P Dist.

June 11, 1971

PARC Papers for Pendery and Planning Purposes

Summaries

Dave Damouth: ANALOG INPUTS TO INFORMATION SYSTEMS

John Urbach: ARCHIVAL STORAGE

J.G. Mitchell: CONSIDERATIONS FOR FUTURE OFFICE SYSTEMS

Alan Kay: DISPLAY TRANSDUCERS

Summary — Analog Inputs to Information Systems

Dave Damouth

Much information is in a form unsuitable for direct input to data manipulation machines. Handwritten or printed documents and the spoken word are two important examples. Conversion to digital form is necessary to allow computer transformations and storage and also can increase the reliability and reduce the cost of transmission and repeated reproduction of information.

Optical Charater Recognition (OCR) is a special case of bandwidth compression in the document scanning part of the fascimile process. Low cost computer logic and storage implementation of scanned image analysis plus the existing population of typewriters and paper documents implies widespread use of OCR and FAX through the next decade. Increasing availability of on-line information handling capability will cause OCR and FAX use to diminish in the 80's.

Automatic conversion of natural speech to digital machine readable form will not be practical until the 80's. Specialized speech input devices will increase in usefulness during the 70's.

Devices to convert position and motion into digital form on-line will find increased application this decade.

ARCHIVAL STORAGE

John C. Urbach

Summary

Archival memory can be defined as being inherently expandable and stable, but inaccessible for direct operations by central processors. It includes both digital and analog forms, and is used both as an adjunct to computer main memory and as storage for images and sound records intended for direct human use. These two uses can be expected to coalesce to an increasing degree during the 1980's.

On the computer memory side, archival memory is less desirable than main memory, but technological, cost and design considerations make it essential for the foreseeable future. To be useful, it must have a cost/bit substantially below that of main memory.

Magnetic tape technology promises significant improvements during this decade, and will eventually approach a cost of 10^{-5}¢/bit on-line and 10^{-7}¢/bit off-line. This will be combined with access speeds of a few seconds (well under ten) to files of 10^{12} bits, achieved largely by automation of tape handling systems.

Optical storage systems may become more competitive with tapes in this field, either by development of effective read-write optical storage materials or by use of very high density read-only storage which might provide cost/bit between one and two orders of magnitude lower than tape. The latter systems would supplement rather than supplant read-write storage.

Information, including alphanumerics and, to a lesser extent, graphics, will increasingly be stored and transmitted in digitally encoded form. Advantages in the cost of encoded storage and transmission, in availability for further machine manipulation, and in minimizing errors all point toward more digitizing of information. The decreasing cost of logic will make the requisite coding and decoding operations economically advantageous in many applications.

Nevertheless, considerations of both equipment cost and the nature of original image sources will favor the use of analog image stores in certain applications. These will center on one-way dissemination of information from source to user in situations, akin to publishing, in which further machine processing is not anticipated. For maximum compatibility with both present and future use patterns, a human readable - machine readable format for data will often be desirable. Systems using such a format will be more immune both to initial user resistance and to early obsolescence.

A factor now emerging which has great potential importance for the 1980's is the development of low cost video recording and playback systems. Such systems, whether magnetic, optical or mechanical in nature, share an extraordinarily low cost/bit for both on-line and off-line storage, which can approach 10^{-7} and 10^{-9} cents/bit respectively. Readily adapted to many other uses than video, including both analog and digital storage, these systems represent an already-developed technological resource which can have a major impact on archival storage and information dissemination.

Considerations for Future Office Systems

A Summary

J. G. Mitchell

This report examines hardware and software features of possible offices of the future. A view of an office as a system of processors (human and otherwise) communicating knowledge to one another is espoused, and a set of principles is developed in the context of current offices to be applied to the study of such systems.

The examination of future offices encompasses man-machine interaction, personal terminals for using the office, functions available to the office's human processors, and the scope of a software technology sufficient to support the system. Access to shared information and privacy considerations for such accession are also discussed along with the possibilities for networks of offices. Finally, a starting point for developing a sequence of future office systems and its present-day and projected 1980 economics are outlined.

