STORAGE TECHNOLOGY: A REVIEW OF OPTIONS AND THEIR IMPLICATIONS FOR ELECTRONIC PUBLISHING

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STORAGE AND DATABASE BUILDING

Mass storage is the cabinet in which electronic information is kept. The more generous the storage area, the richer, more detailed, and more comprehensive is the database. Mass storage is usually defined as a means of preserving computer-generated information for subsequent use or retrieval. In practical terms, storage places limits on electronic information products. Database producers shape electronic data to fit the available shelf space. When more storage becomes available, information providers test those limits with new types of machine-readable files, and new databases flow into the market. Although mass storage can seem drab at first glance, it is one of the fundamental building blocks of an electronic information system or product.

For 25 years text timesharing companies have provided access to massive amounts of information in machine-readable form. Until recently, high-capacity, multigigabyte storage was the domain of the mainframe. (Readers interested in refreshing their memory on common units of storage may find the information in Table 1, shown at right, helpful.) Companies like Dialog Information Services and Mead Data Central warehouse data in central, very secure mainframe environments.

Timesharing companies are criticized, somewhat unfairly, for not being more PC-like, for not offering images or combined databases, and for ignoring customer cries for pricing reform, database consistency, and better quality control. But in a mainframe environment built on time-tested architectures, some system and user needs simply cannot be met: for example, adding correction records to online databases and implementing user-friendly, graphical interfaces. More importantly, as the size of databases increases, basic housekeeping becomes a larger and larger task consuming a growing share of available system resources.

PC users have a steadily growing familiarity with electronic information, great adaptability and a healthy dose of impatience. Most make-do; they shoe-horn information into the space available in their personal computers or on their organization's system. When more storage becomes accessible, users find new things to put on their electronic shelves. Mass storage works like a new super-highway: traffic expands to fill the open space, and the new road is choked quickly with cars and trucks. More and larger applications crowd the new storage area as well, creating even greater storage requirements.

What sparks this thirst for mass storage? The need for space for large machine-readable files is coming from virtually every market sector. Researchers and engineers in the storage business are trying to respond to a demand created by surging computerization, powerful new software, and mounting megabytes of data. For instance, the latest version of Aldus' Pagemaker for Windows, a popular desktop publishing program, can easily create files that overwhelm a 40MB hard disk. Just five years ago, a 20MB hard disk seemed a generous

TABLE 1
STORAGE QUANTITIES AND ABBREVIATIONS

Name	Mathematical Representation	Whole Number	Common Abbreviation
Kilobyte	1024	1024	K KB
Megabyte	1024^2 1.045×10^6	1,048,576	MB
Gigabyte	1024^3 1.07×10^9	1,073,741,824	GB
Terabyte	1024^4 1.10×10^{12}	1,099,511,627,776	TB

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TABLE 2
OVERVIEW OF MASS STORAGE OPTIONS

Type	Synonyms	Media	Capacity	Attributes	Applications	Cost/Mb	Manufacturer(s)
CD-ROM	CD	Aluminum substrate with a clear plastic protective shell.	~550-650 MB	Durable Unliimited read-writes Estimated 50-year life	Distribute reference databases or multimedia	~2¢/MB	Reference Technology (Boulder, Colorado) Meridian Data, Inc. (Scotts Valley, California)
Digital Paper™		Sensitive substrate in a plastic film May be prepared as tape or diskettes	Approaches 1 terabyte or 1,000 GB	Extremely high capacity medium Unaffected by magnetic fields Less sensitive to distortion than magnetic tape	Archiving data An alternative to 9-track tape in some situations	~.006¢/MB	Imperial Chemical Industries PLC (England) CREO Products (Vancouver, British Columbia) Laser Tape, Inc. (San Jose, California)
Floppy Disks	Floppies, Flexies, Micro Floppy Disks	Coated plastic in a flexible or hard plastic sleeve Most IBM-compatible computers use the 3½-inch format	Range from 360 Kb to more than 4 MB	Economical Widely accepted	Local storage Distribution of data	~90¢/MB	3-M (Minneapollis, Minnesota) Sony Corporation of American (Park Ridge, New Jersey)
Hard Disk	Fixed Disks	Coated metal or glass platters	Range from 20 MB to 2 GB (capacities are increasing) Transportable (pull-out) versions are available	Capable of high-speed throughput Susceptible to shock and dirt Local online storage	Local online storage for personal computers and LANs	~$4/MB up	Fujitsu America Inc. (San Jose, California) Western Digital (Irvine, California)
Magneto-Optical Drive	Read-Write Optical Drive Erasable Optical Drive MO Drives	Substrate when heated by a laser allows magnetic field to write data; laser can read written data	~400 MB and up	Data can be changed Standardization is coming so MO discs written in one manufacturer's drive can be read in another's Sensitive to environmental factors like ultraviolet light	Archiving large hard disks Jukebox storage devices for online or near-online access Data distribution to a limited number of sites	~$8/MB	Hitachi America Inc. (San Bruno, California) Maxtor Corp. (San Jose, California) Storage Dimensions, Inc. (Los Gatos, California)
Helical Scan Tape	Digital Audio Tape DAT or R-DAT	Coated plastic tape 4mm, 60- or SO-meter lengths 8mm, up to 212-meter lengths	4mm ranges from 1.2 GB to 4 GB 8mm ranges from 2.3 to 5.0 GB	Random read-write Sequential updates Uses helican-scan (rotating head) technology	Archiving high-capacity hard disks Data distribution to multiple sites	~$4/MB	Hewlett-Packard (Bristol, England) Irwin Magnetic Systems (Ann Arbor, Michigan) JVC Corp. (Santa Clara, California) Maynard Electronics (Lake Mary, Florida)
Tape	Magnetic Tape; Quarter-inch cartridge or QIC; Streaming Tape or Streamers; Data Cartridge DCT Drives	Coated plastic tape in varying lengths and data capacities	Ranges from 40 MB per cartridge to 400 MB and up depending upon format	Reliable Sequential read-writes limit throughput	Archiving hard disks in personal to mainframe systems Data transfer from site to site	~13¢/MB but can vary depending upon application and system	Colorado Memory Systems (Loveland, Colorado) Irwin Magnetic Systems (Ann Arbor, Michigan)
WORM	Write-once, read many times	Substrate when heated by a laser allows magnetic field to write data	~500 MB/disk	Captures an unchangeable archival back up	Archival storage where an audit trail is valuable	~50¢/MB	Literal Corp. (Colorado Springs, Colorado) Maxell Corp.of America (Fair Lawn, New Jersey)

amount of storage space; it was a luxury. According to research conducted in 1990 by the Gallup Organization, Inc., 80MB hard drives are now standard [1]. Joseph Sung, president of Everware, says, "Our customers want big, fast hard drives. They need the space for programs, data, graphics, images, and digitized sound. There is no limit to the storage demands customers have" [2].

