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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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on

Methodology of Large Dynamic Files

by

A.K.Gillis

NORTH ATLANTIC TREATY ORGANIZATION

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METHODOLOGY OF LARGE DYNAMIC FILES,

by

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Section I

THE FILE SYSTEM

1. THE FILE SYSTEM

A file denotes a data collection without regard to physical size or to format. It further denotes the physical features associated with the file, e.g., the storage cabinet, the microfiche file box, the magnetic tape hardware, the mass store unit. Also implied by the term file is the human organization which manipulates the physical features containing the data collection; hence, the user's secretary, his data processing department and possibly the user himself could all be equally a part of the file. What we now have is a file system consisting of three major elements: data, equipment, and humans.

When characterizing a file as large, we often imply that the file tends to be unmanageable and inefficiently manipulated by currently implemented techniques. A paper file contained in a bulky paper folder is difficult to manipulate; however, the same file when reduced to microfilm becomes easier to manipulate. File size, with regard to information content, does not change when converted to microfilm, but access is facilitated. Directories, inventories and catalogs are typical examples of files which may be "large" in paper format but "small" in microfilm format. Similarly, a simple relocation of a "large" paper file from a collection of drawer-type filing cabinets to an automated, or even an optimized file storage device significantly reduces the apparent file size.

Another implication of large, when characterizing a file, is that the file tends to fill to capacity available storage. File size is measured in storage units; hence a file becomes large when the number of storage units required by the file is a significant percentage of available storage units. Expansion of storage capacity may alleviate the problem, but as the number of individual storage devices increases, the file again becomes unmanageable, hence "large".

A third implication of the term large is that it is used to classify those files which have or are envisioned to have the greatest data content of any other known file; i.e., they are physically immense. Obviously this class of file will both fill to capacity available storage devices and tend to be unmanageable. The methodology applied to this class of file, however, is no different than that which should be applied to any other file.

Dynamic, also a relative term, implies that a sufficient number of accesses are being made to the file system to overwhelm some aspect of the system's implementation. This results in reduced response time, hence, inconvenience to the user. To illustrate, a small cabinet paper file is not necessarily dynamic until individuals who access the file either must wait for access or find that the information is being accessed by others and is unavailable. A file may be dynamic not only on access but also in any other function associated with the file system. The physically immense files coming into existence are dynamic because of not only their real-time access but also their real-time update requirements which can overwhelm all aspects of the file system.

Figure 1 summarizes the definition of a "large dynamic file". The methodology associated with this type file can most generally be defined as the application of optimized devices, both firmware and software, which facilitate file manipulation and maximize file response time. It is basically no different than the methodology applied to any other type of file system.

LARGE – Volume exceeds handling capacity producing unmanageability and manipulation inefficiency.

DYNAMIC – Access requirements overwhelm implementation capability reducing response time and inconveniencing users.

FILE – An information source consisting of a system of data entities, hardware devices, and human beings.

Fig. 1 Definition Summary

The following paragraphs of the report explore the file system and define its various functions and physical states. The report's objective is to present at a nontechnical level an insight into what constitutes a file system, how it evolves, and where special emphasis needs to be placed in its design and implementation. Although generalized file systems are considered where possible, digitally oriented files are preferentially covered. Emphasis is also placed on the physically immense files.

1.1 File Function

A file, regardless of size, has functions which can be categorized as Data Collection, Data Conversion, Data Storage, and Data Retrieval. The degree of sophistication associated with each function is determined by the complexity of the data processed and by the information dissemination requirements. Figure 2 depicts typical data flow within a file system.

To be useful, data must be extracted from the file and processed into information; the fact that a file stores data but a user wants information is important to recognize and understand. Information is derived only when data is interpreted. Data interpretation to create information is a function normally performed by the data retrieval file function.

If data is to be available for retrieval, the file must have a collection function. Appropriate collection practices facilitate all subsequent file functions and the timely collection of data such that it is available when needed is of prime importance. No specific data collection procedure is applicable to all data sources, hence, a wide variety of data collection hardware and software devices are available throughout the industry. In addition, it is not unusual to find specialized data collection procedures specifically tailored to unique applications.

The data collection function does not necessarily produce data which is compatible with the file storage apparatus. A conversion function is therefore provided to process collected data and to convert it into a format suitable for storage.

1.2 Data Formatting

To facilitate retrieval, data must be segregated into distinct entities which can be cataloged and referenced. A significant characteristic of a file data entity is that it is the smallest segment of data which can be accessed by the file's retrieval function.

A data entity within a file system denotes an ensemble of raw data elements. A raw data element is the fundamental data constituent and can exist in one of two basic forms: fact or thought. A factual data element is specific; numbers representing size, weight, temperature or characteristics such as gender, color or location are examples. The factual data element can be stored within the file by a fixed number of file storage units which are known a priori. The thought-type data element is abstract; alphanumeric text strings representing letters or documents are examples of this type of data element. The number of file storage units required to accommodate a thought-type data element cannot be exactly specified.

Basic data elements are collected together to form a data entity; however, this does not preclude the possibility that a file's data entity can itself be a single data element. Data entities can be composed of both element forms; hence, the data entity can be either fixed size or variable size as measured in file storage units required to contain the elements. Fixed or variable are the more common terms used to characterize a data entity and often the term "data record" is used synonymously for the term "data entity", especially in electronic data processing environments.

When accessed and retrieved from file storage, elements can be processed along with other elements from other entities. This constitutes the process of generating information. Data in its fundamental form or even when collected into entities is not necessarily information. Information implies that knowledge is imparted to an individual and this is a critically important consideration when defining the architecture of a file system. It is a simple task to configure a file capable of inundating a user with data from which little or no information can be derived. It is a nontrivial design problem to create a file system which can supply information to a user at the proper time and place needed.

Unfortunately, many files and especially physically immense files, have evolved without proper design guidelines and do not yield information at the rate or in the quantity needed. Minor file system redesigns can alleviate some problems, but unless the total file system is considered and a total system approach established, the attained performance is substantially less than desired.

1.3 The File Cycle

When captured by the file system's collection function, a data element is launched on an evolution process which ends in purging. Throughout the cycle a data element will exist in various physical states as shown in the file cycle state diagram, Figure 3. A data element cannot simultaneously exist within the file system in two states; however, the storage state is an exception to this rule since access to a data element often does not physically remove the data element from the storage device.

