. N. M. NELSON (1987c) includes several pages for each title, focuses on product description and producer's comments, and provides sample screens to illustrate system functions.

The following subsections view existing and potential CD-ROM applications from several different perspectives: by function or use, by user type, and by task domain. Because of space limitations, only a few of the earliest or most interesting applications are considered in any one area.

Functions

Optical disk technology can be used for various purposes. The most common needs are for archival storage, to distribute information, to support reference, or to encourage human-computer interaction.

Archive. One of the earliest large-scale optical information systems proposed and later implemented is the Megadoc system; its history and developmental problems are summarized by URROWS & URROWS. WALTER discusses current options for optical filing systems, a timely subject since tech-

nology appears to be sufficiently mature for focused efforts. LYNCH & BROWNRIGG consider the broad issues of conservation and preservation, arguing that although significant expenditures are required, in the long run it will be more cost effective if digitization occurs soon. LYNCH considers the entire life cycle of optical storage for libraries, reviews the various media, discusses permanence and archival stability, explores problems with the changing technology and its management, and relates these problems to networking and standards. R&D activities at the National Library of Medicine have included construction and testing of a prototype system to capture scanned page images with high throughput workstations (THOMA ET AL.) in a distributed network environment (WALKER ET AL.). While many technical issues remain, these activities demonstrate that pages can be captured and archived in less than a minute with the image transferred over local networks.

Distribution. CD-ROM is a cost-effective medium for distributing large quantities of information, even when end users are simply copying or downloading moderate-sized chunks of data for local use. HENSEL lists many of the issues that should be considered in planning this type of distribution. LOWELL discusses an early example in which the Library of Congress extended its Cataloging Distribution Service to include CD-ROM as yet another medium that could be used to disseminate cataloging information.

Reference. In recent decades, reference centers, such as in libraries, have shifted from working solely with paper products to a mixed environment involving online search services. MEYER explores the issues that arise when libraries must decide whether to add CD-ROM as another tool. He discusses whether CD-ROM should be for end users or for intermediaries; he faces issues of currency, completeness, database size, and pricing; and he considers alternatives for database producers regarding how information can best be moved to CD-ROM. COHEN & YOUNG take a more quantitative approach. They consider start-up as well as annual costs in various categories to compute the yearly and total costs for accessing each of three different databases, using paper, online, and CD-ROM services. They conclude that while paper products are the least expensive, CD-ROM-based services are less costly than online in two cases and only slightly more expensive in the third. We may conclude that CD-ROM reference products should be carefully compared against online services and may often be the better choice.

Interactive. As NegroponTE explains, "CD-ROM is by definition an interactive medium" (BRAND, p. 23). Thus, another class of applications for optical disks is to support highly interactive access to multimedia information. In the volume by LAMBERT & SALLIS, this is discussed from the conceptual, design, application, methodological, and implementation perspectives. Thus, R. L. MILLER reviews interactive systems going back to filmstrip and computer-based training (CBT) and computer-assisted instruction (CAI) systems. He describes the most promising types of (generally, videodisk) applications and elucidates the design considerations for each:

- Consumer applications, such as art, education, and financial management;

- Arcade games;
- Point-of-purchase and public-access applications ranging from the use of videodisk players in General Motors showrooms, which began in 1979, to more recent systems at kiosks for explaining kitchen products, to systems describing: consumer information, banking, or hotel checkout;
- Training, including surrogate travel (as in the 1978 *Aspen Movie Map* (see also BRAND, p. 141)) or teaching management skills or cardiopulmonary resuscitation;
- Military training, from the 1980 *Army Track Gunnery Trainer* to the current EIDS (electronic information delivery system) involving more than 40,000 units;
- Education (e.g., the *BioSci* disk including over 5,000 images on aspects of biological science, and a whole series of disks covering NASA space missions); and
- Custom applications, as in Walt Disney World's EPCOT center with more than 275 videodisk players.