NEW VISTAS IN MASS STORAGE

In the last five or six years, remarkable storage products have come to market with increasing speed. These storage devices fall into several broad categories:

- **Backup storage.** These are storage devices that are used to archive data. Archived data on floppy disks, for example, are a form of insurance, allowing important files to be restored if critical data are erased or lost.
- **Reference storage.** These devices allow large amounts of data to be placed on media that can replace, complement, or supplement microfilm or paper. InfoTrac CD-ROMs are an example of this storage category.
- **Online storage.** These devices allow a user to read and write data on the storage media. The information is available to users in real-time from a hard disk in a computer or linked to the PC on a network.

More and more storage devices in all three categories share a common attribute: new, high-capacity storage devices are rapidly migrating from the old locked, air-conditioned computer rooms to the users' desks. In the '80s, storage power rested with MIS, not the MLS. New developments in mass storage promise to weaken users' mainframe handcuffs.

Ready access to mass storage allows the decentralization of database use, giving that control to individuals or departments. High-capacity mass storage equips people to shape electronic information to meet their needs. For considerably less than $10,000, one can build a local information "factory" by setting up a network of several PCs and installing a 500MB hard disk. Another consequence of mass storage innovation is the weakened grip of the timesharing companies on access to commercial or governmental databases. A library (public, academic, special, medical, or research) can use PCs, high-capacity hard disks, and a mix of readily-available storage devices to mount databases on CD-ROM or on hard disks. Each library can address such issues as cost, access rights, and fees directly, cutting out the timesharing company or middleperson.

Regrettably, many online database producers and timesharing companies see mass storage as an electronic wall flower at a flashy high-tech dance. Customer focus groups wail, "Give me more full text"; "I want access to all databases on a related subject at one time"; and "I need the pictures, charts, and graphs from the original document." Not surprisingly, some innovative timesharing customers see mass storage as the means to take data matters into their own hands. It is no secret that information consumers are asking for more — more data, sound, graphics, and video along with text and numbers. Customers want local access and control of customized databases. A sharp surge in the availability of different types of mass storage devices and falling prices for storage hardware are rewriting the rules of the electronic information game.

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TABLE 3
STORAGE EQUIVALENTS IN VARIOUS MEDIA TO BACK UP A 500MB HARD DISK

Storage Medium Used for the Back Up	Number of Pieces of Back-Up Media	Time Required
1.2 MB 5¼-inch floppy disks	~420 floppies	~6 hours
120 MB QIC cartridge tapes	~5 QIC cartridges	~3 hours
400 MB MO cartridges	2 MO cartridges	~ 1½ hours
1.2 GB DAT cartridges	1 DAT cartridge	<1 hour

A QUICK ORIENTATION TO MASS STORAGE

To help orient readers who think about mass storage as only a hard disk in a PC, there are different types of storage media:

- **Magnetic media.** This includes the 3 1/2 and 5 1/4 inch floppy disks, hard disks, and tapes in cassette-like cartridges and on open reels.
- **Optical media.** This includes any storage device that encodes data using laser light. Most optical media look similar to the audio CDs found in record stores. (Optical storage devices record data on a thin film by burning microscopic holes in the film's substrate with a laser. Then data are read by a laser device that notes the presence or absence of holes, called "pits" and "lands," in optical jargon.)
- **Hybrid media.** This includes storage devices that use a combination of laser and magnetic technology to store information. The media can be formed into disks or tape. (Several other potentially useful storage technologies are described in the sidebar, "Other Storage Technologies," beginning on page 44.)

Mass storage devices can be fixed or removable. The most common fixed device is the hard disk found in most personal computers. Removable storage media can be taken from a drive's case and put on a shelf or used in another machine. There are

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information "robots" or jukeboxes that store various media and automatically insert them into a drive when information is needed.

Mass storage can be:

- **Online:** ready to use immediately like DIALOG databases
- **Offline:** stored on a shelf like backup tapes
- **Nearline:** media placed in a device that automatically inserts the correct tape or disk in the drive and then removes it when the user no longer needs the data. (FileNet's image disk system for insurance companies and hospitals works in this way.)

It is from the mainframe world of drum storage and open reel tape that today's rich array of storage options has grown. Table 2, "Overview of Mass Storage Options," highlights eight storage technologies that can be used with all sizes of computers. A mainframe today is just as likely to have a digital audio tape device as a PC-based local area network. A power user with a 486 machine or a hopped up Sun workstation will already have a CD-ROM drive, and will probably be shopping for high-capacity magneto-optical or R-DAT devices. The development curve for mass storage is like a Trident missile. Many computerists would prefer that the take-off of innovation in mass-storage be slower, more gradual, like a DC-3's. Mass storage is a hodgepodge of acronyms, new techniques, incompatible media, tremendous competition, and almost no standards.

The technology of mass storage is evolving rapidly. Actually mass storage has been and continues to be cross-pollinated by many technologies, including biotechnology. One engineering litany is that storage devices will become smaller, faster, higher capacity, and cheaper each year. Mass **storage** is one of the crossroads of technology where mechanical engineering, electrical engineering, and organic chemistry meet. A number of advanced storage devices use organic dyes as an essential component of the storage device. Rock-and-roll (or at least the concept of the jukebox) plays a part as well. "Jukebox" devices, including automated tape libraries, move data from nearline to online status as user needs warrant.

One can find suggestions in various popular, trade, and technical articles that a particular mass storage technology has gone as far as it can. This is idle talk because storage technologies have a peculiar characteristic: they undergo constant refinement as innovations are lashed onto an established platform. (See the sidebar, "Other Storage Technologies," for a glimpse of some of the oldest and newest storage techniques.)

MAGNETIC STORAGE MEDIA: NEW TRENDS

The public relations blitz for CD-ROM and other optical technology has overwhelmed information about important developments in magnetic storage. Recognize that capacities of hard disks and tapes have been advancing rapidly. Digital audio tape (DAT) has attracted considerable attention among audiophiles. Breakthroughs in microelectronics, materials engineering, and read-write head manufacturing have contributed significantly to the explosion of high-capacity tapes and hard disks. Because magnetic floppies and cassette tapes are ubiquitous, let's begin our review of new storage technologies with magnetic storage media.

