A Review of Publishing and Access Issues for Optical Discs and CD-ROMs

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ABSTRACT

Optical discs in general and CD-ROM in particular are helping fuel a revolution in information access that media, hardware, and information providers and producers hope will not only reach a variety of targetted groups, but will also lead to interactive involvement of the general public. This chapter reviews the events of recent years in this dynamic area; discusses the variety of read-only, write once, and erasable media that have been developed; considers standards that provide consumers with confidence to acquire new systems and products; describes approaches and activities to publishing and accessing CD-ROM and related materials; surveys the broad application areas; considers the research underway and required; anticipates future trends; and draws conclusions regarding the importance of this exciting technology. While videodiscs are frequently referred to, the focus is on CD-ROM, along with related products like CD-I. The importance of having second generation products that are highly interactive and which draw on the best work on hypertext, hypermedia, and retrieval methods is emphasized.

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1 INTRODUCTION

Laser disc 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, in a variety of forms and areas, become directly usable by the masses. As will be shown below, optical disc technology is rapidly maturing, and the burden of properly utilizing it falls on those with 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 disc read only memory), the 12 centimeter virtually indestructible plastic discs that have become popular in recent years for distribution of high quality audio recordings.

1.1 Scope of this Report

Though MISCHO & LEE briefly discuss optical disc technology in the previous ARIST volume, the most recent detailed ARIST coverage was in 1984, when GOLDSTEIN reviewed storage technologies in general, especially those involving magnetic media, but also including optical approaches. That same year, FUJITANI spoke of the coming revolution in storage with laser optical discs. 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 to not only explore the basic technology (see the next section), but to also deal with publishing and access issues (see following two sections) that are crucial for making information available to those willing to apply new methods in a variety of application areas (see the fifth section). Current research efforts (described in the sixth section) suggest the future prospects (discussed in the seventh section) we may hope for. Finally, some conclusions (in the last section) should help put the entire discussion into perspective.

While there will be some coverage of most of the types of optical discs that have been or are being used, the bulk of the discussion will be on CD-ROM and related compact disc products. Here the role of standards has been particularly important. Scant attention will be given to magnetic media, since people are generally more familiar with them, but discussions of access approaches frequently carry over. Similarly, other forms of storage, involving cards or tapes for example, will be ignored. The emphasis is on approaches involving interactive rather than sequential 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, 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 bearing the same title as this chapter, it became clear that understanding the literature in this field requires familiarity with the relevant jargon. While many articles define important terms as needed, the most accurate, complete, and clearest glossary on the subject appears in the first book in this field by the company that has played a lead role in the development and propagation of optical disc and CD-ROM technology (see Appendix B in [PHILIPS INTERNATIONAL]).

1.2 Related Publications

There have been hundreds of relevant publications of all types appearing in recent years that fall within the scope of this report. Yet many of those are articles in the popular press which are quickly superceded as new products and approaches gain acceptance. Thus, while reference has been made to product descriptions, press announcements, and trade publications, the vast majority of the entries in the bibliography below have been taken from books, journals, conference papers, and some related periodicals. Though there is some repetitive coverage (e.g., of basics or historical background), the articles selected are generally free of technical inaccuracies. Following subsections deal with some of the key publications in the field; later sections refer to these or articles contained in them, as well as to some other sources.

Books and booklets. Perhaps we can tell that this area is indeed having a revolutionary impact; one of the COINT reports focuses on that theme [43]. LAMPTON also must believe CD-ROM will have long lasting effect since he has written an excellent book for young children. On the other hand Saffady has prepared two annual issues in the Optical Storage Technology series which cover the history, technology, products, and providers of media and equipment, geared toward knowledgeable information professionals. The first is also in book form, and covers turnkey systems for entering, storing, and retrieving very large stores of documents [131]. The second has less emphasis on turnkey systems but provides an update on the technology and is filled with useful facts and comments on current offerings and trends [132]. Another pair of early works, giving a British persective on the subject from one involved in many CD-ROM developments, has been prepared by Hendley. The first covers the early developments quite well, including videodiscs [HENDLEY 1985]. The latter, somewhat more professionally published, provides a moderate length survey of many of the areas covered by this chapter [HENDLEY 1987]. While the longest section is on applications, there are discussions on media, standards, production, workstations, and comparisons between CD-ROM and other optical and conventional publishing systems. Another early guide to CD-ROM [128] has been prepared by Roth and includes excellent diagrams, though the product and supplier information is rather dated. Longer and much more up-to-date is the guide by BUDDINE & YOUNG. Building upon an excellent practical introduction in the first three chapters, and good discussions of multimedia and disc production, the last third of the book covers technology and standards, making the key points of CD-ROM and newer technologies easily comprehensible.