PHILIPS INTERNATIONAL explains how CD-I products can be designed, considers applications in which success is most likely to occur first given the constraints of current methodology, and suggests that many of the practices and content collections developed for videodisks should be retargeted for the potentially larger CD-I market.

Users

While MISCHO & LEE point to the overwhelmingly positive reaction of end users to CD-ROM products, ultimately the success in applying optical disk systems depends on the degree to which end users are served in dealing with their varied information, education, entertainment, or other needs.

Library. Libraries traditionally provide patrons with access to materials made available in various media. LOWE ET AL. describe one of the earliest prototype applications of optical disks to locally publishing and accessing bibliographic data. The very first commercial CD-ROM publication, the BiblioFile Catalog,* is discussed by MARTIN, who explains its rationale, design, development, product details, and actual project management. RAITT (1985b) presents the broad picture of how electronic publishing in all forms can be applied to library needs. He considers its potential advantages and disadvantages, discusses what impact this technology will have on librarians, and advises them on how to cope with the inevitable changes. D.C. MILLER (1987a) focuses on implications of digital optical printing for library departments. VANDERGRIFT ET AL. provide a handy annotated bibliography and

*CD-ROM database.

explain some of the most popular applications of CD-ROM for public-access catalogs and optical publishing, including Brodart's LePac* catalog, Bowker's Books in Print Plus,* the Grolier Electronic Encyclopedia,* and the InfoTrac II* and GEOVISION* databases. N. M. NELSON (1987b) provides a handy reference guide to CD-ROM products that might serve library information needs and that can run on machines such as the IBM Personal Computer.

Education. AMBRON & HOOPER bring together the views of developers, educators, and information providers involved in the 1986 invitational Apple conference on Multimedia in Education. Thus, WEYER explores his vision of intelligent hypermedia knowledge systems for learning, beginning with a categorization of learner goals, describes the crucial need to filter information, calls for reorganizing information from the user's perspective, considers the use of similarity and links, and emphasizes the need for systems to serve as guides. Several other authors in the volume deal with content areas, suggesting how multimedia systems might be tailored to existing or developing collections. FRIEDLANDER, from a background in theatre, explains how the plays of Shakespeare can be truly understood only when students are actively involved in the process of theatrical creation. He describes three components of a prototype videodisk-based computer package: 1) a kit for scholars to analyze a play and scene in detail, 2) a kit for directors so that students can creatively design a scene, and 3) a version of both for home use. In the light of advanced computer technology, FRISCHER considers how problems in providing proper instruction in the classics can be addressed. His intriguing model is of a core of multimedia databases, an inner ring of scholarly utilities for using and modifying those databases and an outer ring of pedagogical applications. He suggests that this perspective be used along with a guide, Cicero, to aid navigation through the Roman civilization, using a 60-foot diameter detailed museum model of Rome. CAMPBELL & HANLON, having collected some 55 works relating to Steinbeck's *The Grapes of Wrath*, have organized their materials into 33 topical areas to serve high school classes and others. GIBBON & HOOPER review the *Voyage of the MIMI* videodisk-based educational project by Bank Street College. They relate their experiences in producing TV programs to teach science and mathematics to the goals of interactive videodisk-based teaching. ANDERSON discusses another effort—this one involving WNET (channel 13) in New York City which attempts to link enormous investments in TV programming such as the PBS show *Creation of the Universe*, with computer graphics simulations conveying quantum mechanics theories, to provide interactive TV instruction. Clearly optical disk technology and computer systems have tremendous potential to bring together educational materials on all types of media for user-oriented, highly interactive learning.

Consumer. The largest potential market for optical disk-based systems, such as CD-I, is that of the general consumer. While many applications dis-

*CD-ROM database.

cussed in this section might appeal to consumers, one that is the focus of ongoing development and prototyping is the electronic encyclopedia. COOK describes Grolier's strategy for developing a multimedia encyclopedia, which builds on their *Academic American Encyclopedia*,* and illustrates through a series of figures based on computer screens, each of the proposed methods for information access. He concludes with a discussion of how audio, dynamic graphics, picture databases, and motion sequences can be integrated.