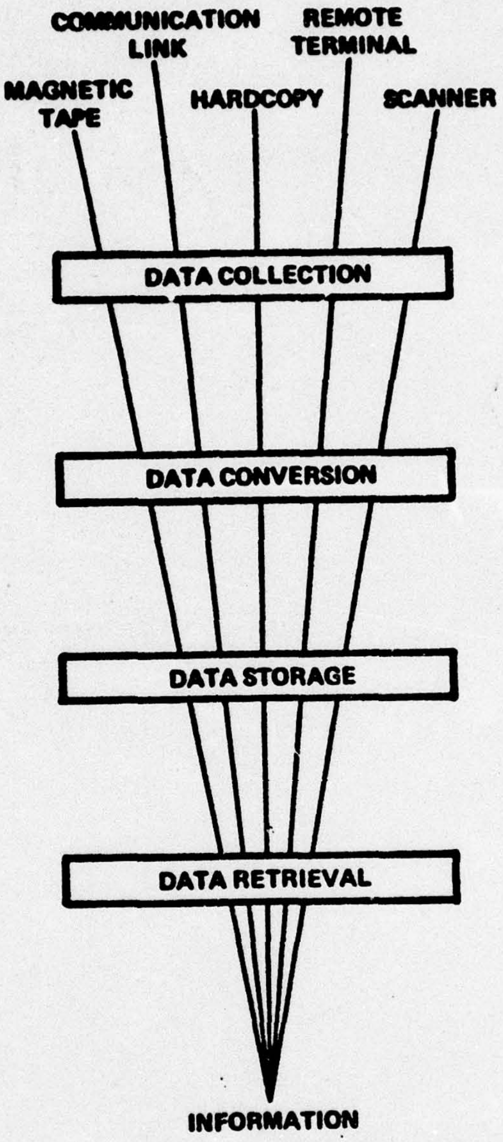

Fig.2 File functions

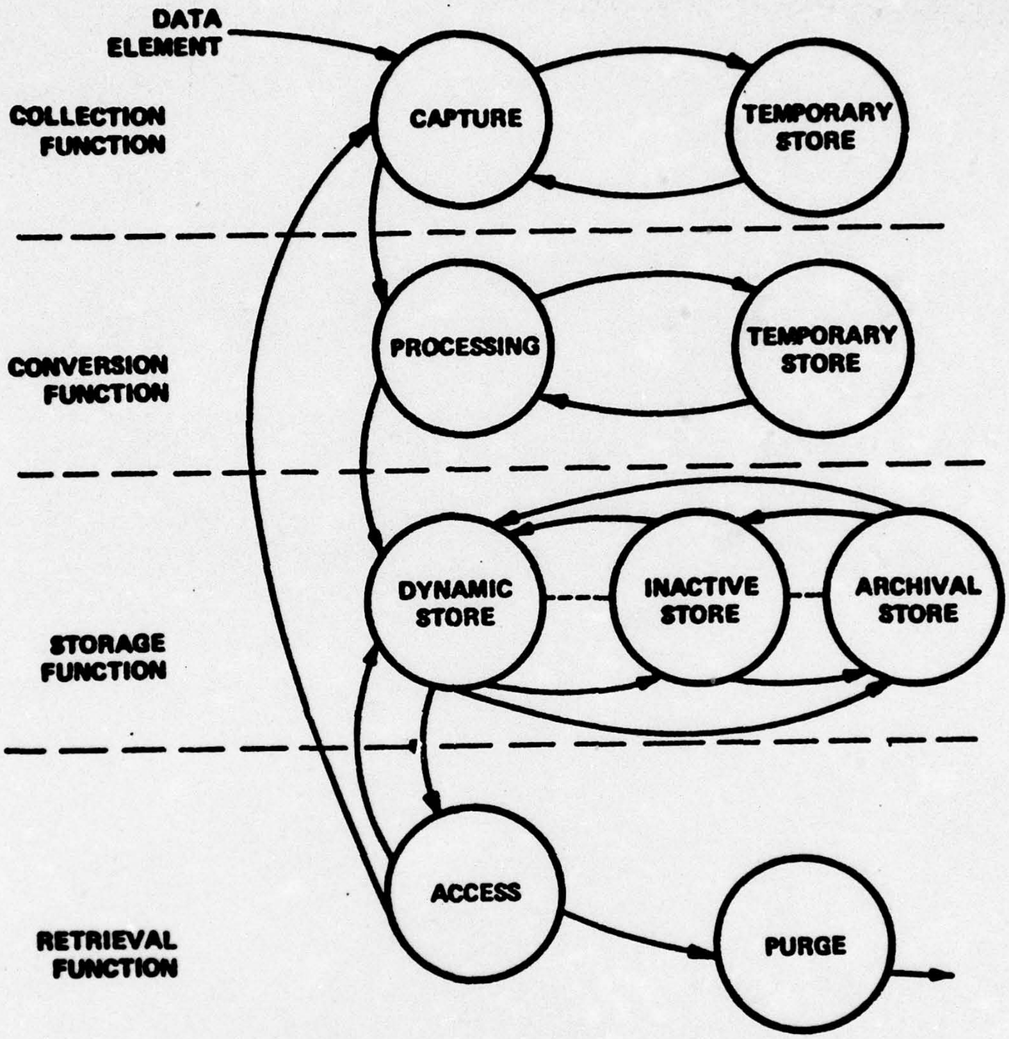

Fig.3 File cycle state diagram

Connectors between states represent all possible transition channels whether automated or manually accomplished. A time interval is associated with a state change; for example, the access time to a memory represents (or is a part of) the transition time from a storage state to the access state.

The primary purpose of the file system's data collection function is to capture raw data elements. The collection process, therefore, must be capable of manipulating all data elements which are to be entered in the file system. Based on the data element form, many unique devices and activities may be involved simultaneously in the data collection function. Temporary storage may also exist within this function.

Processing converts the raw data element into a format suitable for storage and assembles the elements into entities. It is not unreasonable to employ different storage devices, hence to require a variety of processing activities within the file system. It is also not unusual and often it is most efficient to combine data element conversion as an integral part of the collection function.

Most data element transitions involve a storage state which is the most common file state and which is often the limiting feature with regard to file capacity and response efficiency. Possibly because of this, industry has for several decades been pressing to develop larger capacity and faster access memories, not only for digital format data, but for paper and film formats as well.

Retrieval of data elements and their conversion to information is the key file function. If it is not adequately addressed, the file system closely approximates the proverbial (and useless) write-only memory. The output of the retrieval function is information and may consist of reports, tables, graphs or other forms of assimilated data elements. It is also not unusual tor the output of the retrieval function to cause stored data elements to be updated or to generate new data elements which must be entered into the file system. These characteristics of the retrieval function represent a data element feedback path which must be as carefully considered in the configuration of a file system as an electronic feedback path is considered in the design of an electrical system.