Classics in the field are the three volumes prepared by Microsoft, to coincide with their first three international CD-ROM conferences. The New Papyrus includes insightful perspectives pieces; discussion of CD-ROM systems, retrieval, and production; and covers the earliest applications [LAMBERT & ROPIEQUET]. The second volume continues the same themes but avoids some of the redundancy and lower quality articles, and provides focused practical advice for publishing [ROPIEQUET ET AL.]. Volume three [AMBRON & HOOPER] on the surface only indirectly deals with optical discs and CD-ROM, since the theme is interactivity, but indeed that is the key concept that most CD-ROM producers must comprehend if their products are to reach wider markets. Also on this theme, but giving how-to-do-it guidance and more details on lessons learned from working with videodiscs, 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 is edited by FREESE ET AL. Of historic interest especially is the report on the first CD-ROM conference sponsored in early 1986 by Microsoft [105]. Though many of the now frequently occurring conferences on CD-ROM and

optical discs lack published proceedings, there are at least a good number of focused (really, too short) papers in the recent book edited by Roth [128] from "Optical Information Systems '87."

Newsletters and periodicals. The OPTICAL INFORMATION SYSTEMS publication has provided fairly good short articles about media, systems, and applications in the field for a number of years. THE LASERDISK PROFESSIONAL, a new publication targetted 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 one is of particular interest to readers involved in government activities; CD-ROM APPLICATIONS FORUM has grown out of the SIGCAT group of U.S. government employees interested in CD-ROM publishing and access.

2 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 this text, readers will be aware of the early research and developments, especially the emergence of videodisc systems which are today still in use in much the way they were first shown a decade ago. 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 suited to investigate the development of both recording and playback equipment and access software.

2.1 Magnetic

As GOLDSTEIN discussed in the most recent related ARIST chapter, the vast majority of information used by computers is stored in digital form on magnetic media. Magnetic fields are used to store that data, so these media are erasable (which reflects on the reliability and longevity of their use 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.

As WAID discusses, magnetic discs are high performance devices, and the trend of rapid improvement of that technology is expected to continue for some time. To provide some perspective, modern winchester drives might be considered. A common personal computer drive in 1988 might store 80 megabytes (million characters), while one for a large computer might store 300 or 600 megabytes. On average, data can be accessed in 15 to 150 milliseconds (i.e., access time) and can then be transferred to a computer at the rate of 2 to 30 megabits per second (i.e., transfer rate). These discs are not removable, and cost at least $10 to $40 per megabyte. They are mechanical devices and the magnetic discs can be damaged if dust enters the drive since the "read head" is within a few microns (millionths of an inch) from the disc 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.

2.2 Optical Storage Approaches

Optical storage units generally use lasers to access data, so durable removable media is common and can be accessed by heads that are on the order of a millimeter away from the surface. Drives for CD-ROM cost $500 to $1500 and allow access to roughly 600 megabytes of data; the plastic costs around $2 to produce and is prepared by pressing from a master--publication is the paradigm. Transfer rates and access speeds are about an order of magnitude worse than for quality winchesters. Other optical discs allow user recording, may hold more data, are more expensive but may have faster drives, and in some cases closely parallel magnetic systems except that the data is much more secure, even for archives that must last 10 years or more.

Analog. As ISAILOVIC discusses, laser discs can store data in either analog or digital form. Videodiscs (sometimes called laserdiscs) commonly hold roughly 50,000 image frames recorded in analog form. While digital data and sound can be stored, the key strength of videodiscs is the capability for handling large slide collections or video sequences. This is especially appropriate for delivery of motion or still video in similar vein to VCR players, though videodiscs also allow random access to any point on the disc in about a second. Players typically cost at least $1000, and when used for interactive information programs may be part of a computerized system costing $5000 to $10,000. Thus, their appeal has been strongest for training and other shared use situations.