Domain

CD-ROM applications are perhaps most naturally grouped by content area. The following paragraphs mention only a few areas, those selected by developers for the earliest products.

Medical. Medical information has long been sought and provided through innovative technologies. WINOKUR ET AL. describe the earliest CD-ROM product for the medical community, a clinical information system arising out of their earlier online services. They review the history of the effort, beginning with a 1974 computer-output microfiche edition, explain their design decisions, budget, implementation, distribution, and the market response. They conclude that for important, usable information, the delivery mechanism is not the paramount issue but that CD-ROM is clearly a viable alternative or supplement to other publishing efforts.

Geographical. While medical information in text form is easily delivered through various mechanisms, geographic information is best seen through color images or motion sequences. PETERSON retells the illuminating story of the evolution of the National Geographic Society, reinforcing its commitment to education. While a variety of geographic CD-ROM products are targeted at professionals and some will serve consumers (e.g., automobile reckoning and navigation systems), interactive programs from the Geographic Society will likely be among the most exciting and enlightening products that will appear. Products for researchers, however, by bringing together on one disk a variety of geoscience collections and powerful tools for access will undoubtedly encourage discovery of new interrelationships that may be crucial to our identification and handling of global changes.

Other. A wide variety of other applications have been and will be developed. One of the most intriguing videodisk efforts is PROJECT EMPEROR-I, directed by C. CHEN. A pair of videodisks bring archeologists, art historians, scholars, students, and the public to one of the most exciting archeological finds of the century, the magnificent tomb of the first Emperor of China (Ch'in Dynasty); here they all explore his many accomplishments, including the completion of the Great Wall.

Shifting from art to computer science, the announcements by WEGNER and FOX (1988b) show the Association for Computing Machinery's (ACM) effort toward building an electronic library, and to produce not only books but a

*CD-ROM database.

variety of other materials, including optical disks and CD-ROMs. Interested parties are encouraged to communicate with the editor of ACM Press Database and Electronic Products to explore product ideas that will serve students, professionals, and other computer users with applications that can be built on: journals, conference proceedings, curriculum materials, tutorial films, graphics animations, simulations of algorithms and other processes, and so on. As similar professional organizations take similar steps, it is likely that authors, practitioners, and developers will become involved in the production of a wide variety of applications.

RESEARCH

For this field to develop further, ongoing investment in research is clearly needed. Efforts to improve media and hardware have been considered in previous sections; this section concentrates on research in both systems and software for improved access.

Optical Information Systems

Optical information systems have been developed for various applications. Research has focused on developing particular prototypical applications and on investigating alternative approaches.

Applications. The British Library has funded several efforts to explore the potential of the new optical technology. CLARKE describes their experiment to prepare a CD-ROM from three bibliographic files available through the library's online service, and covers the objectives, development history, and future plans. The follow-up effort, Project Quartet, is described by ARCHER ET AL. In addition to providing a survey of existing products, they discuss the Hatfield Experimental CD-ROM*, aimed at demonstrating access to a large collection of free text and showing the capabilities of hypertext on a CD-ROM. They also consider issues of enhancing CD-ROM products with read/write support on magnetic media, methods for multi-user and network access, embedded systems, and mixed-mode documents. A related project that seeks to demonstrate the viability of locally publishing various types and forms of information and to allow experimentation in a number of areas is being managed by this author and will lead to the production in 1988 of a series of CD-ROMs (FOX ET AL., 1988a). The contents of Virginia Disk One* (FOX, 1988a) include agriculture and consumer-oriented extension information, professional materials from ACM, test collections for information retrieval and image-processing research, archives of electronic digests on information retrieval and artificial intelligence, bibliographies, public domain data, and so forth. Hypertext and advanced retrieval systems are compared

*CD-ROM database.

also. Virginia Disc Two* has library catalog data as its theme, and includes searchable MARC records for holdings of periodicals at VPI & SU.