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R-DAT (Magnetic Tape Cartridges)

Digital audio tape (DAT) allows a consumer to make a duplicate of an audio CD-ROM, preserving the fidelity of the original. This media, mass storage experts discovered, has computer applications as well. (R-DAT is the designation used to differentiate the audio DAT from the computer DAT.)

For less than $5,000, one can buy from Irwin Magnetics (Ann Arbor, Michigan) a 9131e R-DAT drive bundle for personal or network use. The Irwin product uses an Archive Corp. drive mechanism (Irwin is a subsidiary of Archive) and an Adaptec SCSI adapter. Irwin includes EzTape backup control software and drives, and all necessary hardware. Irwin offers both an internal and external models in four-millimeter tape with a capacity of 1.3 gigabytes without compression and an eight-millimeter external model that offers 2.3 gigabytes of storage.

Says Irwin's Glen Harmon, "For an old nine-tracker like me this device is a marvel. It's smaller, more reliable, and faster than traditional media. Most important, it can restore faster and with more flexibility than the open reel media" [3]. Irwin's offering joins R-DAT products from Mountain Network Solutions Inc. and Maynard Electronics Inc. [4]. R-DAT is available in four- and eight-millimeter widths. Sony Corp. of America is now providing manufacturers 90-meter lengths of streaming tape that increase storage capacity to more than 2GB for four-millimeter cartridges. Devices are available from Exabyte which use the Sony 8mm media and store 5GB on one cartridge [5]. For comparison, the tape drives now used with most personal and office PCs have capacities in the 40MB to 250MB range. A single four-millimeter DAT holds the same amount of data as twelve 120MB magnetic cartridges.

The key to these mind-boggling densities on "old-fashioned tape" comes from recording head innovations and a different approach to laying down the data. DATs are sometimes called "helical scan tapes" because the recording head lays down data in diagonal stripes. Traditional recording heads lay down data like stripes on the highway. Angling the head at 6 degrees, rotating the recording head itself at 3,600 rpm, and slowing down the transfer speed of the tape itself contribute to the storage capacity of DAT.

High-Capacity Drives

Paralleling the capacity increase of magnetic tape is the sudden proliferation of high-capacity hard disks with a formatted capacity of 250MB or more. Northgate Computer Systems, Inc. (Eden Prairie, Minnesota) markets a line of AT computers to individuals and businesses, and is consistently rated among the top mail-order sources of this type of machine. The basic 80386 25 MHz Northgate Elegance comes with a 100MB hard disk. The 80386 33 MHz has a 200MB drive, and 1.2GB drives are available. Two years ago, a gigabyte drive (storage capacity of 1024) did its work hidden behind a locked door and security alarms, not on a PC user's desk.

Virtually all manufacturers of hard drives offer high-speed (that is, less than 15-millisecond access time) high-capacity drives. More importantly, these drives can be purchased and installed in most personal computers. Significantly, the basic AT-class machine can accommodate two of these drives. That translates to about 2.4GB of online hard disk storage in a desktop machine. Fujitsu America recently announced a 2GB drive that increases the PC's mass storage to almost 4GB. Three years ago, most corporate computer centers did not have that kind of online storage resource.

Massive amounts of hard disk storage translate into two opportunities. The first we have addressed. With that much data online, a new approach to archiving is required. The solution, in part, seems to be the DAT technology. The second we need to investigate further. But before looking at what can be done with high-capacity hard disks, we need to spend a few moments revisiting briefly the commercial timesharing business.

BRINGING COMMERCIAL TIMESHARING IN-HOUSE

Rapid strides made in hard disk and tape capacity has blindsided many publishers and purveyors of optical media, but no one can be more surprised than traditional text timesharing companies. Overnight, it seems, their largest customers want to buy data for one negotiated, annual fixed price. The high-capacity magnetic storage devices make it possible for a network of PCs to do a mainframe's job. If the capacities of hard disk, R-DAT, and other magnetic media continue to increase, optical technologies may face magnetic competitors for years.

It is important to remember that in the world of online textual databases, only a small percentage of 3,000 commercial files yield more than $1 million per year in revenues. Most searching takes place in large, established databases like ERIC, Chemical Abstracts, PsycINFO, MEDLINE, COMPENDEX PLUS, and a few others. If a heavy online user of one of these files brings the database in-house for a flat fee, the databank-middleman-timesharing company stands to lose substantial revenue. If an alternative technology allows such a migration at a competitive cost, the timesharing dinosaurs could face a long, cold winter night of sharply declining profits. Only the most nimble could replace the lost big-users' spending with other revenue sources.

As magnetic media for personal computers have increased in capacity, innovators have rediscovered magnetic media as a way to deliver large databases. This development parallels the surge of interest in loading magnetic tapes on local computers, and allowing users to access data from terminals located in a public library or on a college campus. From North Carolina to California, in Illinois and Florida, and points between, states are exploring state-wide or regional schemes to increase access to certain databases. We have come full circle.

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TAPE LEASING

Tape leasing .was a sideline activity for information providers throughout the 1980s, since timesharing companies offered a less complex alternative. Many leading electronic publishers retained a core of a dozen tape lease clients and provided price quotations for a trickle of inquiries each year. Obtaining a new tape lease client was desirable from the database producer's point of view because it returned control of the customer and pricing to the producer. (Timesharing companies have made it a contractual issue to wrest control of pricing and the customer from the database producer.) Until recently, barriers like the cost of retrieval software and support programming made a tape lease difficult to justify

CD-ROM: A TAPE LEASE SOLUTION?

At first glance, CD-ROMs seem to offer a practical alternative to online. Personal computers have sufficient power to process search requests. Software for retrieval is typically included in the subscription price to the information product. Many organizations had functioning networks that could access the CD-ROM drives like another hard disk. Every few months, the cost of creating a CD-ROM and replicating 650MB of data continue to drop.

CD-ROM has significant market momentum. Several manufacturers, including Sun Moon Star (Korea), offer PCs with a read-only optical drive, U.S. workstation builders Hewlett-Packard and Sun Microsystems bundle optical drives with their newest machines. But CD-ROMs are not ideally suited to applications where fast response and simultaneous access to gigabyte-plus databases are desirable. Libraries, for example, discovered that CD-ROMs erected different barriers to online network access, including:

- Component upgrades, including cache controllers to reduce the amount of time a user must wait for data
- Software incompatibilities among different programs like DRDOS 5.0 and Microsoft CD-ROM extensions, versions 2.0 and 2.1
- Proprietary data formats that require dedicated systems (UMI's image disk product line is an example.)
- User confusion in differentiating among information products
- Wide variety of interfaces
- Network inefficiencies in handling data transfers

The solution to many of these problems is for an organization to acquire a CD-ROM network solution from Online Systems, Inc. (Germantown, MD) CBIS, Inc. (Atlanta, GA), or Meridian Data, Inc. (Scotts Valley, CA). It is possible to link a network of

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CD-ROMs to a Novell network using Artisoft's LANtastic. The procedure is to load Novell's' IPX/SPX software, place NETBIOS on top of that, plug in a card, and *voilá*, a CD-ROM subnetwork linked to the Novell network. Unfortunately, unless the organization can invest heavily in advanced controllers, massive static RAM caches, state-of-the-art servers, and masterful network support staff, CD-ROMs are less responsive than magnetic disks and harder to support.