Display Transducers

Alan Kay

The minimum acceptable display terminal in 1980 will have the following characteristics:

1. 1024 x 1024 picture elements of color/b&w, 90 $\sim$ 100 lines/inch.
2. 90 $\sim$ 100:1 dynamic range with 64 shades of grey.
3. TV compatible, picture storage for 10 minutes, selective updating.
4. Portability: flat screen and <10 lbs. Max dimension - 1-1/2" x 12" x 15".
5. Local computation and buffering provided by powerful LSI chips and cassettes.
6. I/O includes telephone, picture-phone and TV bandwidths for analog and digital data. Keyboard, pointing devices, stereo, etc.

Several thousand documents of mixed digital and analog information will be stored and used locally. Windowing and high resolution allow Xerox like quality and larger effective surface.

The super display will have more of everything, will not be portable, (but part of it might be worn) and will mainly differ from the minimum device by offering much more real time computation for TV frame rate simulations.

Today's technologies are not quite extrapolatable to 1980. CRTs have focusing problems and are bulky. The Crystalflex is slow or requires much power. The eidophor is too large and messy. LED panels are too expensive and draw much power. The plasma display is flat, but requires voltage switching and has poor modulation of grey scale. It will appear in a color/1024 x 1024 version which will allow spatial half toning. Cost will go to $10 a panel. A small modulated laser,raster scanned onto a Ruticon, using Schlieren projection, appears to be the best candidate so far. The main disadvantages appear to be power and frame rate.

The computer mediated display should be well on its way towards supplanting paper in 1980, to become the main source of <u>all</u> kinds of visual information.

Papers

Dave Damouth: ANALOG INPUTS TO INFORMATION SYSTEMS

John Urbach: ARCHIVAL MEMORY

James Mitchell: CONSIDERATIONS FOR FUTURE OFFICE SYSTEMS

Gary Starkweather: ADVANCED OUTPUT/PRINTING DEVICES

Richard Shoup: SOME NOTES ON LOGIC AND NON-ARCHIVAL MEMORY FOR COMPUTER SYSTEMS OF THE 1980'S

William Gunning: PBX SUMMARY

Alan Kay: DISPLAY TRANSDUCERS

ANALOG INPUTS TO INFORMATION SYSTEMS

D. Damouth

I. Introduction

Right from the beginning, one must admit that analog devices tend to be slow, error prone, and clusmy, compared to digital devices. Their reason for existence is that man himself (at least in his external manifestations) and most of his works, is inherently analog, and the best communications channels available into and out of a man are currently analog. (Perhaps when we can connect to individual nerve endings or neurons, we will eliminate all need for analog devices - that is a subject for the "Technology of the '90's). It by now is a truism that the medium has a strong effect on the message, but nevertheless, it requires reemphasizing in this context - Rembrandt, stripped of his brush and canvas, and given a keyboard, might not have been a lesser artist, but he would certainly have been a different artist. Analagous, although perhaps less dramatic, effects, must opperate in our business communications where face-to-face conversation seems to be essential to most important business negotiations. By definition, we are unaware of many subliminal clues that are nonetheless an important part of the communication process. Picturephone helps but needs extended definition and field of view control.

Analog imput devices allow humans to communicate, either with each other through a machine-controlled system, or directly to a machine, in a manner that is somehow easier, more natural, or requiring less training, than is the case with structured digital devices, such as the keyboard. A basic parameter in information systems is the channel capacity, and it is interesting to note that the channels from the computer today are an order of magnitude faster than the channels to the computer from humans. For example, a man can read computer output at up to 2000 words per minute, or listen to the computer speak at up to 250 words per minute. On the other hand, he can type the same information into the machine at only about 75 words per minute (and even this requires a lot of training). At present he can speak to the computer only in a limited, unnatural way.

Thus there is a significant bottleneck in the real-time channel from humans to computers. .

Graphic or relative position information is a somewhat different subject from the word related data just considered but here we are not significantly better off. There are now a number of devices that rather efficiently digitize analog position in real time - the various light pens, digitizing tablets, Englebart's mouse, etc.