HLAVA & REINKE provide one of the few reports on studies of user reactions to CD-ROM products, measuring hardware/software performance, frequency of use, and user satisfaction. While their anecdotal comments are valuable, substantive and quantitative studies are sorely needed. In the final report on the Isocrates project (to develop application and system software to support a CD-ROM database of Classical Greek literature), KAHN (1987) reviews the history and findings of that innovative effort and provides quantitative results on such dimensions as access times for various searches involving hard disks or CD-ROMs. It is hoped that many other research activities will be funded regarding the development and use of optical disk-based information systems and that future reporting will focus more on controlled studies that lead to definitive conclusions.

Approaches. Scholarly research contributions dealing with approaches to optical disk information systems are available. BERRA & TROULLINOS discuss applying optical techniques to data- and knowledge-base machines, introduce work on optical computers, and indicate how optical disks might have higher performance when closely coupled with other components of a totally optical system. OOI ET AL. demonstrate this coupling principle in their multimedia DBMS where they have made use of a magnetic disk cache (for a database that is mostly on WORM drives) to provide faster average access time and higher data transfer rates. Their implementation is transparent to users, and also helps with version management and reduction of scattering and wasted copies of files that are updated. SATYANARAYANAN, in his dissertation, explores the use of object-oriented programming methods to model complex storage systems; those methods are clearly relevant to the design and simulation of CD-ROM and other systems so that optical and hard disk, primary memory, and network configurations can be balanced and tuned. VITTER, considering write-once optical disks, in which a mirror in the access mechanism is added to provide very fast access to nearby sectors, discusses methods to adapt B-tree and other file organizations for allowing updates by linking to previously unused areas of the disk. His careful analytical investigation and discussion of algorithms set a high standard for future studies of this type. Applying similar ideas to a WORM drive with this type of mirror, SHANI ET AL. describe a file management system to handle very large collections of records accessed through keys. They place related data nearby to minimize access time, and use packing to reduce the time needed for reading. Investigating keyed access to CD-ROM, COOPER & THARP compare the use of signature files, inverted signature files, and B+ trees. They find that the latter two have similar performance, which is much better than the first scheme when reasonable size encyclopedias are considered. Though their analysis could clearly be refined to be more precise and have real examples and data, it does illustrate that estimating the per-

*CD-ROM database.

formance for CD-ROM is useful when deciding whether or how to develop better access methods.

The work of Christodoulakis and his colleagues is the most relevant research regarding WORM and CD-ROM storage systems that has been reported in the computer science literature. The background for this effort is the construction of a multimedia document system, MINOS, which is a model for future development as well as a prototype system (CHRISTODOULAKIS ET AL., 1986). The focus is on: multimedia document structure; formatters for text, images (graphics and bit maps), voice, and annotation; and integrated facilities for searching, extracting, transforming, merging, and creating new information. Further discussion (CHRISTODOULAKIS & FALOUTSOS) deals with the use of object-oriented methods to design such a system and on performance issues relating to searching the various types of data, especially text. CHRISTODOULAKIS considers the problem of object and record retrieval from optical disks, presents an abstract model, gives exact and approximate analytical results for evaluating retrieval performance for various-sized objects, and illustrates the expected results through simulation studies. While many of the results are obvious, some novel insights are provided, and both researchers and developers would do well to study, apply, and extend results like these that might be more closely tailored to particular retrieval approaches. CHRISTODOULAKIS ET AL. (1988) provide a short overview of the current research activities of their group. Additional performance results are given in a later study (CHRISTODOULAKIS & FORD) where constant linear velocity optical disks (e.g., CD-ROM) are characterized and earlier models are applied to object access for this media. An interesting claim is that for faster random access, searchable collections should be placed on the outer edge of a CD-ROM rather than close to the center as is now commonly done.