The purge state of the retrieval function is another important state and represents the complete elimination of a data element from the system. In some situations, the purged data element may be recaptured, but in most situations the element is irretrievably lost. The purge state is often considered to be synonymous with the archival storage state. This is incorrect and if the archival store state is used to retain elements which should be purged, the file system becomes clogged and inefficient. Obviously, when a data element reaches the purge state, its file cycle has been completed.

1.4 System Objectives

A file's mere existence does not necessarily imply that the file is accomplishing much more than data storage. To be truly useful, a file must furnish information which can impart knowledge. It is therefore extremely important to establish what information is to be derived from the file; this is equivalent to defining what specific data elements must be made available, how they are to be cataloged and referenced, and how they are to be processed.

A file which presents only those data elements necessary to extract a specific item of information is an exception rather than a rule among commonly encountered file systems. The common file system procedure is to overwhelm a user with data elements in hopes that he will be able to sort through the elements and generate the desired information. This has long been a major problem associated with Management Information Systems (MIS). These electronic data processing software systems were created to supply relevant information in a timely fashion to senior corporate management such that they could more effectively make management decisions. They probably represent one of the initial forms of data management systems and a great deal has been learned about file systems methodology during the evolution of MIS into a viable and useful tool.

Definition of file system objectives is not an easy task, but since the file is to be implemented with physical devices which only do specific functions, it is an absolutely necessary task. As with any system design, the first questions to ask are who will use the file, what information will he seek and what data elements are needed to support the information generation process. Having formulated answers to these three basic questions, the file system architect can optimumly configure a design which addresses specified objectives.

Of additional importance, the architect must configure the file system to meet the changing needs of a dynamic environment. The one overriding information sciences theorem which has the greatest impact on file system design, is that data element criticalness and importance changes with time. Consequently, file system objectives established during a definition procedure change slightly throughout the life of the file system. A well-defined file system facilitates the capture of new data elements classes, the deletion of old classes, the regrouping of elements within entities, and the introduction of new information generation processes.

Section II

DATA COLLECTION

2. DATA COLLECTION

Data collection is an integral part of the file system; in fact, it is the foundation of the file system. Appropriate collection practices affect all subsequent file functions; timely and efficient data collection minimizes information delay to the user and accurate data collection optimizes the effectiveness.

2.1 Data Capture

Sensors capture raw data and temporarily store it, hopefully in a format which facilitates conversion. The human eye is one of the most commonly used data sensors in a manual data collection activity. Temporary storage for data collected in this fashion typically is a paper form which is marked in some fashion by the person collecting the data. If consideration is given to the total file system concept, a format and marking procedure can be implemented which automates the conversion function; hence, data transition times between file cycle states are reduced. Naturally a machine-readable format facilitates processing, however, if subsequent manual sorting or review is a requirement of the collection function a human-readable format must also be maintained.

Automated sensors and, more specifically, remote electronic sensors are also involved in the data collection process. In these situations data collection can easily overwhelm the file system, particularly the conversion function, and raw data must be stored for extended periods in its capture format (possibly on analog magnetic tape) for subsequent conversion. This procedure, if present, is usually indicative of an uncoordinated, piece-wise file system implementation which did not fully consider all aspects of the system definition.

2.2 *Implementation Concepts*

Implementation of equipment and procedures to capture data implies that the type of information which the file system is to provide has been defined and that necessary input data elements have been identified. Each data element's format (i.e., paper, film, magnetic or electrical) and its size characteristic suggest possible equipment implementations. Data element priority and availability plus economic factors also contribute significantly to the physical implementation of the sensor utilized to capture the data element. A further consideration is the output format of the data element when transferred to the conversion function for processing. The file collection function, therefore, is implemented by an assortment of sensing devices whose purpose is to capture data elements and present them to the conversion function.

To illustrate these concepts consider the capture of the raw data element temperature. Numerous sensor types and procedures can be quickly identified and range from an individual person observing the reading of a thermometer to a thermoelectric device producing an electrical signal. The collection function, however, is not complete until the raw data has been recorded in a format which is transferrable to the conversion function. Hence, the captured data elements must be transcribed to some format which is reaccessible. Again a broad range of techniques is available which for the above example may be anything from a slip of paper in the human case to a strip recorder or magnetic tape for the thermoelectric device. Each sensor mechanism and formatting technique produces different response times, accuracies and efficiencies; the selection of the optimum approach can only effectively be guided by the file system's ultimate objective.

2.3 Data Collection Trends

Trends in file system implementation are toward automated sensors which capture data elements and transfer them directly to the file conversion function. For example, significant technology advances are being made in point-of-sale sensing equipment which immediately updates inventories and performs real-time accounting fuctions. This technology can also be readily applied to a wide variety of data collection requirements.

In the processing of alphanumeric text, optical character recognition (OCR) technology is available. OCR equipment, however, is still limited in capability because only a limited number of different fonts can be recognized by any one equipment and a human operator is needed to aid the equipment in defining unrecognized characters. For those organizations which have control over text generation, these limitations are minimal and data collection is greatly facilitated by the application of OCR.

National and international earth satellite data collection systems are other examples of very sophisticated sensor systems. Also noted in current trends is the fact that collection and conversion functions are becoming less distinct. It is quite common to observe sensing subsystems which not only capture data elements but also immediately process these data elements for direct transmission to file storage. Hopefully this will be an increasing trend in earth satellite systems which need some form of data element selection process to reduce the tremendous data volume presented to processing centers.

Section III

DATA CONVERSION

3. DATA CONVERSION

The file's conversion function assembles data elements into entities which can be conveniently stored and accessed. Often the conversion function transforms data from one format to another, physically, mathematically, or by means of some other procedure which fulfills file objectives and implementation constraints.

3.1 Entity Formatting

The grouping of data elements into entities is determined by a number of factors including logical relationships between elements, element utilization in information generation procedures, and physical attributes associated with the file system equipment. Logical relationships are definitely the major factors affecting the arrangement of elements into entities; however, file system efficiency tradeoffs exist with respect to entity size selection and file system data manipulation attributes.

Most file systems are record or volume oriented so that fixed physical quantities of stored units are manipulated. For example, the microfiche file manipulates a fixed film chip size even though all storage units (an image cell) on the microfiche are not utilized. Digital files similarly manipulate fixed size physical records of digital data which are subdivided into binary words; within a record all words are not necessarily utilized. The conversion process, therefore, must overlay the physical attributes of the file, especially those of the storage function, with a logically assembled data entity whose size characteristics often does not match the file's physical data manipulation attributes.