II. <u>Analog Input Devices of the 1980's</u>

<u>Facsimile:</u> By facsimile, we presently mean the unintelligent, element by element, capture of an analog graphical (alphanumerics is a special case) input image. The purpose is either to store it for later re-creation, or to transmit it to another human. Facsimile devices are being given increasing engineering attention, and this can be expected to increase even more over the next few years, resulting in a steady reduction of cost/performance ratio. At the same time, the communications channels and digital storage devices are becoming cheaper (as discussed elsewhere) giving added impetus to the hardware developers. Because of its broad applicability (electronic mail in the most general sense, image storage and retreival a la Videofile and Transfile) and compatibility with traditional human ways of communication (handwriting, typewriters, photographs) facsimile has a strong appeal to many people, and thus will probably thrive into the 1980's in spite of inroads into special applications by other technologies.

Although digital data caputre at its source, rather than from pre-imaged pieces of paper, will grow rapidly, there will continue to be a large volume of information that cannot be captured at its creation, either because of economics or because of human prejudice (e.g. picture postcards, sketches on restaurant napkins, handwritten love letters, marginal notes on preimaged papers, etc.). Given a sufficient volume of these things to support a large number of facsimile scanners and printers, other more efficient but more specialized devices may have trouble competing except in special cases.

One thing that will help facsimile compete is the very low cost that can be projected for redundancy reduction devices (bandwidth compression). It is safe to say that a device containing logic comparable to a small computer, a fixed program, and enough memory to do real time analysis on a small peice of an image (say a few thousand bits) will be such a small part of the overall cost of a piece of facsimile hardware that it will universally be included and will yield an order of magnitude improvement in transmission time or storage requirement.

Because of the increasing cost of human labor, automation features on this class of devide will become increasingly important. Further, social scientists predict a decrease in day-to-day mobility of the working population, because of the increased crowding and resulting loss in efficiency in transportation. This may reduce the need for portable devices, again suggesting that more or less fixed, but very automated, devices will be of the greatest importance. (Again, one suspects that there will always be a special class of highly mobile people - the question to be answered is simply how big is this class).

OCR: OCR, perhaps even more than facsimile, is an interim technology, which will someday be displaced when people do all of their communicating and information recording "on-line" to a data capture machine. It is doubtful if a change of this magnitude can affect a large percentage of the general population during the 1980's, although it may affect a large fraction of the business offices in this time frame.

Forecasts indicate a tremendous growth for OCR, continuing at least through the 70's. This will be helped by the great reduction in cost of digital logic and optical scanning devices, which will allow simple OCR input terminals which will cost approximately the same amount as bandwidth compressed facsimile scanners. In both cases, the major cost will be the paper handling rather than the elctronics. Speeds will be limited only by the paper handling device, and can thus range from hundreds of characters per second for the cheapest devices to many thousands of characters per second for devices with more elaborate mechanical systems or larger arrays of inexpensive photosensors. All the input automation features will be important, as noted under facsimile. The main use of these devices will be to capture alphanumerics generated on the office or home typewriter, allowing efficient storage, processing, and transmission. On economic grounds it is difficult to imagine this population of typewriters being displaced by anything else until well into the 80's.

It is entirely possible that OCR and facsimile techniques will be combined into a single input device, which operates in OCR mode for most efficient bandwidth compression but automatically switches to facsimile mode whenever it fails in a recognition task. This would occur when it encountered either graphics, unrecognizable characters, or a signature for example.

Automated Speech Recognition (ASR): This is presently the fastest output channel from a human. Thus, a great deal of money will continue to be spent in development of machines capable of "understanding" the voice. Informed estimates are that it will take at least another decade to solve the general problem of understanding natural connected speech. Limited vocabulary, disconnected speech devices have already been built, and can be expected to improve steadily. They should find widespread applications in capturing dictation in fields where the vocabulary is inherently limited such as (a) programming languages, warehouse inventory control, catalog inquiry, (b) in cases where an additional channel is needed in parallel to the hands (command and control in complex situations), (c) or for handicapped people (e.g. paraplegics).