Multimedia

There has been a rapid growth in interest in multimedia that has paralleled the development of CD-ROM. SCHWARTZ presents his vision regarding future capacities of optical disks and how learning could be dramatically improved through multimedia computerized systems. While his scenarios encourage efforts toward converting those dreams into reality, BRAND describes demonstrable results of ongoing research at the Media Lab. This fascinating glimpse of people, visions, projects, accomplishments, and inventions is well worth reading by anyone interested in multimedia. Providing a more detailed and focused account, MENASCE & IERUSALIMSKY describe the architecture of a multimedia database on CD-ROM which applies the concepts of object-oriented databases to the Portinari Database Project. They hope to capture paintings, papers, and letters of that famous Brazilian painter, and then to integrate them along with interviews of important personalities who interacted with him. While the project is like MINOS in using a multimedia object management system, other efforts aim to exemplify concepts of hypertext or hypermedia.

Hypertext. Hypertext has come into vogue, as evidenced by the tremendous interest in the first conference in the field, Hypertext '87. A collection of papers from that conference appears in the July 1988 issue of *Communications of the ACM* (SMITH & WEISS). Incidentally, an earlier theoretical study aims at formalizing a model of text with nonlinearity and suggests a measure of how appropriate a given text is for hypertext (SHASHA).

Hypermedia. The broader field involving links between multimedia materials is also the focus of numerous research efforts. Two of the most interesting efforts are under way at Brown University and the University of Maryland. In the latter location, Shneiderman and his colleagues apply concepts of human-computer interaction and carry out empirical tests of various innovative approaches. Thus, MARCHIONINI & SHNEIDERMAN compare fact-finding and browsing capabilities in one commercial and one experimental hypermedia system. YANKELOVICH ET AL. (1988b) provide a detailed overview of the IRIS (Institute for Research in Information and Scholarship) project at Brown, and the Intermedia system in particular, including sample sessions. They successively explain the problems and issues in ever more complex environments—i.e., with read-only documents, read-write documents, or with multiple users. In a shorter overview (YANKELOVICH ET AL., 1988a), they review the basic concepts (considering applications and functionality) and explain the construction approach which involves object-oriented programming and a Macintosh-oriented framework with building blocks for methods that can be shared to build applications. They suggest that this methodology is viable for supporting the most complex types of environment for hypermedia.

Retrieval Models and Methods

Since BELKIN & CROFT provide an excellent overview of retrieval techniques in the 1987 *ARIST* volume, there is little need to consider the general area, so attention is paid here to other more applied or recent articles. While access to optical disk contents is clearly crucial, there has been surprisingly little research into tailoring or developing new retrieval models and methods for optical devices. FOX (1986) explains some of the unrealized potentials of retrieval approaches. Nevertheless only a few companies (e.g., Personal Library Software and Verity, Inc.) have brought fully functional, innovative products to the marketplace. In the long run, state-of-the-art intelligent retrieval systems should be integrated with optical disk-based information stores. Work is beginning to take systems like CODER (COMposite Document Expert/extended/effective Retrieval) (FOX, 1987) and connect them to generally available (e.g., the ERIC database disk provided by OCLC, Inc.) and specially produced CD-ROMs (e.g., one of the Virginia Discs (FOX, 1988a)).

Several retrieval research efforts, though not related to optical disks or CD-ROM, may ultimately prove beneficial. One line of work has been to provide access to text and other records through signature methods, such as superimposed coding. The dissertation work of FRENCH provides a unifying framework for this approach to multi-attribute retrieval, through an

indexed-descriptor access method. French evaluates the benefits of several techniques, considers the impact of sorting, clustering, and top-down creation, and encourages future research to extend this model. FALOUTSOS & CHRISTODOULAKIS describe and give analytical and simulation results on performance expected from several different signature schemes. It would be worthwhile for implementors of CD-ROM systems to supplement the ubiquitous inverted files with a tuned version of signature files to optimize system performance for long multi-attribute queries.

CHEN & HARRISON provide a theoretical framework for comparing different document-representation schemes. Their results may lead to interesting new insights for retrieval systems aimed at supporting context-oriented retrieval requests. Finally, the graphic icons suggested by ELMORE may provide a key to integrate feedback approaches to improving interactive retrieval with graphic interfaces so that complex search methods can be applied in a way that end users can readily conceptualize.