Digital. Many other optical discs have been developed to store data in digital as opposed to analog form. This relates to storing of computer data, or to recording digital audio. Images take up a great deal of space when put in digital form --perhaps a megabyte each for a TV color image. Digital data has the advantage that it can be easily manipulated by computer, and can be copied indefinitely without any loss in quality. Building upon the established base of expertise in videodisc production, efforts to store digital data on optical discs proceeded, with the aim of allowing users to record on their own drives, thereby obtaining high capacity removable archives (containing around a billion characters per disc), with performance almost comparable to magnetic discs [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, that is not acceptable; indeed error rates must be on the order of one in a million million, or even one to five orders of magnitude better. SHIFMAN discusses the use of various Reed Solomon code schemes, and provides evidence regarding which methods might be best for allowing the computer to detect and correct errors. By devoting roughly one third of the storage capacity on optical discs to error detection and correction (EDAC) data, desired levels of reliability can be achieved and have been specified by standards groups [NUGENT]. The approaches used for CD-ROMs are clearly and carefully discussed by HARDWICK.

2.3 Write Once

Since the early 1980's, optical discs have been available where users could store roughly a billion characters (a gigabyte). A blank disc was provided, initially for hundreds of dollars in a twelve inch size, and users could create an archive by using a laser that would burn pits in the surface to store digital information. These units thus provided the ability to write once and

supported later reading many times with a lower powered laser (i.e., write once read many or WORM). HERTHER provides a clear and concise overview of the methodology and utility. ROSCH also discusses WORM drives, concentrating on capabilities and products at 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 $2000 and will store 200 megabytes on a single side of a 5.25 inch $60 cartridge, other vendors market more advanced drives storing 400 megabytes on each of two sides [ROSCH].

2.4 Erasable

While read-only devices are suitable for publishing, and write once devices are valuable for archiving data, for certain computer applications it is nearly essential to be erase information. Certain media with special magnetic and optical properties have been developed and studied for use in erasable optical discs [GARDENER ET AL. 1986, 1987]; a magnetic field is applied to the entire surface but only causes changes in a micron sized spot where a fairly high powered laser causes the temperature to raise beyond the Curie point. Application of a different magnetic field allows read out of the data with a lower powered laser. While other erasable optical disc systems have been developed (e.g., involving lasers applying heat to force melting and subsequent phase shifts in spots on the media), the magneto-optical (M/O) scheme was sufficiently well perfected in 1987 for several vendors to begin announcing commercially available products [SIMPSON]. The recent article by FREESE summarizes the methods and current status, suggesting that erasable disc drives will be commercially available in the 5.25 and 3.4 inch sizes during 1988, albeit for prices comparable to winchester drives.

2.5 Compact Discs

Compact discs are 12 centimeters (4.72 inches) in diameter, made of durable plastic. While computer systems most commonly accomodate 13 centimeter (5.25 inch) or 89 millimeter (3.5 inch) diskettes and discs, compact discs have become quite popular for a variety of optical disc products.

Compact disc digital audio (CD-DA). In the early 1980's, Philips and Sony collaborated to develop a methodology for recording over an hour of very high quality audio data in digital form on a compact disc. 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 discs were recorded in the "Red Book" made available to licensees. An international standard formalizes this for digital audio discs [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 disc 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 CHEN [33] and by DAVIES. In general the discs are the same as for CD-DA. However, discs recorded with a flag indicating Mode 2 contain digital audio, while those with a flag for Mode 1 are required to have extra

EDAC, bringing down the amount of usable data in a disc sector to 2048 bytes but increasing the reliability to beyond that of most magnetic discs. Since CD-ROM drives are generally improved versions of CD-DA players, prices are expected to significantly drop below the early 1988 lows of around $500. The drives run at the same speeds as CD-DA players, so an entire disc with roughly 600 megabytes can be read (sequentially) in an hour, reflecting the transfer rate of 1.2 megabits per second.

CD-ROMs can be viewed simply as discs containing 300,000 or more consecutively numbered sectors of data. Since such a large amount of space is very difficult to directly use, widespread application of CD-ROM was not expected unless most computers could access data on CD-ROM through some uninversally accepted 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-ROM have been prepared following those specifications. The 1986 draft is the basis for a national [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 will be followed in almost all future CD-ROM productions. Ultimately, then, the directory and 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" standard in a concise but relatively complete form; those 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 digital data, that data can represent anything that can be interpreted by computer hardware or software. Clearly, having the capability to record graphics, images, or motion video is desirable, but using straightforward approaches only 30 seconds of full motion video could be stored in digital form on a CD-ROM, and it would require one hour to play that back! At the David Sarnoff Research Center, a special set of VLSI chips were developed to support "digital video interactive" (DVI), where 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 [47]. 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 utilization [REGIS MCKENNA INCORPORATED].