Incompatibility of logical entity size and physical storage record size is especially common in electronic data processing file systems. Often the matching of logical entity sizes to physical storage characteristics is not addressed, since data management software tends to mask physical attributes of the storage media. The end result of this fallacy, however, is similar to that obtained by storing legal size documents in a standard sized filing cabinet; substantial storage space is wasted. Also it is often not even possible to achieve an optimized match since a specific file entity format must be overlayed on existing equipment facilities. However, when both entity format definition and equipment data manipulation attributes can be traded off to yield an optimized match, significant improvements can be achieved in file system data handling efficiency.

Data conversion, especially with regard to entity formatting, is closely tied to the data management protocol established by the retrieval function. Although the actual process of formatting data is accomplished by the conversion function, the formatting procedure is established by data retrieval techniques. Hopefully a data management procedure, as discussed in Section V, will provide an entity format scheme which is independent of any one specific information generation procedure. Such a format scheme eliminates element storage redundancy since unique entity formats are not required for each information generation procedure.

3.2 Element Transformation

Transformation of data elements from one form to another can be as simple as a conversion between units of measure to as complex a procedure as redundancy removal procedures associated with imagery data. Several basic factors motivate element transformation. First, transformation can be required because the information generation process is optimized by using the transformed elements. Secondly, data in its transformed state may require less file system resources to process and maintain; normally an inverse transformation is required for this type data element prior to its utilization in the information generation process.

Section IV

DATA STORAGE

4. DATA STORAGE

Three fundamental categories or storage states can be overlayed on the data storage function and typically a file system divides its storage facilities into segments associated with each category.

Dynamic store is the primary data store category and represents that facility from which the retrieval function most frequently extracts file data elements. The executive's personal desk file and a computer's core/disk memory are examples of dynamic store. Characteristics of dynamic store include fast and preferably random access to data entities contained within the storage mechanism.

The second category of storage is inactive storage and is characterized by easy accessibility, but access time is significantly slower than for dynamic store. Parallel examples are the executive secretary's file cabinet and the computer facility's magnetic tape library.

Archival store is the third storage category, and warehousing of non-current records or of magnetic tapes are illustrative examples. Archival store is characterized by extremely slow and often inconvenient access procedures but should not be confused with the purge state of the retrieval function.

Although the fundamental file storage categories are applicable to all classes and types of file systems, the paragraphs of this section address only those file systems which are digitally oriented.

4.1 Digital Storage Alternative

A range of storage devices is again available to address the digital data dynamic store configuration. Semiconductor, core, and magnetic media are most prevalent and currently serve as industry standards. A recent memory device development, the charge coupled device (CCD), is adding an additional memory storage capacity which falls between core and random-access magnetic media in both capacity and access time. CCD memory cost is similarly less than magnetic media costs, but greater than random-access memory. Other relatively recent memory implementation additions are the floppy disk and magnetic tape cassette which represent a different way to package and utilize magnetic media. Naturally each configuration addresses some applications very effectively, but an improperly applied memory device can significantly reduce overall system efficiency.

The impetus of digital storage development has been the demand to make storage capacity bigger, access faster, and cost-per bit cheaper. For many years, numerous technological areas have been actively investigated in hopes of developing new devices and techniques which would achieve these objectives.

One major area of development activity has addressed electron beam memories (EBM) and has fluctuated between periods of enthusiasm and despair. The small size of an electron beam provides a potential for high digital data packing density; however, materials technology does not easily yield devices which compete with magnetic technology. However, recent refinements in EBM storage media have significantly improved leakage characteristics which affect long term data storage and improved high voltage power supply components have allowed electron beam addressing problems to be overcome. As a result, as EBM with 10 to 30 megabits of storage capacity is projected to be commercially available this year (1976). The unit is anticipated to be a disk replacement and will have storage costs comparable to magnetic disks but with improved performance characteristics, primarily reduced access time to stored data. Hopes of using EBM technology in large scale memories having (10^{12}) to (10^{13}) bits of storage capacity still exist in certain segments of industry, but near term utilization within this decade seems remote.

Another technology being actively pursued is the magnetic bubble memory. This technology offers significant potential but is best summarized as being still in the research stage. No applications oriented device is anticipated this decade.

Optical memory technology is a third highly active area which offers substantial potential but which has been handicapped by materials technology. During the past several years a considerable effort has been undertaken by industry to apply optical techniques to a broad spectrum of memory and storage applications. The research is directed toward both intermediate-capacity, fast access time read/write memory applications as well as the large-capacity, longer access time read-only storage devices. Read/write memories have not yet emerged from the research laboratory, since efforts have been hampered by the unavailability of suitable materials which are needed to configure several key memory components.

The prospects for read-only optical memories are significantly better because problems associated with high-speed input data formatters and reusable storage media are obviated. Optical memories using metallized millar strips have been commercially available from Precision Instruments Company and read-only optical memories using standard photographic film are currently in various stages of development by other companies.

4.2 Storage Characteristics

The two most widely used performance measures for memories are capacity and access time. Clearly there are many other factors such as transfer rate, size, power consumption, interface ease, reliability and reproducibility which may play equally important roles in characterizing memory performance.

Figure 4 shows conventional memory technology state of the art in terms of capacity and access time. Technology ranges from the relatively small but fast semiconductor memories through moving head disk memories to the larger and slower bulk storage devices such as magnetic tape. Clearly most memory and storage technology is confined to magnetic phenomena. The exceptions to the magnetic dominance are at the low-capacity, fast access end with semiconductor technology and at the large-capacity, slow access end with the IBM 3850, the Ampex Terabit Memory, the Precision Instrument Model 190 bit-by-bit optical memory and the Control Data Corporation 38500 mass storage systems.

The trends in memory and storage technology indicate a gradual (although sometimes rapid) shift toward larger and faster devices. Memory trends also indicate a decrease in cost per bit of storage. The significant reduction in semiconductor memory cost is a most dramatic illustration of this characteristic.

When determining memory cost, both the total system cost and the storage media cost must be considered. Conventional computer magnetic storage system costs range from $2(10^{-2})$ to $6(10^{-2})$ cents/bit and storage media costs are approximately 10^{-7} cents/bit. If one considers only on-line storage, an increase in capacity means that additional hardware must be added; therefore, the cost per bit remains relatively constant as capacity increases.

Mass digital storage systems are currently available from industry and provide storage capacities up to 10^{12} bits with some companies claiming 10^{13} system capacities. Costs for these systems average around $2(10^{-4})$ cents/bit and, as would be expected in a competitive environment, costs are relatively consistent between manufacturers.