Pattern Recognition: Here, we refer to recognition of more abstract graphics, and begin to enter the field of "artifical intelligence". Much research is underway on various aspects of this problem and some useful fallout has already occureed in highly specialized applications. It will probably be at least a decade before applications begin to have significant impact in market areas of interest to Xerox.

Manipulators: Devices have been built, and are in routine use in certain industries, which capture fairly generalized motions of human hands, or even of the entire body. Servo and digital control technology is advancing rapidly and will make such devices more precise and much less expensive. It is difficult to see how these would affect the office, but rather easy to imagine how they would affect the factory (machinists, assemblers, stock clerks), automibile drivers, and others who manipulate solid objects.

Similarly, anyone who manipulate multi-dimensional concepts or abstract objects, may find great utility in this multidimensional input channel. It is possible to "handle" and manipulate a three dimensional "picture" within a computer, with visual and tactile feedback, in a way exactly analagous to how a real object would be manipulated or altered (without, of course, being subjected to the physical restrictions of working with real objects). In this context it is important to note that these devices add new dimensions to the communication channel. Not only do they allow three dimensions of physical motion, but also can capture time derivatives of the motions. Velocity in human movements and speech contains considerable information.

Conclusions: One can expect the office of the 80's to contain at least some of the following analog devices: an inexpensive OCR scanner, for rapid transmission or computer input of documents typed (or hand-printed) off line; a facsimile scanner (possibly combined with the OCR scanner) and printer for transmission and/or storage and retrieval of generalized documents (high resolution, bandwidth-compressed), a voice-controlled typewriter or computer input channel, for rapid (twice as fast as typing) dictation of synthetic languages (such as Fortran) and a computer-controller alphanumeric and graphic display system, with analog input in the form of a six-dimensional (x,y,z position and velocity) manual manipulator. From an economic standpoint, the off-line typewriter, together with an on-line OCR page reader which serves several typists will probably be the cheapest possible near term way of inputing information to a computer or communications system (since the typewriters are paid for). The other analog devices and the digital on-line keyboard will be used to speed up or add dimensions to the channel where this can be economically justified.

ARCHIVAL MEMORY

J.C. Urbach

1. Introduction

For purposes of this discussion, archival memory is defined as encompassing relatively slow access information storage and retrieval systems having a low cost per bit (typically under 10^{-3}¢/bit) and having the property of being expandable without encountering sharply defined physical limits. Included in the concept of archival storage is the idea of permanent or semi-permanent data retention, with cost, capacity and durability of storage all permitting such long term storage. Classic examples of such systems are file cabinets full of hard copy, and conventional libraries. Here we examine the prospects for change in archival storage and consider both traditional and computer-related storage methods, as well as possible interplay between them.

2. Archival Memory for Computers

In the context of this survey, the dividing line between central and archival memory occurs somewhere in the disk file area. The fastest disks, used with virtual memory concepts, are closely linked to main memory. In general, disk packs are too expensive and too limited in expansion possibilities to serve as archival stores in our sense. In large installations, such systems as the new IBM 3330 approach 3×10^{-3}¢/bit. XDS projects new disk system costs at half this level, and it is reasonable to assume that a cost of 10^{-3}¢/bit will be attainable in the 1980's. The significance of this is mainly that large disk files may have use as rapid access archival stores where cost is less important than short access time. It is worth observing, however, that the cheapest systems use non-interchangeable disks, thus limiting the possibilities for expansion and/or off-line storage that we regard as prime characteristics of archival stores.

Magnetic tapes currently dominate archival storage for computers. This technology has not yet reached its limit, and recent products have shown impressive performance improvements. Conventional computer tape systems offer on-line storage costs in the 10^{-2} to 10^{-3}¢/bit range, with average access times in the tens of seconds. Off-line storage costs are in the vicinity of 10^{-5}¢/bit.

Two new products have recently reached the marketplace, both based on digital adaptations of high density video recording techniques. One, Ampex's Terabit Memory System (TBM), stores information (before twofold redundant coding) at a density of 1.4×10^6 bits/in^2. A single 3800 foot reel of tape contains over 4×10^{10} bits. Average access time is kept down to the 15 second range by using one of three fast search speeds to locate data addresses on longitudinal tracks before initiating transverse readout of the data itself. The fastest search speed scans past data (while reading addresses) at 10^9 bits/sec. Although costs are hard to compare, TBM literature projects on-line user costs in the 10^{-3} to 10^{-4}¢/bit range, with off-line costs nearer 10^{-6}¢/bit.