Compact disc interactive (CD-I). Philips and Sony announced in March 1986 their plans for CD-I development. Progress has been detailed in a newsletter [CD-I NEWS]. This effort involves development of a standard for storing interactive programs on a compact disc (specified in the "Green Book"), specification and construction of a packaged computer system capable of running those programs, and production of programs following the standard that can run on conforming computer systems [ISBOUTS]. 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 sale of Motorola 68000 family based systems (possibly available for roughly $1500 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 disc products. As discussed in the book by PHILIPS INTERNATIONAL, a number of other CD products have or are being developed. CD-V (compact disc video) stores video in analog form (according to a scheme similar to LaserVision developed by Philips; at least one other competing scheme has been proposed) and digital audio. Later, CD-IV (compact disc interactive video) will evolve from CD-V and CD-I.

2.6 Other Size Discs

As mentioned earlier, other size discs have been used for a variety of optical disc products. The original laserdiscs had 12 inch diameters and are still in widespread use. For applications where portability or economy of production was desired, 8 inch discs were utilized. Both sizes are suited for analog or digital storage. But with today's computer systems, economies dictate use of much smaller discs.

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 with 5.25 form factor. 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 coding schemes have been considered. There are active efforts by various committees to establish a suite of standards for 5.25 inch products. It is likely that faster, higher capacity digital disc drives will be available for read-only, write once, and erasable media. Emphasis, however, will be on optical digital data discs (OD^3).

3.5 inch products. Even smaller discs are being developed, and parallel those for the 5.25 inch form factor. Active work is underway on M/O erasable drives for 3.5 inch media [SANDER & SLOVENKAI]. It is expected that erasable discs with 50 to 100 megabytes capacity will be available in 1988.

3 PUBLISHING

Publishing with optical discs such as CD-ROM can be viewed from various perspectives. First, there is the cost perspective involving the media, equipment, and time to produce a disc with data. Here we can distinguish between the most expensive option, erasable, the next most expensive, WORM, and the inexpensive read-only (especially CD-ROM). Second, one can focus on 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 discs it is usually publishers.

Throughout the discussion below, the context will be that of videodisc or CD-ROM publishing, though 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 [123]. Data of all types, when made available electronically, can be copied or replicated on optical discs. 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.

3.1 Data Protection

One of the areas where considerable attention must be given in future years is in the area of understanding data protection issues, and in the formulation and passage of appropriate legislation at all levels, especially since CD-ROM production requires collecting large amounts of data. The current situation and concerns in this regard are thoroughly described in BREMNER, with 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 p23].

3.2 Authoring

Authoring involves collecting materials, reshaping/converting/reorganizing them, and creating an integrated whole. As in other electronic publishing ventures, authoring of optical disc products involves 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 parameters involved in interactive design, including those relating to the user, the equipment, and the system operation. In cases like videodisc or CD-I design, there are many pre-determined decisions, while for CD-ROM there are a larger number of options of all types. For any media, however, there is flexibility regarding how and when the user is involved. HOLDER & DAYNES provide 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 that audio can be applied to promote interaction, and provides an outline for design and development, in addition to explaining 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 one type of authoring system for CD-ROM. Workstations may be needed for text entry, graphics, music or sound effects, and animation. "Scores" must be developed, and all actions properly coded. General blocking of program components followed by specification of detailed timing, testing, and debugging is required.

Videodisc. Videodiscs generally are prepared to support one or more levels of interactivity. Level I allows control with hand-held or remote controls. Level II involves programming of the videodisc player's built-in computer [KENT] which rarely has more than 7 kilobytes space for

instructions, and is thus far too limited for complex interactive operation. Level III uses a separate computer to control the videodisc 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 upon experience with level III videodisc 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 upon still frame handling, and concludes by discussing of authoring tools and production facilities. MILLER [108] focuses on what was known about CD-I in early 1987, and provides general suggestions that are useful, but has 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.

3.3 Data Preparation

Various forms of information must each 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. With regard to conventional databases (e.g., in columnar form), COLVIN describes the organizational and indexing aspects involved. HAMILTON provides abbreviated guidelines regarding text handling, including aspects relating to fields and search capabilities, viewing them in contrast with those for online search systems.