4.3 Storage Hierarchy

A multiplicity of data storage devices is utilized to solve the file system's storage requirements. As a result, data storage is distributed over a network of storage devices whose characteristics range from high speed and high cost-per-bit to low speed and low cost-per-bit. The network of storage devices is configured into a hierarchy which utilized high speed memory to store those data elements currently being processed and low speed memory for data entity storage.

As the file's memory capacity is expanded, devices are employed which physically must access increasingly larger blocks of data for each storage or retrieval request; hence, data entities must be further assembled into larger ensembles. This process of concatenating data ensembles into larger data segments also forms a logical data hierarchy which must overlay the storage hierarchy.

One extreme of the storage device hierarchy is characterized by the computer processor's data register which provides high speed data element access. The hierarchy progresses up through random-access core or semiconductor memory, to random-access disk or drum storage and finally to large scale mass storage devices which are typically magnetic tape oriented with storage capacities in the 10^{10} to 10^{12} range. All storage devices within the hierarchy are normally read/write devices employing magnetic technology to accomplish data storage.

A recent addition to the storage hierarchy has been the archival mass memory. Since magnetic media suffers degradation during readout and over extended storage, the need for archival data storage is gaining urgency. To date, this need has been met by optical memories using bit-by-bit recording techniques. Holographic techniques, however, offer more cost-effective approaches. Holographic storage devices are currently operational in prototype form and one system will become fully operational within the next year. This system and other holographic mass storage systems under development by Harris Corporation are discussed in a subsequent paragraph.

A common way to evaluate storage hierarchies is to establish a generalized information creation task which is then executed. Since this is done after the file system has been designed and implemented very little can be done to optimize storage hierarchy. The literature defines numerous analytical hierarchal memory design approaches which

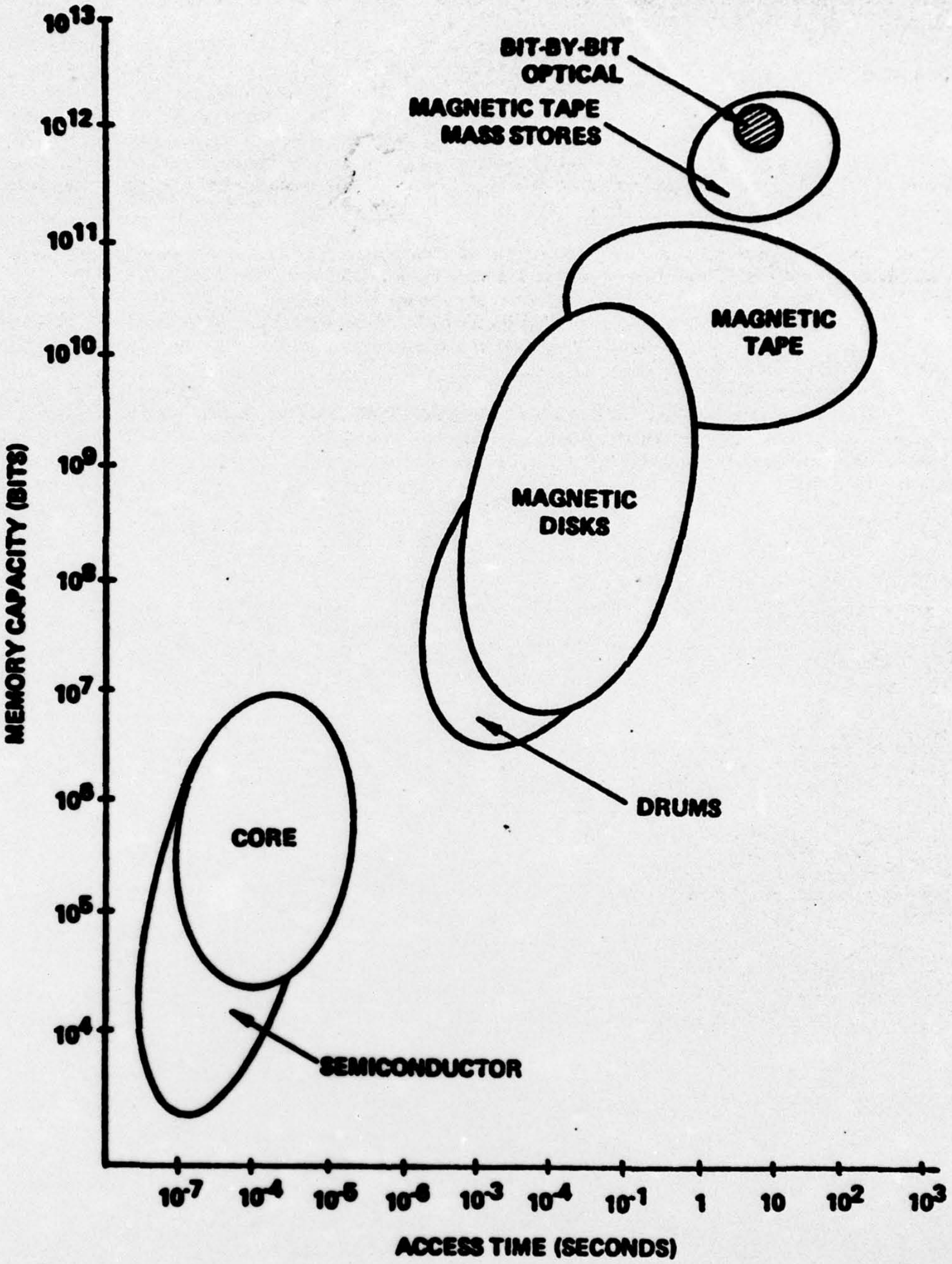

Fig.4 Memory technology characteristics

can be employed by the file system architect. As with the design of other file functions, the degree of optimization of the file storage function is directly dependent upon the effectiveness of the file system's operational objective definition.

4.4 Read-Only Optical Memories

Read-only holographic memories typically use film as the recording media. Once exposed, the film record is removed from the recorder, developed by normal techniques, and placed in a holding area until data retrieval is required. If any portion of the recorded data must be changed or updated, the entire record must be re-recorded and replaced within the memory. Read-only memories, therefore, are ideally suited for archival applications where updating is relatively infrequent.

Recent advances in materials and components have allowed the production of prototype holographic memories as is demonstrated by several special purpose hardware systems being developed by Harris Corporation's Electronic Systems Division. Synthetic holography has been successfully applied to the storage of digital data in the Human Read/Machine Read (HRMR) System developed under contract with the Rome Air Development Center. A research prototype, shown in Figure 5, was delivered in May 1973 and an engineering prototype version is currently in the final stages of fabrication.