A somewhat less sophisticated, and considerably less expensive, system based on a similar design philosophy, is the IVC 1000 digital tape system. Access times are longer than TBM's by about a factor of five, with data scanned at a rate of about 4×10^8bits/sec, but cost is substantially lower. IVC literature asserts that costs are about 3×10^{-5}¢/bit on-line and 4×10^{-7} ¢/bit off-line. In both these tape systems, average access time can be traded for capacity (by employing shorter lengths of tape) with a corresponding increase in on-line cost.

As noted at the 1971 INTERMAG Conference by R. Gentile of DOD, it is highly desirable to cut down access time to the large files. Naturally the worst delays are caused by the need for manual handling of off-line archival stores, such as tape reels. IBM's Comanche, a highly advanced, and as yet unannounced, tape cartridge system, promises major improvements in tape system performance. Each cartridge will hold over 6×10^7 bits, with total capacities of 6×10^{11} bits in a maximum size system. Access to any cartridge will be automated and will take 6 seconds, with less than one second needed to search a full tape. A high performance subsystem with lower maximum capacity will have two second access to each cartridge and about 0.4 seconds search time, giving less than 2.5 seconds maximum access time to about 10^{11} bits. Using longitudinal tracks only, this subsystem scans data at about 1.6×10^8 bits/sec. No cost estimates for Comanche are available, but its mechanical complexity and lower packing density should keep its cost above that of TBM.

All three of these systems will be old products by 1980. All but Comanche may well be quite obsolescent by then. It seems reasonable to extrapolate to fully automated tape systems having the moderate access time of Comanche, combined with larger capacity and resulting on-line costs around 10^{-4} to 10^{-5} ¢/bit and off-line costs near 10^{-7}¢/bit.

Optical Analog Storage Concepts

Although we shall return to digital storage techniques in a subsequent section, let us first consider the analog storage of information by optical means. This is the traditional form of storage, and is likely to remain with us in some versions almost indefinitely. One of the great natural strengths of this form is the parallel transfer of data into and out of a two dimensional storage medium, in contrast to the one-dimensional, time sequential serial transfer of data to and from a magnetic medium. As a simple illustration, note that about 10^8 bits of information can readily be recorded in 10^{-6} seconds, an input transfer rate of 10^{14} bits/sec. Of course development time for silver halide materials brings the transfer rate back down to a more conventional 10^7 bits/sec, but this can be transcended by novel processes.

The other natural advantage is storage density. It is easy to store over 5×10^8 bits/in^2, and far more if volume storage is used. Like high throughput, however, this great potential of photo-optical recording has not been fully utilized in practice.

Before considering the status and future of photo-optical recording, let us note that the use of paper "hard copy" as a storage medium in offices, homes and libraries, can be considered the most common form of "optical" storage. Its direct cost is relatively low, on the order of 1¢/page, hence about 10^{-6}¢/bit in uncoded form or about 5×10^{-5}¢/bit for the information content of a page of alphanumerics. Paper is rapidly losing favor because of at least three factors: its bulk and weight, which is absorbing increasingly scarce and consequently valuable storage space; its cumbersome form, ill-suited to rapid automated retrieval; and consequent upon this, the high cost of manual handling and indexing operations (estimated to average about $20 to $30/book in a library, thus nearly tripling the cost/bit in this application).

Microimage Storage

For over 100 years, the technology has been available for microphotographic storage of large files. Although microfilm has not made great inroads in the past, the rapidly worsening situation in paper storage and retrieval resulting from the "information explosion" has recently accelerated the slow movement toward microimage storage. Acting as a brake on this movement has been a severe lack of standardization in format and indexing methods. Numerous reduction ratios ranging from 10X to 250X are in common use, with the resulting format and equipment incompatibility restraining the adoption of any one approach as standard.