ONLINE IN-HOUSE: A HIGH-CAPACITY MAGNETIC SOLUTION

Rapid developments in mass storage have made possible a simple, magnetic solution. The idea is to use the low-cost, gigabyte-plus magnetic drives to store an online database. Standalone PCs are linked to the PC with the data using a low-cost network like LANtastic's. Each month an information provider delivers an R-DAT cartridge containing the new information needed to update the database on the server PC. A customer inserts the cartridge, runs a batch file, and returns the next day to find a refreshed online database. This is the '90s approach to tape leasing.

CD Plus (New York, New York) has had in a relatively brief time a significant impact in the medical and health information market. Martin Kahn, President, first challenged SilverPlatter's grip on the MEDLINE CD-ROM marketplace by offering CD-ROM users more data on fewer disks, a feat achieved by engineering know-how and data compression. The first CD Plus product minimized disk swapping, which is a factor in mechanical failures of read-only drives. Like many other CD-ROM producers, Kahn's company offered a network solution using a bank of eight optical drives that supported four simultaneous users. As useful as the multiuser optical network solution proved, CD Plus discovered that some customers wanted to support dozens of online users with no fall-off in response time.

Kahn and his staff modified the traditional tape lease model, an approach that usually flings open a Pandora's box of problems. In the mainframe world, for example, a tape lease customer's computer center would receive updates to the MEDLINE database on magnetic tape. The computer operator would merge the new information with the data already online. In some cases, the operator would delete older data. CD Plus worked around this time-consuming and error-prone process with new mass storage technology: high-density magnetic hard disks and R-DAT. With these two technologies and the CD Plus retrieval software, a library can have a dedicated online network with a database accessible to all terminals.

R-DAT allows 1.2 gigabytes of storage in a cartridge-type case about the size of a standard audio cassette. PlusNet uses several speed-up tactics to allow the PC-based network to operate at speeds comparable to those achieved on commercial online services. For example, the CD Plus software resides on a RAM disk in the server's memory.

The server can be equipped with a

Other Storage Technologies: A Short List

Lest I leave the reader with the impression that R-DAT, high-capacity magnetic drives, WORM, and magneto-optical drives cover the mass storage waterfront, I must address other mass storage possibilities. It is quite probable that to solve a specific mass storage problem in a particular organization, one of these technologies will offer the proper combination of price, speed, and reliability to meet a particular need. If not, here's a short tour of other important options.

DIGITAL PAPER™

Digital Paper is a trademarked name of Imperial Chemical Industries (England). It is a bit like the organic dye read-write optical disk substrates in that the laser changes the substrate. However, Digital Paper "burns" the data into the Melinex polyester substrate. Digital Paper is a WORM technology.

Digital Paper is less input-output bound than helical-scan, R-DAT tapes. The medium has a thickness of 75 microns, compared to 13 microns for ordinary magnetic tape. It supports very high fast-forwarding mechanisms. It has an estimated 15-year life and can be placed in cartridges or open reels It can be formed into disks as well. "A piece of Digital Paper 2,400 feet long and 1/2-inch wide (equal in size to a 10.5-inch magnetic tape reel) would store 600GB of data, the equivalent of 1,000 CD-ROMs."

Sound interesting? LaserTape, Inc. (San Jose, CA) plans to use 25-micron tape in a standard magnetic tape-cartridge. This will yield 20 or more gigabytes of storage, compared with the 200 megabytes of data stored on the same amount of magnetic tape. A tape drive is available from CREO Products (Vancouver, Canada). At this time, the cost of the drive is about $200,000 for the CREO drive. (See John McCormick's book cited in Reference 16 in the main article.)

VIRTUAL DISKS

Virtual disks are sometimes called solid-state disk drives, silicon files, or GIAM (Gigantic Instant Access Memory). If a controller (the device that governs the input-output to a storage device) has 16MB of cache memory on board, it can function as a virtual disk.

These terms refer to the use of a bank of memory chips as a temporary storage device. Like any RAM disk, when power is switched off, the virtual disk or solid-state disk loses its information. The principal advantage the virtual disk offers is speed. It operates at the same velocity as the other RAM in a system. Response is almost

9600-baud modem to allow remote users to access the data. The database is, of course, stored on the high-capacity hard disk or disks in the system. PlusNet software duplicates many features of commercial online systems, including password control, SDIs, and search saves. The basic configuration of the PlusNet product supports about 24 terminals, although other versions of this magnetic network can support up to 250 simultaneous users.

PlusNet2's magnetic network poses an interesting challenge to traditional online services and other network solutions. The use of R-DAT simplifies the database updating process. Although less complex than accessing a database on a mainframe, the CD Plus solution may be too involved for some library and research settings. Nevertheless, high-capacity magnetic storage gives organizations a way to provide real-time online access to selected commercial databases. For timesharing companies, it probably means more big-user migration to magnetic networks.

OPTICAL STORAGE TECHNOLOGIES

The laser has engendered an important group of storage technologies. There are three broad types of optical storage media:

- Prerecorded
- Writeable
- Rewriteable

Each is here to stay. Technical innovations will come in a steady stream over the next decade. Compared with magnetic media, optical or laser mass storage is in its infancy. Most readers have first-hand knowledge of CD-ROM information products. These read-only disks hold about 300,000 pages of text or about 600MB of data. Drives that can write data to a laser-sensitive media can squeeze about 800MB on a 4.72-inch disk. The read-write technologies have a somewhat lesser capacity, typically in the 250-400MB range.

The number of CD-ROM products grows each year. Judy Wanger, vice president of Cuadra Associates, publishers of the Cuadra/Gale (formerly Cuadra/Elsevier) *Directory of Portable* Databases told me in January 1991 that they had cataloged more than 5,000 products [6]. She added, "There's no end in sight" [7].