Regarding text collections, BRIDGE & MORIN consider problems of obtaining data, whether by scanning and use of OCR, 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 Standard for document markup. The AAP Standard is based on ISO 8879, Standard Generalized Markup Language [INTERNATIONAL ORGANIZATION FOR STANDARDIZATION 1986] (SGML) , which the U.S. Department of Defense and other organizations will require for many documents submitted in future years. The AAP Standard is working toward international approval as a standard for markup of books, journal articles, and journals, and includes conventions for tables and equations as well as special characters and document organization. As eloquently argued by COOMBS ET AL., this approach of "descriptive" as opposed to "procedural" 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 precise requests, calling for some keyword appearing in a narrowly defined context (e.g., in the title of a subsection). NELSON [112] makes clear how valuable the application of the AAP standard is 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 versus storage (e.g., sampling, quantization, compression) and explores the distinction between audio prepared for CD-DA or CD-I. He considers choices for audio sources, and explains mastering with audio.

Regarding graphic images, MILLER [106] describes them, explains the various types present, 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, image format conversion; survey key points in the area of 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 the need for change. ROUX considers the amount of information that can be handled through various distribution methods to supplement an initial collection of CD-ROM. He summarizes the relevant issues and practices, and suggests update models for partial or full replacement of raw and index information. Incidentally, ISO/DIS 9660 provides for logical deletion and updating of old discs in multi-volume set, but that requires users to switch between several discs using a single drive, or to go to the extra expense of buying several drives.

3.4 Production

A number of plants can press compact discs (see, for example, [STRUCKHOFF 1987]), and the worldwide capacity 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 involves both premastering and mastering [ARMSTRONG].

The first step involves simulation and premastering, using a system with adequate storage to load in and organize data into the proper directories [MERIDIAN DATA, INCORPORATED]. ISO/DIS 9660 requires that special files be created to handle volume and directory descriptions. The layout of all data on the disc must be specified, and EDAC codes computed. Eventually, data bits are encoded and 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.

4 ACCESS

While considerable attention has been given to the problems relating to 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 discs. Better, smaller hardware is becoming available, and operating system interfaces following established standards have been developed, but in spite of pleas encouraging use of more advanced retrieval models [54], most retrieval software shows little improvement beyond that common with 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 developing software architectures that will on the one hand promote interchangeability (as encouraged by ZOELLICK) and on the other hand encourage experimentation and innovation.

4.1 Drives and Interfaces

To access data stored on optical discs, 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. 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 in spite of the incredibly high density of information (e.g., 20,000 separate tracks of data per inch), and the 3-dimensional motion of the disc platter, the laser beam can be kept in focus during sequential reads and re-focused after "seeking" to a new location. While price competition puts pressure on cutting drive costs, performance competition keep 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, where access time of several seconds is common (as opposed half-second average access 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. Unfortunately, in spite of standards in many other areas, the cartridges required for loading CD-ROM into these drives are not standardized, creating further confusion and burden for users. In any case, CD-ROM drives sales have been and should continue to rise, with encouragement by vendors offering discounts and making retail purchase possible from a wide variety of outlets (e.g, see [STRUCKHOFF 1988]).

To connect optical drives to computers, some type of disc controller or interface is required. A strong case has been made by WARREN [153] for drives with a SCSI interface, so that by only changing a software driver the disc 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 to take, even though there are special interface cards available for IBM and related personal computers. More complex, however, is the problem of connecting and using large numbers of disc drives on a single computer for network access or of effectively using jukebox devices that store scores or hundreds of optical discs. 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, Incorporated hold promise of allowing hardware support for accessing multiple CD-ROM drives attached to a server through local networks, a specially important development for libraries and offices, but related software support is needed for this to be truly effective.

4.2 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 discs as just another hard disc drive [ZEICHICK]. WARREN [154] 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.

4.3 Methods and Implementations

For a CD-ROM product to achieve extensive market penetration, it is essential that the human

computer interface be tailored for direct use by end users interested in the information content provided. This involves helping people familiar with paper-based information systems make the transition to use video screens [KERR]. The surface design, the interface design, and tools provided for "wayfinding" are crucial aspects to consider. While CD-ROM can contain data 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. While product descriptions are frequent, there is little fundamental variation between systems available, and comparisons like that of HELGERSON, while saving time in accumulating reliable data, lack criteria that would distinguish a conventional from a more innovative system. Many important distinctions relate to quality of the user interface, as has been carefully explained by KAHN [1988]. He assesses the interfaces in six popular systems along functional lines: browsing, using menus, refining a search, accessing a related online version, or printed and saving results. Unfortunately, he is forced to conclude that little real change has been made from 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 is also possible if application software is tuned to media like CD-ROM. OREN & KILDALL propose pre-storing 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 as well as copies of the CD-ROM itself, and outline approaches to accomodate multimedia and new hardware capabilities. CICHOCKI & ZIEMER likewise make recommendations regarding 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, for multiple key searches using hashing on each of the keys (and storing data redundantly) to locate single records or index buckets, for inverted files having B-tree dictionaries (with large buckets, good cache management, shallow flattened trees), for long searches providing status reports to impatient users, and for very large files using compression.