The increasing popularity of COM as a computer output medium has stimulated interest in microimage storage in general. Most of the subsequent comments apply both to COM and to conventionally generated microfilm.

It is difficult to obtain reliable cost comparison figures for microimage storage. On-line costs in particular are hard to determine. Off-line storage costs should ultimately fall in the 10^{-8} to 10^{-10}¢/bit range for silver halide microfilm used at the higher reductions. This is based on estimates of film and processing costs, and of the information capacity of high resolution emulsions. Some estimates have been published by Microform Data Systems (MDS) of micropublishing and dissemination costs for a distribution of 10^7 pages to 2000 libraries using various reduction ratios. These show the following results on raw (uncoded) storage: At 20X reduction (a common microfilm ratio), the total dissemination cost is 1.5×10^{-7}¢/bit; at 60X, it is down to about 3.2×10^{-8}¢/bit, and at ultrafiche ratios (150X to 250X) it is about 1.5×10^{-8}¢/bit.

These low costs argue strongly for the use of high reduction microimages for information storage and dissemination when no frequent information update is required. Ultra microforms are cheap enough to discard rather than modify. Also favoring their use is the simplicity and low cost of readout equipment. For example, a simple projection reader, whose cost may fall in the \$50 to \$500 range, is substantially cheaper than the combination of high speed video or digital tape units and CRT terminals required to convert a magnetic tape record to a human readable display. This reflects both the parallel readout characteristics of image-wise information storage, and the velocity-independent nature of optical data retrieval. The latter lends itself well to asynchronous readout concepts that are closed to moving magnetic media.

The question of motion is closely linked to that of retrieval speed. Moving film in strip form is roughly analogous to moving tape, with similar indexing and access speeds possible. Film lends itself well to fiche formats, which are in turn well suited to rapid access mechanical handling. These are especially useful at high reduction ratios, where several thousand pages can be stored on the common 4" x 6" fiche format. Any of these pages could be retrieved in a few tens of milliseconds once the fiche is in position. Thus effective data search speeds could range from about 10^9 bits/sec to 10^{11} bits/sec.

No film handling system the size and sophistication of the Comanche is available now. A Microform Data ultrafiche system can give access to about 10^{11} bits (analog form) in a maximum time of five and one half seconds. The data search speeds are 3×10^8 and 10^{10} bits/sec in the random and sequential search modes respectively. On-line costs in a typical MDS system fall in the 10^{-4}¢/bit to 10^{-5}¢/bit range. This system may be representative of an increasingly common approach. Information for human use is stored in analog form, with digitally encoded indexing information. Retrieval is handled by a minicomputer attached to one or more (up to about 100) separate systems. This utilizes low cost modern digital logic to help handle the retrieval problem, while taking advantage of the low cost of photo-optical methods for the data storage itself. A copy of some MDS literature is appended.

At present, the minicomputer costs are still a major portion of the on-line costs of most MDS installations. Further reduction in logic costs, together with refinements in fiche handling, could bring on-line costs of such systems down toward 10^{-6}¢/bit in the 1980's. Off-line storage currently costs around 10^{-7}¢/bit, and should move below 10^{-8}¢/bit in large quantity.

A manually operated prototype holographic ultrafiche system has been designed and built by the Electro-Optics Center of Radiation, Inc. This type of system can give optical performance superior to that of conventional ultrafiche with similar area reduction because it can transcend certain aberration problems of reduction and blowback lenses used in conventional systems. It also has drastically relaxed fiche position and focus tolerances, permitting use of simpler positioning mechanisms. Its main present drawback is the cost of the reconstruction laser, but possible sharp reductions in the price of blue-emitting lasers could make this approach highly competitive by the 1980's. Off-line costs of automated versions should be similar to those of comparable conventional ultrafiche systems, while on-line costs may be somewhat lower.

Holographic techniques combined with efficient replication methods can offer substantial cost savings in the storage and dissemination of information. These will be noted in the subsequent section on video cassettes.

Digitized Photo-Optical Storage

Just as magnetic tapes can be used for either analog or digital storage including audio or visual information so can silver halide films and other photo-optical recording materials. Digital storage on film is becoming increasingly widespread. It can be used either for computer mass memories or for image storage with the distinction diminishing as computer manipulation of images becomes more practical.