The road to CD-ROM is filled with pitfalls for producers and customers. Producers, for example, must:

- Restructure a database to conform to the CD-ROM data preparation requirements
- Replicate disks
- Manage marketing, pricing, and distribution

Owners of read-only optical drives have paid $500 or more, and then must:

- Load the Microsoft CD-ROM extensions
- Configure device drivers
- Deal with memory management problems

In the last year or so, the obstacles have required less effort to conquer.

A publisher's decision to offer a CD-ROM product appears to hinge on

instantaneous: that is, less *than* .05 milliseconds, compared with *more than* 15 milliseconds for most high-capacity magnetic disks, and 300 milliseconds for most CD-ROM drives. Where speed is of the essence, the virtual disk can deliver it.

These devices are dropping in price, and they are finding their way into single-user systems. Promise Technology, Inc. (San Jose, CA) offers a controller that can support up to 16MB of high-speed RAM. The basic board retails for about $350 dollars with 512KB of RAM. Taking the board to 16MB pushes the retail price to about $1,000.

Static RAM caches are one way to speed up the response time of various optical drives. A cache anticipates the information required by the system's user, accesses the disk, and places it in the high-speed virtual disk. When a piece of information is requested, the cache can deliver it almost instantaneously, A 4MB cache can make a standard CD-ROM drive perform with only a second or two delay from the user's point of view.

FLEXIBLE MEDIA

Flopticals: This is a mass storage technology that combines the 3 1/2 inch format, laser technology, and magnetics. Insite Peripherals, Inc. (San Jose, CA) announced in 1988 a 20MB floptical drive that can read and write conventional 3 1/2 inch disks. The company predicts an average seek time of 65 milliseconds. The diskette is inscribed with indelible optical servo tracks space at 20 micron intervals to increase the recording density of 1,250 tracks per inch (tpi). (For a more detailed discussion, see Mike Seither, "Magnetic-Optical Mix Yields Innovative 20M-Byte Mini-Floppy," *Mini-Micro Systems,* November 1988, volume 21, number 11, pages 42-46.)

Model 1325 will use standard, high-density 3 1/2 inch disks. Insite's technological innovations are twofold; first, the company created a laser-based machine called the Path-Maker, which cuts optical tracks 180 micro inches wide into the mylar surface of off-the-shelf, high density three and one-half inch diskettes. Second, insite has mounted an optical sensing mechanism on top of the drive's read-write head carriage. The Floptical presently looks like a Winchester or hard disk to the host, whereas users see it, not as a second flexible drive, but as drive C, D, and so on. This configuration makes it ideal as a method for distributing large programs on one disk, and as a method for reconfiguring installed hard disks.

VHD Floppies: Toshiba (Japan) and Brier Technology Inc. (San Jose, CA) use the 3 1/2 inch media and vertical recording to create Very High Density floppies. Toshiba's very high density (VHD) technology yields about 12MB of storage from a track density of 431 tracks per inch (tpi), about triple the density of today 1.44MB flexible disks. Brier's track density is 777 tpi and accepts about 21MB of data. By the end of 1991, diskette manufacturers from Japan, Hong Kong, China, Taiwan, Korea, and Singapore will introduce a range of drives and media that offer a range of high-capacities. Japanese manufacturers have begun production of 4MB floppies. Two other manufac-

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two factors: 1) having a body of information large enough to warrant a CD-ROM, and 2) having sufficient cost incentives to use CD-ROM, not paper or another medium, to deliver data.

As costs for manufacturing CD-ROMs fall, more publishers will consider it as a publishing medium. Lower costs will also attract associations, academic institutions, research centers, individuals, and small presses.

Although many readers are intimately familiar with CD-ROM products, a broad-brush review of the major types of optical storage options may help differentiate overlapping technologies. We will then look at desktop CD-ROM manufacturing. Could this be the next major personal computer application?

WORM OR WRITE-ONCE, READ-MANY TECHNOLOGY

WORM — what a memorable acronym. WORM refers to the use of a laser to burn pits in a substrate encased in clear plastic to store data. Once the data are burned into the substrate, they cannot be changed. It is permanent, although it is possible to overwrite directory information making the data inaccessible.

Permanent data have many applications in organizations where information must not be changed: for example, documents bearing signatures. Accounting firms, nuclear power station records management, quality control, and financial transactions are four applications where the WORM technology has found enthusiastic customers. The technology allows organizations to achieve several objectives:

- WORM is an effective medium for storing text and images.
- A relatively high volume of data can be moved from relatively high-cost magnetic stored to a lower-cost media.
- WORM disks can be held online or nearline using jukeboxes.
- WORM retrieval is accelerated by holding the index on a magnetic disk and using software routines to request the data residing on a WORM disk.
- The database is secure.

Two examples illustrate WORM applications. The Washington, D.C. law firm of Howrey & Simon computerized its index to various legal documents in the 1970s. But the combination of high volume and the inefficiencies of having to use the index and then manually retrieve the document became a bottleneck. The systems staff added WORM devices to store document images. According to partners, the application is speeding up document management and boosting productivity and service [8].

The U.S. State Department uses WORMs for its STARS (Secretariat Tracking and Retrieval System) which adds more than 200,000 image pages annually. Each document is indexed and held in magnetic (fixed disk) storage for 30 days. At the end of this time, the data are moved to WORM disks and stored in a jukebox a capacity of more than 170GB [9].

MAGNETO-OPTICAL DRIVES (MOs)

To *some* people, WORM drives represent half a loaf. The user can write

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turers plan 13.5MB and 16MB versions. "The future of the 4MB disk depends upon IBM's decision to use the higher-capacity drives," says *Asian Sources Computer Products.* See "Higher Capacity 3.5-inch Floppy Disks Available," *Asian Sources Computer Products,* February 1991, page 720.

BUBBLE MEMORY

Bubble memory technology was invented at Bell Laboratories in the 1970s. The technology stores memory in bubble-like magnetic areas on a chip's surface. The bubbles are non-volatile; that is, they do not lose data when the power is cut off. These solid state devices use a magnetic field to represent logical data. The data can be manipulated within the bubble module by rotating an external coil field currents. Bubble memory devices maintain data integrity in high temperatures, resist dirt, and are unaffected by vibration. Bubble chip prices are higher than prices for other types of memory. This storage technique is used in applications requiring rugged, temperature-resistant devices. Bubble memories are used in military and defense equipment. For more information see Doug Chandler, "In Light of the DRAM-Chip Shortage, Bubble Technology Looks Promising," *PC Week,* 7 June 1988, volume 5, number 23, page 21.