The HRMR System addresses the document storage, retrieval and dissemination problem which is impacting both government and industrial complexes having large document data bases. The HRMR concept is based upon annotating a standard microfiche with the digital equivalent of the associated images. Optical readout of the digital data directly from the microfiche facilitates storage, retrieval and dissemination of data to both local and remote locations.

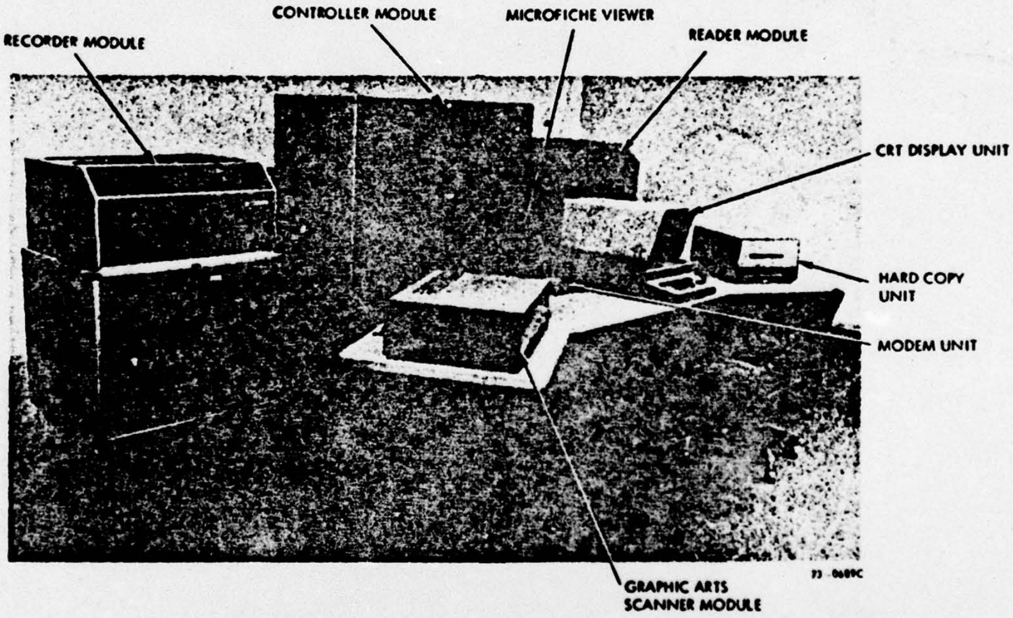

Fig.5 HRMR Holographic memory research equipment

A direct extension of the concept is the full utilization of the microfiche film chip for digital data recording. Thirty megabits of user data per microfiche film chip is presently being realized at a packing density exceeding one megabit per square inch. Since this packing density is significantly below theoretical limitations, considerable improvement can be anticipated as components and techniques are refined. Further, the synthetic recording technique has been shown to be compatible with the developing dry silver film technology which eliminates wet film processors.

The HRMR engineering prototype system collects microfiche film chips into a mass data store which has a maximum capacity of $2(10^{11})$ bits. A physical data block size on a single microfiche chip is approximately 433 kilobits and represents the smallest addressable and retrievable physical data segment. Because of the chip rather than tape media format, data accessibility is enhanced; any physical data block within the total store can be retrieved in less than 15 seconds. True archivability of the standard silver halide film recording media and nondestructive readout are additional advantages.

While the use of synthetic holography for storage of digital data on microfiche provides a solution to some mass memory requirements, different recording techniques and physical record formats are more suitable to other types of applications. For example, the storage and retrieval of digital data in very large data records at extremely fast recording and readout data rates can be best handled using roll film and interferometric holography.

As with magnetic tape recorders, the large supply of continuously moving recording media allows very large (i.e., tens to hundreds of megabits) data records to be recorded and played back with little interface buffering. Roll film formats also allow sustained data processing at hundreds of megabits per second. Thus, holographic recording on roll film offers an extension of the large data buffer capabilities now offered by high speed instrumentation-type magnetic tape recorders. Currently, single transport magnetic tape recorders can operate at recording and playback speeds of up to 80 or 90 Mb/s and can store data at a linear density of about 600 Kb/inch on one-inch wide tape. In comparison, holographic techniques can be used to record and reproduce digital data on single transport devices at several hundred megabits per second at linear packing densities that are at least six times greater than now practical with magnetic tape.

The Wideband Holographic Recorder Exploratory Development Model, also under development by the Harris Corporation Electronic Systems Division under contract with the Rome Air Development Center, uses roll film format and an interferometric recording approach. An operational breadboard has demonstrated the recording and readout of data at rates up to 600 Mb/s. Using interferometric Fourier transform holography, about $3(10^{11})$ bits of data can be recorded on a 5000-foot roll of 35 mm film. At recording rates of up to 500 Mb/s, nonstop recording could be sustained for approximately 9.5 minutes. Readout rates reduced by 10:1 or 100:1 from record rates are easily implemented. Although recording is readily accomplished using roll film supplies, once recorded, the film can be segmented and cassette mounted when faster, more random access data or distribution of duplicate data packs is desired.

Section V

DATA RETRIEVAL

5. DATA RETRIEVAL

The collection, conversion and storage of data elements collectively make up what is commonly referenced as a "data base", although the term is somewhat ambiguous and ill-defined. If one were to ask an organization's senior level manager what comprised his data base, a typical response would suggest that only machine-readable digital data was included. In actuality, an organization's data base is much more complex and includes microfilm and paper files, as well as those "special" desk files of individual personnel throughout the organization. It also includes the hardware facilities and people used to store, process and transfer data elements.

Data is very much an organization's resource which must be carefully preserved and managed. Like cash resources, data is useless if it is unavailable when needed. All too often, data is integrated into specialized functions of a given department or a given individual. When a need suddenly arises to utilize the data in other areas, it is often frustratingly difficult if not impossible to access the required data elements.

Data base management is integrally associated or is synonymous with data access and the successful management of data is crucial to the success of any organization, regardless of whether that organization is a government, company, or individual. Data management includes not only the formatting of data and its manipulation, but also the control and allocation of all file system resources: firmware, software and personnel. Unfortunately, data management is often restricted to just the control of data files by a software system and does not encompass the total file system.

The management requirements associated with large data files has become so complex and critical that a new technology area is emerging: the science of Information Management. Previously, procedures and techniques of this science have evolved in a haphazard and uncoordinated manner. Each data management application within each organization has developed discretely from others and has produced great waste and inefficiency. Only recently have unified approaches been documented. Applications techniques are also just beginning to materialize in the form of hardware systems and electronic data processing software.