Hypertext and hypermedia. In a seminal 1945 paper, BUSH elaborated on his vision of a desktop portal into the world's store of recorded knowledge that would build upon and give expression to the manifold associations between information items. Engelbart demonstrated in 1968 a first implementation of some of these capabilities, and has since extended those results to the realm of cooperative systems for augmenting human reasoning and information processing [ENGELBART & HOOPER]. In the early 1970's NELSON [115] coined the term "hypertext" to describe systems where associations (links) between parts of text files are easily built and followed; at the same time he predicted computers would become near 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, where text, audio, video, animation, etc. may all be interlinked for true multimedia information access. YANKELOVICH ET AL. [160] provide a vision of the "electronic book" where computers become our primary information access method, and where authoring and reading are much more closely connected than at present. They consider tools required, efforts undertaken at Brown University and elsewhere, and research problems yet to be solved.

BROWN describes the first CD-ROM implementation of hypertext, CD GUIDE, and demonstrates how easily access to text and graphics can be accomplished with a CD-ROM and Macintosh. Recently, with rapid growth in 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.

5 APPLICATIONS

By the end of 1987 there were roughly 200 different CD-ROM products, providing evidence of an emerging market, but also providing challenges to users interested in deciding whether and what to buy [104]. While those products can be evaluated comparatively, and ultimately instead should be evaluated as they relate to user needs, they are most often evaluated descriptively (by determining content, price, support and documentation, search software, user interface, hardware, operating system, and standards followed) [104].

While several CD-ROM products include demonstrations of a range of products, three printed directories are available for a nominal charge. BOWERS covers mostly CD-ROM, but includes a small number of videodisc products as well, devoting a full page to title. NELSON [113] has shorter descriptions of each product, but appears in more conventional book form, with a simple introduction included as well. NELSON [114] includes several pages for each title, focuses on Product Description and Producer's Comments, and provides sample screens to illustrate system functions.

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

5.1 Functions

Optical disc technology can be applied to various functional needs. Most common are to provide archival storage, to distribute information, to support reference, or to encourage human-computer interaction.

Archive. One of the earliest large scale optical information system proposed and later implemented is the Megadoc system; the history and problems faced are summarized in URROWS & URROWS. WALTER discusses current options for optical filing systems, a timely subject since technology appears to be sufficiently mature for focused efforts. LYNCH & BROWNRIGG consider the broad issues of conservation and preservation, arguing that though 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, reviewing the various media, discussing permanence and archival stability, exploring problems with technology change and its management, and relating them to networking and standards. Research and development activities at the National Library of Medicine have included construction and testing of a prototype system for capture of scanned page images with high throughput workstations [THOMA ET AL.] in a distributed network environment [WALKER ET AL.]. While many technical issues remain, they demonstrate that pages can be captured and archived in under a minute, with image transfer over local networks.

Distribution. CD-ROM is a cost effective media for distribution of large quantities of information, even when end users are simply copying or downloading moderate size 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, where the Library of Congress extending its Cataloging Distribution Service to include CD-ROM as yet another medium supported for dissemination of 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 as well. MEYER explores the issues when deciding whether to add CD-ROM as another support tool for reference. He discusses whether CD-ROM should be for end users or intermediaries; faces issues regarding currency, completeness, database size, and pricing; and discusses alternatives for database producers regarding how information can best be moved to CD-ROM. COHEN & YOUNG take a more quantitative approach, considering 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 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 p23]. Thus, another class of applications for optical discs 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, MILLER [108] reviews interactive systems going back to filmstrip and computer based training (CBT) and instruction (CAI) systems, describing the most promising types of applications and elucidating the design considerations for each (generally, videodisc application):

- consumer applications, such as art, education, and financial management
- arcade games
- point-of-purchase and public-access, ranging from the use of videodisc players in General Motors showrooms that began in 1979; to more recent systems at kiosks for explaining kitchen products; to systems describing banking information, jeans, shoes, or hotel checkout
- training, including surrogate travel (as in the 1978 Aspen Movie Map--see also [BRAND p141]) or teaching cardiopulmonary resuscitation, basic skills, or management skills
- military training, from the 1980 Army Track Gunnery Trainer to the current Electronic Information Delivery System (EIDS, involving more than 40,000 units)
- education, where the BioSci disc includes over 5000 images covering aspects of biological science, and a whole series of discs covers NASA space missions
- custom applications, as in Walt Disney World's EPCOT center with over 275 videodisc players

PHILIPS INTERNATIONAL explains how CD-I products can be designed, considers areas of application where 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 videodiscs should be re-targetted for the potentially larger CD-I market.