FUTURE PROSPECTS

While there are various discussions of the future of this field, the subsections below concentrate on specific lines of promising investigation.

Media, Standards, and Hardware

Clearly the development of new media and the establishment of standards will progress. There is need for agreement and conformance to standards on CD-ROM cartridges for half-height drives, formats for 5.25-inch write-once disks, and formats for both 5.25- and 3.5-inch erasable disks.

CAMPBELL suggests that the design of drives should now concentrate on performance. His hope is that magneto-optical erasable drives will perform about as well as high-performance magnetic Winchester disks. He analyzes media with lower power requirements and higher optical quality, read/write systems with higher signal-to-noise ratios, better modulation codes, and more suitable disk formats; he suggests work on disk geometries, servo error detection, and seek control.

TOWNER discusses the use of a small mirror to scan a focused beam across the entire radius of a disk at very high speeds. This revolutionary change in drive operation would lead to a dramatic improvement in performance and may indeed be possible if different designs are considered and if R&D efforts can surmount the difficult problems involved. Other developments such as the use of holographic-laser optical head technology may lead to almost as significant improvement by reducing weight, simplifying design, and increasing the yields for head production (HELGERSON, 1988, pp. 3-4).

Applications and Software

The COINT REPORTS STAFF (1986a) considers whether books will be replaced by CD-ROM. Their comments on the functions and culture of books

are enlightening, and while they conclude that books are here to stay, one can expect that CD-ROM will certainly supplement and in many cases replace certain types of book products. From a very different perspective, OFIESH (1986) suggests that given the existence of CD-ROM and optical disks, we must develop a completely different view of education, training, and the nature of knowledge. He elaborates on the earlier vision of BUSH, provides a series of scenarios, and calls on us to develop tools that become as "transparent" as books, newspapers, and TV. With content material development (such as the work by Palmer to transform the Domesday Book into a CD-ROM repository of records on English history), high-fidelity interactivity, appropriate feedback, and a reorientation of pedagogy to a scientific base, we may indeed be able to develop means for optical disks to support "expert"-aided access to knowledge (OFIESH, 1987).

Market

SCHWERIN reviews the market segments for first-generation CD-ROM products—libraries, business and finance, medicine and science, law, music, and commerce. She suggests that there are opportunities for those who learn from the early experiences and build a new generation of products that stand on their own merits, not just on those of the technology.

GALE (1988), after introducing the technology and discussing alternatives for information delivery systems, gives a technology forecast, relates that to supporting industries, explains market implications, and considers the various possible markets. He concludes with forecasts depending on optimistic, probable, and pessimistic scenarios. According to his probable scenario, roughly one million CD-ROM drives will ship in 1991, each selling for perhaps as low as \$250. Furthermore, multimedia information products will be a necessity for companies to remain competitive, as the mix of applications shifts from the current one with a predominance of bibliographic and full-text databases to one in 1998 where multimedia accounts for perhaps two-thirds of the applications.

CONCLUSIONS

Optical disk technology is rapidly evolving on all fronts, and the promise of low-cost mass storage, whether read-only, write-once, or erasable, is being fulfilled with a wide range of media. While erasable disks are beginning to appear and will compete in the late 1980s with magnetic media as computer-storage peripherals, write-once disks are already becoming established. Write-once disks will not only compete with magnetic tapes as archival devices but will also support development of large electronic libraries and document stores.

CD-ROM, along with related products such as CD-I and DVI, will have a very different effect on the development of the information age. As publishing products rather than computer products they will be designed to carry information of all types and in all forms to both broad (e.g., consumer) and

narrow (e.g., special clients or classes of professionals) communities of end users. As retrieval and hypermedia methods become more tuned to the media and more oriented toward users, truly interactive products will emerge that may, with the aid of ongoing improvements in computing and communications, lower barriers to information access and allow motivated individuals to turn their desk tops into active portals to man's accumulated knowledge.

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