5.1 Data Base Management

The most common approach to data base management is to store data elements along functional lines of the organization. Even within this structure, data is organized around special activities of the functional organization. As new activities are identified, redundant data is created to satisfy the new requirements. Similarly, if another level of organization needs access to the data, the data is copied and transferred. A typical office is a perfect example of the redundancy associated with human-readable paper records; each individual must or strongly feels that he should have his own personal copy of key memos, correspondence and reports. The fundamental reason for this attachment to redundant files is accessibility. Redundancy can be eliminated by means of a management system utilizing centralized files; unfortunately these are often difficult and time consuming to access. To be effective, therefore, any data base management technique must make data accessible while still accomplishing a primary objective of reducing redundancy within the file system.

Since data exists in either human-readable form or machine-readable form, data bases can be and are configured around each form. The major human-readable form of a data base is the micrographics files, the major machine-readable form is the electronic data processing, digital data base. Naturally technology of both areas can be merged to form a hybrid data base which can provide unique advantages in special situations.

The most common data base form is the digital data base which facilitates the processing of data elements into information and the dissemination of the information to remote locations. The digital data base can be configured into a self-contained facility which can be accessed only by programmers or it can be oriented around a specialized computer language which allows easy access to and manipulation of large quantities of data by nonprogrammers. This specialized software is called the Data Base Management System (DBMS).

Commonly available data base management software systems address only a limited segment of data base types such as accounting, inventory control, and other commercial functions. Specialized systems are being developed to address applications unique to specific professional areas such as the medical and legal professions. The big gap in data base management software is in the scientifically oriented data base. These applications are usually characterized by large, variable length data elements and by uniqueness; hence, scientifically oriented file systems usually generate their own management techniques which satisfy individual and unique access requirements. The ultimate objective of these management techniques are no different from other applications areas; i.e., the objective is to eliminate data element storage redundancy and to facilitate data element access.

5.2 Management Systems Software

A data base management system (DBMS) software package usually is co-resident with a computer's operating system and serves to intercept and service all input/output requests for data entity retrieval and storage. Consequently, file security and integrity procedures are easily implemented within the DBMS package. Applications programs, which are a digital file's primary information generator, access the DBMS facilities by means of macro-type instructions which define new files, establish new data hierarchies or retrieve old files and hierarchies for processing. The DBMS facilities may be accessed both by normal host language compilers such as COBOL or FORTRAN or by special DBMS applications programs which allow a nonprogrammer to easily manipulate the data base.

A multitude of commercially available DBMS software packages exist and a non-exhaustive list is provided in Table 1 to illustrate this fact. Each package provides distinct characteristics which can effectively accommodate certain categories of file systems. Some packages are machine oriented while some are machine independent. Naturally, the machine independent versions provide an additional measure of flexibility if hardware changes are anticipated. Also, the machine independent packages are usually generated by non-hardware oriented vendors and must be efficient and cost-effective if the supplier is to stay in business.

TABLE 1

Commercially Available DBMS Software

System Acronym	*Vendor Source*
ADABAS	Software AG
CICS	IBM
Data Com/DB	Computer Information Management Corporation
DBMS-10	Digital Equipment Corporation
DMS-II	Burroughs Corporation
DMS/90	Sperry Univac
DMS 1100	Sperry Univac
IDMS	Cullinane Corporation
I-D-S/I	Honeywell Informations Systems
ISM-VS	IBM
IMS-2	IBM
INQUIRE	Infodata Systems Incorporated
Model 204	Computer Corporation of America
System 2000	MRI Systems
TOTAL	Cincom Systems

Without exception, generation of new software for any purpose, is an expensive undertaking. Utilization of existing software is less expensive, less time consuming, and less risky than the do-it-yourself route. Consequently, commercially available DBMS software is recommended when implementing or updating a file system.

5.3 Implementation Considerations

A DBMS system is only as good as the facilities, both software and firmware, which are available to it. Although applications software programs are normally involved in the process of information generation, the human who initiated the retrieval procedure is also involved. In many instances, and particularly in the access of dynamic files, the human is very actively involved. This individual performs a real-time analysis of the information presented to him. From the knowledge he gains, he introduces new data elements into the file system or initiates additional information generation activities within the file system. Obviously the file must be highly dynamic as the newly introduced data elements should (must) be available in real time for subsequent processing. This is not an easy task for most general purpose computers, especially large scale computer systems which tend to be input/output constrained.

The retrieval function, therefore, must not only retrieve and transform data elements into information but also must present this information in human detectable form, normally human-readable form. Alphanumeric printers form one class of output devices and range from a simple teletype to a high speed printer. This class also includes CRT terminals. Another output class is the image output device which includes the graphics terminal, television display and facsimile reproducer. Other less common classes of output devices stimulate the human's audio, smell or touch sensory systems.

In addition, implementation considerations of the retrieval function include presentation of the data at the place where needed. Often this implies remotely locating the output terminal. The implementation of even this capability has been facilitated by the development of modems which allow remotely located devices to interact over standard communications networks.

Section VI

CONFIGURING THE FILE SYSTEM

6. CONFIGURING THE FILE SYSTEM

When an organization identifies a need to establish a file, it typically strives with great diligence to implement the file system using general purpose electronic data processing (EDP) equipment which exists within the organization. There are certainly strong economic factors for making such considerations. Unfortunately, however, the common approach taken is one of tailoring and constraining file system requirements around current equipment units rather than one of determining how and what existing equipment can be used to optimumly implement total file system objectives. Naturally, if the common approach is taken, operational results do not meet anticipated performance specifications. It is, therefore, informative to review cursorily the development history of general purpose EDP equipment and the typical evolution of file systems which are processed by this equipment.

Computers were first configured to replace manual activities in accounting functions. As their versatility grew they expanded to other functional areas, but normally these computers still processed a single job stream in serial fashion. The processing unit of these early computers (and in many of today's computers too) was idle a majority of the time waiting for the input/output (I/O) facilities to supply data or procedures. This condition caused improved I/O networks and peripheral devices to be developed with faster I/O transfer capacities. Processor unit improvements continued in parallel with I/O improvements such that typical system configurations were still I/O bound.

Availability of sophisticated software monitor systems which introduced memory partitioning and multitask processing significantly helped but still did not fully alleviate the I/O problem. In general, EDP systems continued to grow bigger and to increase the capability to process larger quantities of data, but jobs were still serial or batch processed and sophisticated algorithms were used to schedule jobs such that I/O throughput was optimized.