5.2 Users

While MISCHO & LEE point to the overwhelmingly positive reaction of end users to the

introduction of CD-ROM products, ultimately the success in applying optical disc systems depends on the degree to which those end users are served in dealing with their varied information, education, entertainment, or other needs.

Library. In libraries, there is a tradition of providing patrons with access to materials made available in various media forms. LOWE ET AL. describe one of the earliest prototype applications of optical discs to locally publishing and accessing bibliographic data. The very first commercial CD-ROM publication, the BiblioFile Catalog, is discussed by MARTIN, who explains the rationale, design, develoment, actual project management, and product details. RAITT [124] presents the broad picture of how electronic publishing in all forms can be applied to serve library needs. He considers the potential advantages and disadvantages, what impact this will have on librarians, and advises how to cope with the inevitable changes. VANDERGRIFT EL AL. provide a handy annotated bibliography and 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. NELSON [114] provides a handy reference guide to CD-ROM products that might serve library information needs and can run on machines like 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, describing the crucial need to filter information, calling for reorganizing information from the user's perspective, considering the use of similarity and links, and emphasizing 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 only be truly understood when students are actively involved in the process of theatrical creation, and describes three components of a prototype videodisc-based computer package: a kit for scholars to analyze a play and scene in detail, a kit for directors so students can creatively design a scene, and a version of both for home use. FRISCHER considers, in light of advanced computer technology, how problems in providing proper instruction in the Classics can be addressed. His rather 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 applying this perspective with the aid of a guide, Cicero, to aid navigation through the Roman Civilization, building upon 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 the needs of high school classes and others. GIBBON & HOOPER review the Voyage of the MIMI educational project by Bank Street College, relating their experiences in producing TV programs aimed at teaching science and mathematics, to goals of interactive videodisc based teaching. ANDERSON discusses another effort involving WNET, Channel 13 in New York, to make use of the enormous investments in TV programs like the PBS show Creation of the Universe, with computer graphics simulations conveying quantum mechanics theories, to provide interactive TV instruction. Clearly there is a tremendous potential to use optical disc technology and computer systems to bring together educational materials on all types of media for user-oriented highly interactive learning.

Consumer. The largest potential market for optical disc based systems such as CD-I is that of the general consumer. While many applications discussed 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, building upon their Academic American Encyclopedia , illustrating 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.

5.3 Domain

Applications are perhaps most naturally grouped by content area. The following paragraphs mention only a few areas, ones 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 similar 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 a variety of 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 committment to education. While a variety of geographic CD-ROM products are targetted for professionals, and some like automobile reckoning and navigation systems will serve consumers, interactive programs from the Geographic Society will likely be among the most exciting and enlightening products that will appear.

Other. A wide variety of other applications have been and will be developed. One of the most intriguing videodisc efforts is Project Emperor-I, directed by CHEN [31]. A pair of videodiscs bring archaeologists, art historians, scholors, students, and the public from West to East, to one of the most exciting archaeological finds of the century, the magnificent tomb (with its terra-cotta figures of warriors and horses) of the first Emperor of China (Ch'in Dynasty), and explore his many accomplishments, including completion of the Great Wall.

Shifting from art to computer science, we see in the announcement by WEGNER the movement of a professional society to work towards building an electronic library and to produce not only books but a variety of other materials, including optical discs and CD-ROMs. Interested parties are encouraged to communicate with the editor of Association for Computing Machinery (ACM) Database Products to explore possibilities of products to serve the needs of students, professionals, and other computer users with applications that can be built upon: journals, conference proceedings, curriculum materials, tutorial films, graphics animations, simulations of algorithms and other processes, etc. As professional organizations take similar steps, it is hoped that authors, practicioners, and developers will become involved inproduction of a wide variety of applications.

6 RESEARCH

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

6.1 Optical Information Systems

Optical information systems have been developed for a variety of 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 technology. CLARKE describes their experiment to prepare a CD-ROM from three bibliographic files available through the Library's online service, covering the aims and 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 multiuser and network access, embedded systems, and mixed-mode documents. A related project, to demonstrate the viability of local publishing of a wide variety of types and forms of information, and to allow experimentation in a number of areas, is being managed by this author and will lead to production in 1988 of a series of three CD-ROMs [55]. Contents will include library data, 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, etc. Hypertext and advanced retrieval systems will be compared also.