REMOVABLE MEDIA

Removable mass storage pertains to modules that can be removed from a read-write device. Removable media can be magnetic, magneto-optical, or optical. The common attribute is that each media module can be used in another computer equipped with a read-only or read-write device, or simply be put in storage.

Bernoulli Boxes: A Bernoulli Box is a drive that accepts a 5 1/4 inch cartridge. Bernoulli Boxes can be used as primary or backup storage devices. The box contains flexible disks and offers capacities to 40MB per cartridge. It offers an access time of about 32 milliseconds and uses a SCSI interface. The name Bernoulli comes from the Bernoulli principle of fluid dynamics to create a soft interface between the media and the read-write head.

Removable Cartridges: Cartridges offer about 40MB of storage. The cartridges fit into drives mounted either inside the PC or in external cases. Syquest Technology and Ricoh have manufactured these devices, which are essentially specially reinforced hard disks. Reliability is sometimes an issue.

Removable cards: Memory cards measure about 2 inches by 3 inches. They have a 68-pin connector and can hold up to 16MB. The cards are a combination of proprietary chips, miniature memory modules, and a battery with a three-year projected life. The model manufactured by Fujitsu Microelectronics, Inc. (San Jose, CA) is aimed at palm-size applications. Memory cards can store data in read-only form and are available as read-write devices.

-Stephen E. Arnold

data but not change them. Because computer applications are increasingly interactive, some users believe that an optimum mass storage device must allow rewriting of the data. Magneto-optical mass storage devices give users the ability to read and write to media that can contain several hundred megabytes of data. Furthermore, the disks can be transported, can sustain about one million read-write cycles, and have many of the durability attributes of CD-ROM. Prices for MO drives, although dropping, run about 25 percent higher than for WORM drives.

Magneto-optical drives combine two technologies to provide high-capacity storage. Magnetic fields store the information and are read by a polarized laser that detects magnetism via the Kerr Effect. Most of the drives available today are slower than WORM drives. Among the reasons for access speeds that are slower than on hard disks are the weight of the read/write head and the drive's revolutions per minute [10].

It takes two passes of a laser beam to write data onto a disk. The laser first heats a layer of material in the plastic storage media, typically a disk quite like that used for a CD-ROM. At 150 degrees Celsius, the material becomes sensitive to a magnetic field. When the substrate passes through a field, the north and south poles of the material in the region exposed to the field flip. When the substrate cools, the material retains the reversed poles. The difference between regions with north and south in the original position and regions with north and south flipped represent binary 1s and 0s. With this information, the drive's electronics and controller can translate the information into digital data for the computer.

On the second pass, the laser beam is fired at that area of the disk again. When it bounces back after passing through the charged particles, it will have rotated either clockwise or counter-clockwise depending on the direction of the particles' magnetic north pole. The direction of the rotation is detected inside the drive and interpreted as a "1" or a "0". (An alternative approach is called "phase-change." In the first step, a spot on the semimetal media is changed to a reflective state by a laser beam. A more powerful beam changes the reflective state to its original non-reflective state, thus erasing the data.)

In either case, faster operation results from split optics. A mirror is placed on the drive's actuator and the rest of the optics on the deck plate, thus reducing head weight. Also by reducing the magnetic coil that switches poles and getting the laser closer to the disk surface, magneto optical drives can achieve faster read-write times [10].

Japan seems to have the lead in manufacturing MO drives. Why? The Japanese have the ability to manufacture laser, diode, and lens assemblies to close tolerances, and the MO drive requires highly precise optical assemblies [11]. According to *Tokyo Business* Today, in Japan alone there are about 100 companies involved in this business. Only a handful will survive [12].

One promising application area for MO drives is to merge home electronics and microcomputing by enhancing home entertainment electronics systems with 3 1/2 inch MO drives. These drives are expected to be able to store 1.2GB of data using a shorter wavelength laser diode. Thus, the future of the MO may be in both the office and the home [13].

DESKTOP-PUBLISHED CD-ROMS

Making a CD-ROM at an office desk is now possible, ushering in a new type of electronic publishing: personal or desktop CD-ROMs.

In 1989, Meridian Data (Scotts Valley, CA) introduced its CD Professional, a hardware-and-software system that allows a customer to handle small-scale CD-ROM production without using an outside mastering facility. CD Professional can copy about 10MB (about 5,000 pages of text) per minute onto a compact disk at a cost of about ten cents per megabyte. Meridian also sells its CD Producer which allows the user to develop multimedia information products. CD Producer treats the different types of interleaved information as if they reside on a CD-ROM. The publisher can test the application, change it, and repeat the process until the application is completed.

In March 1990, Meridian Data, Inc. announced its CD Publisher: the $18,000-$30,000 product is a desktop

A MASS STORAGE GLOSSARY

9-track magnetic reels: A storage medium capable of storing about 350 megabytes of data per reel.

Automated tape libraries: Use magnetic tape in cartridges (not the older style open reels similar to those used for 16-mm films). There are bigger, more elaborate versions of the devices that play six cassette tapes. The 18-track units can hold as many as 6,000 tape cartridges. This yields storage of about 1.2 terabytes of data. See "Jukeboxes."

CD-ROM: Compact Disk, Read-Only Memory, a sandwich of plastic and aluminum. Data are pressed into the aluminum in a process similar to that used for making records. Diameter is 4.72 inches. Capacity is about 650MB.

DASD: Direct Access Storage Device, a dedicated storage subsystem. Usually contains a number of storage devices.

DAT: Digital Audio Tape; a high-density magnetic storage medium.

Data compression: Applies various algorithms to map the representation of data from one group of symbols to another. The algorithms reduce redundant data. The result is that a 2MB file can be compressed from ten to fifty percent using various techniques like Huffman coding or the LZW algorithm. Compression is transparent to the user. Some storage devices achieve high densities by including the compression process in the firmware of the storage device; thus, compression is not user-selectable.

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Digital Paper? A dye polymer optical recording material coated on a Melinex polyester substrate; has a 15-year lifespan; a size less than .025 mm allows the medium to be used in cassette tapes, open reel tapes, or disks. A 10 1/2 inch reel has a capacity of 1,000 gigabytes.

Disk array: Sometimes referred to as a RAID; a cluster of relatively small disk drives to do the work of a bigger drive.

Disk caddy: A plastic sleeve or carrier that protects optical media from dirt and surface scratches. Many optical drives require that media be placed in a disk caddy before the drive will operate, information not provided with some mail-order drives.

Disk cartridges: Tapes in plastic cartridges similar to those used for audio cassette tapes; come in various sizes.