As seen by this discussion, a major disadvantage to the big EDP system was accessibility. Users submitted jobs and went on to other activities until results were available, minutes, hours, or days later. Typical changes were then made to the job and it was resubmitted. The cycle continued until adequate answers were obtained or until frustration caused inadequate, hence, incomplete knowledge, to be tolerated. The "time-share" approach was then developed which allowed multiple users to effectively use the EDP system simultaneously and with "immediate" response. Unfortunately, when numerous users simultaneously accessed the EDP system, I/O limitations again were encountered and immediate response degraded to seconds or minutes. Naturally, even this degraded response was significantly better than the previous batch processing approach, but human nature has a way of quickly expecting the best response at all times. Special activities are even established around best performance and it then becomes a necessity.

As files evolved in an organization its general purpose computer system was most likely utilized in some aspect of the file's processing activities. The EDP equipment also continued to be utilized for routine data processing activities associated with the normal functions of the organization. When new processing functions were identified or when new file related functions were implemented, storage was expanded, more I/O channels were added (hence more peripherals), a faster processing unit was incorporated, remote job entry capability was added and even time share features to remote access terminals may have been added. The ultimate feature to be considered was the mass store device. The EDP facility typically grew into a big inhomogeneous monster full of redundancy and inefficiency.

To help solve these problems the user was finally forced to implement some form of a DBMS to handle its data files. As noted above, DBMS systems are compatible with and operate in conjunction with computer operating system software. The addition of a DBMS then becomes an expansion in software just as the addition of another peripheral is an expansion in firmware. In many situations the DBMS does provide a viable solution and allows file manipulation tasks to be handled on existing EDP hardware in what might be classified as a centralized, single processing unit system configuration. In many other situations, the DBMS does not provide an adequate solution primarily because generalized EDP equipment, often configured from a single vendor's product line, is applied to handle very specific file system problems. Additionally, routine computational functions may be simultaneously competing with the file system for EDP resources.

The physically immense, dynamic file system design requires that special attention be given to the I/O structure of the system implementation. As noted above, centralized systems funnel all I/O requests into a single processor unit. To handle the I/O throughput problem which is a significantly critical area of the centralized system, additional EDP equipment can be added to concentrate and stage I/O transactions to the central processor.

Having introduced I/O concentration into the EDP system, it now becomes highly economical to locate the concentrator in the general area of the peripheral devices which feed it. In the case of remote access terminals, the concentrator may be physically separated from the central site by a significant distance. What has now happened, is that the centralized EDP system has been slightly decentralized.

Although economic factors were probably the main reason for initial decentralization of I/O facilities, it was quickly discovered that portions of all file functions could be decentralized to remote locations such that total file system response was drastically improved. The limit of decentralization is the distributed file system which applies the "divide to conquer" concept to overcome I/O constraints of the centralized concept. In the distributed system, those portions of the file functions which are closely related and dynamically interactive are segregated into satellite subsystems. The satellite subsystems intercommunicate to allow data element interchange where required.

Satellite subsystems do not necessarily have to be large scale EDP systems. Fortunately, as EDP systems grew in size and capacity, many applications were identified which could more effectively use a small processor with limited performance. This was the impetus for the minicomputer technology development which now yields minicomputer systems having data processing power far superior to so called large EDP equipment of a decade ago.

The evolution of data processing devices is still in process and technology has now yielded the microprocessor which is typically used in non-dynamic programming situations. File systems implementation alternatives, therefore, include large scale, mini, and micro computer configurations.

Section VII

CONCLUSION

7. CONCLUSION

A trend in the world today is to continuously collect more and more data in increasingly bigger files. Those organizations having the biggest physical data collection, however, are often faced with the same file manipulation problems as organizations having relatively small files. This can be attributed to the fact that proper file manipulation equipment, both firmware and software, has not been utilized in the file system implementation configuration.

To assure that a file system meets performance expectations, an organization must establish precise file system objectives and procedures. All functions of the file must be clearly defined and all file states must be identified. Implementation devices may then be overlayed on the definition and performance parameters of alternate approaches may be traded off within each file function area.

The above statements are not to imply that all problems in the handling of a large data mass have been effectively solved. Significant problems still remain to challenge available technology which often is found lacking in required capability. One especially critical area in which technology must be advanced is the area of document conversion into digitally processable formats. Document conversion problems encompass not only textually oriented documents but also maps, graphs, photographs, etc.

Accuracy and conversion efficiency are still fundamental and overwhelming problems even though substantial technical activity has been expended for many years in both areas. For example, character recognition is still limited to basic fonts and requires operator intervention and monitoring. Graphic arts conversion is typically slow even for automatic document digitizers which yield tremendous quantities of data. Manual digitizing techniques yield more efficient data formats, but are substantially slower and often inaccurate. The problems with map conversion are basically a composite collection of all of these problems compounded by the large fundamental data volume associated with a map. Although map conversion and storage is currently tasking available technology beyond its limits, the need to digitally store and process image data is rapidly reaching a point of urgency. Unfortunately, image data volume is at least an order of magnitude larger than map data.

Although numerous techniques and equipments have been developed, none represents a true panacea for the document conversion problems. Optical techniques are possibly offering the greatest potential and are being actively explored. The fallout of this activity can be expected to continuously improve current techniques.

Document conversion is not the only area in which technology can be advanced. Data storage and data retrieval are both areas in which technology is striving to provide improved methods and devices. Data storage has had several major breakthroughs as noted in Section IV. Data retrieval, however, is still an area which needs improved methods Most current retrieval schemes are based on the generation of cross-reference indexes. These work efficiently as long as the data can be accessed by one of the cross-referenced parameters which was established at file definition time. Naturally this is not the normal case: hence, some rapid mechanism for providing an efficient global search of the data base for any parameter must be developed. Also, as noted in the previous section, generalized file structures which facilitate data retrieval and processing are still needed for many classes of data storage systems.

This lack of readily available and efficient techniques and equipment further emphasizes the need to accurately define a dynamic file's purpose and function. Only then can implementation techniques be traded off effectively such that realistic approaches are established.

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14. Abstract

This report discusses what constitutes a file system, how it evolves and where special emphasis needs to be placed in its design and implementation. Although generalized file systems are considered where possible, digitally oriented files are preferentially covered. Emphasis is also placed on the physically immense files.

The file functions of collection, conversion, storage and retrieval are presented and the file cycle associated with data element is discussed on the basis of a generalized file system. Also discussed are file system objectives and their importance in the definition of an implementation configuration.

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