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 anectodal comments are valuable, substantive and quantitative studies are sorely needed in this field. In the final report on the Isocrates project, KAHN [1987] not only reviews the history and findings of that innovative effort, but at least begins to provide quantitative results, such as on access times for various searches involving hard discs or CD-ROMs. It is hoped that many other research activities will be funded regarding the development and use of optical disc based information systems, and that reporting in the future will focus more on controlled studies that lead to definitive conclusions.

Approaches. Scholarly research contributions are available dealing with approaches to optical disc information systems. BERRA & TROULLINOS discuss applying optical techniques to data and knowledge base machines, introduce work on optical computers, and indicate how optical discs might have higher performance when closely coupled with other components of a totally optical system. 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 disc, primary memory, and network configurations can be balanced and tuned. VITTER, considering write once optical discs where 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 disc. His careful analytical investigation

and discussion of algorithms set a high standard for future studies of this type.

The work of Christodoulakis and his colleagues is the most relevant research that has been reported in the computer science literature. The background for this effort is construction of a multimedia document system; MINOS serves as a model for future development and a prototypical system [38]. The focus is on multimedia document structure; formatters for text, images (graphics and bitmaps), 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 discs, presents an abstract model, gives exact and approximate analytical results for evaluating retrieval performance for varying size objects, and illustrates the expected results through simulation studies. While many of the results are intuitively obvious, some novel insights are provided, and both researchers and developers would do well to study, apply, and extend these results and others that might be more closely tailored to particular retrieval approaches. CHRISTODOULAKIS ET AL. [35] provide a short overview of current research activities of the group. More performance results are given in a later study [CHRISTODOULAKIS & FORD] where constant linear velocity optical discs (e.g., CD-ROM) are characterized and earlier models are applied to object access for this media; an interesting conclusion 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.

6.2 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 discs 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.

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 derived from that conference are in the July 1988 issue of Communications of the ACM. Incidentally, an earlier theoretical study aims at formalizing a model of text with non-linearity, 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 are underway at Brown University and the University of Maryland. In the latter location, Schneiderman 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. [161] provide a detailed overview of the IRIS project at Brown, and the Intermedia system in particular, including sample sessions. They successively explain the problems and issues in ever more complex environments: with read-only documents, read-write documents, or with multiple users. In a shorter overview [159], they explain the basic concepts (considering applications and functionality), the construction approach (involving object oriented

programming, a Macintosh oriented framework with building blocks for methods that can be shared to build applications), and suggest that this methodology is a viable one for supporting the most complete types of environement for hypermedia.

6.3 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 will be paid here to other more applied or recent articles. While access to optical disc contents is clearly crucial (see earlier section), there has been surprisingly little research into tailoring or developing new retrieval models and methods for optical devices. FOX [54] explains some of the potentials, and there has been interest, but 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 disc based information stores; work is beginning to take systems like CODER (COmposite Document Expert / extended/effective Retrieval) [53] and connect them to generally available (e.g., the ERIC database disc provided by OCLC) and specially produced (e.g., one of the Virginia Discs [55]) CD-ROM.

Several retrieval research efforts, though not related to optical discs 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 complex search methods can be applied in a way that end users can readily conceptualize.

7 FUTURE PROSPECTS

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

7.1 Media, Standards, and Hardware

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

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

TOWNER discusses using a small mirror to scan a focused beam across the entire radius of a disc at very high speeds. This revolutionary change in drive operation would lead to dramatic performance improvement, and may indeed be possible if different designs are considered and research and development efforts can surmount the difficult problems involved.

7.2 Applications and Software

The COINT REPORTS STAFF [42] considers whether books will be replaced by CD-ROM. While 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 discs, 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 TVs. With content material development (like 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 become scientifically based, we may indeed be able to develop means for optical discs to support "expert" aided access to knowledge [OFIESH 1987].

7.3 Market

SCHWERIN reviews the market segments for first generation CD-ROM products, for 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.

8 CONCLUSIONS

Optical disc 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 discs are beginning to appear and will compete in the late 1980's with magnetic media as computer storage peripherals, write once discs are already becoming established and will not only compete with magnetic tapes for archives, but will also support development of large electronic libraries and document stores.

CD-ROM, along with related products like CD-I and DVI, will have a very different effect on the development of the Information Age. As publishing rather than computer products they will be produced 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 desktops into active portals into man's accumulated knowledge.

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