Document image processing: Sometimes abbreviated DIP. Refers to the process of capturing images of documents on optical media. Usually found in credit card, insurance claim, and check handling operations. Images are scanned and then stored on optical media. IBM's Image Plus system is a DII?

Fixed disks: A read-write storage device containing rigid magnetic disks; sometimes called Winchester disks.

Floptical: A "floptical disk drive" is the product of a floppy disk drive and optical technology. A 3 1/2 inch disk yields a formatted capacity of 20.8MB.

Form factor: "Computer-speak" for references to the standard external size of drive housings, tape cartridges, etc.

CD-ROM publishing system. It operates with IBM 286,386, PS/2, and Macintosh computers. CD Publisher allows do-it-yourself mastering, but it cannot manufacture the finished CD-ROM. The system can convert data to machine-readable form, clean and tag converted data, validate and edit data, index, format software and data, simulate CD-ROM functionality, and pre-master formatted data.

Meridian's CD Professional is a mini-manufacturing system. It uses a Yamaha-based laser recorder that is able to burn pits into a surface of organic dye with a laser [14]. The disk media has a ten-year life. CD-ROMs with aluminum media have a projected life of 50 years. The resulting disk can be read in a standard read-only optical drive. A complete Professional system costs about $100,000, a fee that is easily cost-justified after the system produces several applications. Owners of CD Publisher can upgrade their present systems with either the Sony 'Corp. or the Yamaha Corp. laser recorder. The standalone cost for the Sony laser recorder is about $36,000; for the Yamaha, about $45,000. The principal difference between the two devices is that the Yamaha recorder can handle both audio and data for multimedia applications.

The Meridian CD Publisher and Professional products integrate both high-capacity hard disks (600MB to 7.2GB capacity) and four-millimeter R-DAT or eight-millimeter Exabyte tape drives [15].

What's the impact of devices like these? First, it lowers the cost of CD-ROM publishing for many companies. Organizations wanting to produce proprietary or limited-distribution data can do so without the estimated $40,000 per CD-ROM title expense using consultants and service bureaus. Second, publishers will have more comprehensive control over the final look of CD-ROMs because the platform is PC-based. PCs also speed of the publishing process. Finally, publishers can format data to the multimedia format developed by Philips, Sony, and Microsoft. Text, graphics, and still-image video information can be interleaved with audio for real-time, simultaneous playback.

A TOUGH-MINDED LOOK AT STORAGE OPTIONS

There is no perfect mass storage medium at the present time. Since disk storage typically represents sixty to ninety percent of a system's management cost, mass storage options must be evaluated carefully.

Each major storage option has strengths and weaknesses. Unfortunately many of the issues related to mass storage options pertain to topics that are extremely volatile (price, cost / MB, etc.) or fairly technical (throughput, capacity, etc.). However, it is possible to offer some general guidelines for evaluating storage options.

Determining the costs of different storage options is difficult. A high-capacity, high-speed magnetic drive may cost less per megabyte than another storage technology. To use that device as a backup system, however, may require a special controller that can write (mirror) data to two drives simultaneously. The controller, installation, and maintenance of a two-drive, high-capacity system may be more costly than using a quarter-inch cartridge, magnetic-tape, backup system. So before purchasing any of the mass storage devices, getting first-hand information from people using the mass storage devices can be helpful.

PROS AND CONS OF MAGNETIC MEDIA

Most high-capacity magnetic media hard disks have faster access times and are faster than optical drives. Data transfer is a tricky subject (like 0 to 60 mph ratings in automobile magazines). "Faster" means the read-write heads can locate the data more quickly than read-write heads on WORM or MO optical drives, and the data transfer rate is higher as well. Magnetic drives have an edge in speed, but high-tech static RAM cache controllers and everyday engineering progress will narrow the speed gap between magnetic and optical devices.

To increase capacity of magnetic media, manufacturers have reduced the head-to-disk gaps. As the head-to-disk gap narrows on magnetic media, the magnetic drive becomes increasingly susceptible to damage. Manufacturers go to great lengths to minimize dust, dirt, and impact vulnerability. The higher the capacity of the drive, the more important proper care and handling becomes. Data on any magnetic media can be inadvertently erased or rendered unusable by shock. Inadvertent reformatting can destroy data on magnetic disks. Electrical malfunctions or physical failures can destroy data on magnetic media as well. Most optical products are resistant to these problems.

Hard disks employ technologies that are generally well-known in a wide range of computing applications and, consequently, are quite familiar to computer professionals. Other benefits of magnetic media include:

- For small backups, less than 200MB, magnetic media may be faster and more economical than any other media.
- Magnetic media are more familiar to computer users and systems professionals than other types of storage.
- Software for magnetic backups is readily available from a variety of sources.
- The media (tapes and disks) are competitively priced and readily available.

Magnetic media have some drawbacks, including:

- Dirt, static electricity, or impact can destroy data.
- Magnetic media can lose data because of physical changes in the media.
- Special controllers may be required that cause specific installation and compatibility problems.

Magnetic media represent a viable mass storage option for many personal and organizational applications.

PROS AND CONS OF OPTICAL MEDIA

Storage capacity of optical media seems destined to continue to outstrip magnetic media in raw capacity [16]. Since a beam of light is used to write data, more tracks per inch are possible than with magnetic heads. Consequently, for large data sets, that is, larger than 200MB, the cost-effectiveness of optical media generally exceeds that of magnetic tape. Although not a fair comparison, consider that forty reels of "regular" magnetic tape are needed to hold about 600MB of data. Assuming that tapes cost $20 each, expect to spend $400 for 20 tapes versus $250 for one optical disk [17]. WORM cartridges, which can hold up to 800MB of data, retail for about $150-200; MO cartridges list for about $250-350. Other benefits of optical media include their reliability and durability.

Standards for optical media are gaining acceptance. The Orange Book (the new set of multimedia standards proposed by Sony and Philips) joins the other High Sierra Group specifications that were adopted as IS0 9660 after modifications. Optical storage experts say, "Users will be able to read ordinary CD-ROM disks with write-once drives, but won't be able to read write-once disks in existing read-only CD-ROM drives [18].

Among the well-known drawbacks of optical storage devices are the sluggish data transfer speed, the vulnerability of the drive's mechanics to contamination from circulating air or dirty media, and cost.

One method proposed to speed access times and reduce data transfer speeds has been the use of plastic optics. Although lighter optical mechanisms contribute to faster access times, plastic optics are less stable than those made from glass. Plastic optics are more easily scratched and are harder to clean. The coatings used on plastic optics are less durable than coatings on glass optics.

Media removability is an essential feature for some storage tasks. Although improvements in air flow have been made, abusive opening and closing the drive mechanism and inserting cartridges that are not dust-free contribute to drive failure. Installation and maintenance of optical drives may be new to some support personnel. Consequently, repairs and reconfiguration may be more time-consuming than setting up or replacing a hard disk.

CD-ROM CHALLENGES

Challenges posed by CD-ROMs include:

- Commercial database producers have achieved significant market penetration in public and academic libraries and some corporate markets, and will be difficult to dislodge.
- The optical drive, controller card, and software can be difficult and time-consuming to install and

Jukeboxes: Robotic disk libraries; systems that provide automatic access to a collection of optical disks. A jukebox contains four subsystems: the optical drives and controller; the shelf units where the optical disks are stored when not in use; a set of robotics that facilitate the movement of the disks; and an exchange chamber for transferring disks into and out of the jukebox.

Magneto-optical drives: A device that mimics a hard disk. It uses a combination of laser and magnetic technology to write data. The read process uses a laser beam. Drives have seek time of 35 to 100 milliseconds as compared with 30 minutes for tape and 15 to 65 milliseconds for hard disks. Rotational speed is about 1,800 rpms today compared with 3,600 rpm for hard disks. Media are insensitive to magnetic fields and x-rays. Can withstand large particle contamination; can withstand greater shocks than Winchester drives.

Management software: This phrase refers to a wide range of software tools necessary to make storage devices operate. Functions the software handles include backup, file reorganization, and system configuration.

Multifunction drives: A synonym for magneto-optical drives; drives use rewriteable optical disk cartridges

Nearline storage: Disks or cartridges held in jukeboxes or data robots. When a particular piece of information is required, the jukebox loads the proper disk or cartridge in the drive.

Optical jukeboxes: These devices are data robots that load multiple optical disks and feed them to optical drives the same way jukeboxes once fed 45 rpm records.

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Optical tape: A synonym tor Digital Paper.

Optical disks: Can refer to either the CD-ROM-sized disk or to a larger 12-inch disk found in mainframe optical storage applications.

Optical storage: Data written and read by coherent light systems (lasers).

QIC: Acronym for quarter-inch cartridge; the form factor for the most common magnetic tape format.

RAID: Redundant Arrays of Inexpensive Disks; the name came from a University of California, Berkeley research effort.

R-DAT: Digital Audio Tape used for archiving of high-capacity computers with SCSI interfaces; a synonym for rotating head technology or helical scan recording techniques.

Rewriteable optical drives: A synonym for magneto-optical drives. These drives allow data to be changed; are typically used as secondary storage devices.

SCSI: Small Computer Systems Interface; an interface. that allows up to eight devices to be linked to a single controller; features a higher data transfer rate than other types of controllers; "intelligence" resides in the device attached to the SCSI controller, not just the controller.

Virtual disks: Sometimes called static RAM or caches; virtual disks lose data when power is cut off.

Winchester drive: A fixed disk or hard disk.

WORM: Write-Once, Read-Many drive; an optical drive that can write data once, yet read it many times. Used for archiving data.

configure. Although the physical disks are standardized, each CD-ROM has its own twists and turns. There is no standard front end interface across all products. "According to recent research by [Linda] Helgerson [Helgerson Associates], a whopping 79% of CD-ROM users surveyed were either somewhat (22%) or very (57%) bothered by having to learn new retrieval software with each new package" [19].

- CD-ROM publishers assume that only one product will reside on a user's PC. One unhappy consequence of this short-sightedness is that large chunks of a hard disk can be gobbled up by retrieval software for each CD-ROM the customer owns. Since some retrieval software can take up as much as five megabytes on a user's hard drive, users may conclude that they will get by with fewer CD-ROMs.
- Amid a flood of new CD-ROM products, prices vary widely and can seem illogical. For example, the U.S. Geological Survey puts out a $28 disk called Digital Line Graphic, a mapping disk based on a USGS database; the magnetic tape version of the database costs $1,400. Wide variances like this raise difficult cost-benefit questions in the minds of customers.

BEFORE YOU DECIDE...

Here are some things to keep in mind before you purchase any new mass storage product. Use these reminders to make certain that you have selected the proper mix of mass storage devices and media:

1. Advanced mass storage technologies often require special hardware; for example, SCSI controllers, terminators, or special cables. Nail down the specific requirements your mass storage solution requires and understand what system changes you have to make before you buy

2. Storage technology evolves toward increased miniaturization and greater storage density. Both can increase the fragility of the drive mechanism and the storage media. Match the mass storage solution to the operating environment in which the equipment will be used.

3. Prices for new mass storage technologies start high and then drop as the technology diffuses. For storage technologies that lack mass market appeal, the companies and the technology itself can be orphaned and difficult, if not impossible, to support.

4. Achieving larger mass storage capacity often requires radically different software for installation, maintenance, and error handling. The massive amounts of data stored on optical media can stretch disk-operating system file allocation structures to the limit.

A GLIMPSE OF 2005

To conclude, let's peer into the future by looking at holographic storage, developed at Bell Communications Research (Livingston, NJ).

Bellcore has been exploring the next generation of storage technologies. One promising technology is holographic memory. A holographic memory provides ten times the storage density and 1,000 times faster retrieval speed than any other storage technology. An array of micro lasers makes these incredible figures possible. For example, Bellcore reports that the equivalent of one typed page of data can be transmitted in less than one nanosecond, or one-billionth of a second [20].

The main elements of the holostore device are the laser source, the page composer, the page-selector assembly, the crystalline array, and the detector array [21]. Each micro laser's beam is split into two parts. The data travel on one beam; the second beam aims the data stream. Light strikes photo-refractive crystals. These are made of a material whose properties can be altered by light. Light regulating modulators combine the two beams in the crystal to create three-dimensional holographic images. The data are, therefore, stored holographically and can be retrieved when illuminated by an original reference beam. Thus, a single crystal smaller than a sugar cube can store up to one million images.

In conclusion, mass storage appears to be an unlimited information resource. Libraries can look forward to a future in which electronic shelf space will be plentiful. I heard Paul Saffo, who worked at the Institute for the

Future in Menlo Park, California, use the phrase "information surfing." If mass storage gives us an ocean of electronic data to ride, we should have perfect waves to seek and ride for years to come.

One caveat must be added to the mass storage good news: my father-in-law used to remind me, "You can't get something for nothing, or there is no such thing as a free lunch." The storage revolution has a price — planning for retrieval. If a user is unable to locate the required information, mass storage has only expanded, not solved, an information problem.

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