Early examples of photo-optical mass memories for computers include the IBM 1360, the Itek optical disk pack, and the Precision Instruments Unicon. All these store about 10^{12} bits at an on-line cost around 10^{-4} ¢/bit and with several seconds access time. Cheaper than present day magnetic tapes, they probably cannot compete against the forthcoming tape technologies, which add erasability to similar specifications.

There are three possible directions for advancing digital optical archival memory technologies. One is based on the advent of erasable photo-optical storage materials. Present examples under intensive study include magneto-optic materials, ferroelectrics, thermoplastics, and photochromics. Research and development work on such materials will continue during this decade, with possible major consequences for memory technology. One early example of development in this direction is the Ampex magneto-optic tape system, intended to surpass the capacity if not the access time of the TBM.

If reliable cycling, comparable to conventional magnetic tape, is achieved without sacrificing the convenience, information density and consequent low cost/bit of present-day photographic technology, then photo-optical storage could eventually supplant almost all moving magnetic medium technology. However, the complexity and unknown pace of the requisite materials research make it hard to predict the probability and time scale of such events.

A second direction is improved systems design for large, relatively unchanging archival stores. Here the object will be to more fully exploit the storage density potential of the photographic medium together with its greater write and read versatility, to produce storage stystems which are more cost-effective than the Unicon, TBM or IVC tapes, and at least as convenient as Comanche. Examples of this approach are suggested in the subsequent section on video cassette technology.

A third direction involves the development of medium access speed (millisecond range) optical memories to supplant current disks and tapes. Both low cost read-only memories, and more expensive read-write magneto-optic memories can utilize present day technology to achieve some cost-performance trade-offs inaccessible to moving magnetic media. The Honeywell and IBM R & D efforts on magneto-optics disk or drum systems are examples of work in this direction, and we are investigating other possibilities at PARC.

Some Information Coding Considerations

We have seen that mass archival storage technologies can be used in either analog or digital form. Data should ideally be in digital form for computer manipulation and for reliable transmission or reproduction. However, the cost of coding and decoding tends to militate against unnecessary encoding of those forms of information, such as images of natural scenes, which first are acquired in analog form. This is especially true for images, as distinct from sound or instrumentation records (see below), because of the aforementioned need for two-dimensional to one-dimensional conversion.

Nevertheless, the increased use and decreasing price of logic will lead to more and more digital encoding of information traditionally found in image form. Moreover, it is likely that much of the future COM output will be kept in a coded machine readable form, rather than produced in human readable form, since it may be subjected to additional computer manipulation at a later time. This will save the cost of subsequent re-encoding of the data.

Foremost among candidates for digital encoding are alphanumerics. Either keystroke capture or OCR techniques permit information compression by about two orders of magnitude. Run length encoding and related techniques make possible comparable compression of line drawings. Encoding of general purpose images, for which less a priori information is available, is both more difficult to implement and less satisfactory. Digitizing of these images often is done with the opposite purpose and maintains or increases redundancy for convenient manipulation and reliability, rather than reducing reduncancy for cost savings. An example of such digitizing will be used in long haul Picturephone, where a 6 megabit/sec. digital signal is used in place of a 1 megacycle analog signal.

In attempting to forecast major trends, one finds a likelihood of hybrid systems during a transitional period which will include the 1980's. The first example of such a system is HRMR - the Human Readable, Machine Readable microfiche format proposed by the Air Force. For mixed alphanumerics and graphics, this concept may prove to be quite enduring because of its inherent flexibility. Alphanumerics can be compressed into digital code; some important graphics may be expanded into digital code to assure against degradation in multi-generation copying. All information will be available in analog graphical form for ease of use in simple field readers and reader/printers. Computer-aided indexing and search operations utilizing digitized indexing data can be envisioned even at simple field stations, but the complexity of scan and decode operations on digitized images may limit these latter functions to more elaborate central installations.

Generation of master documents for HRMR files will probably take place in relatively few highly sophisticated facilities. These will be able to process and merge output data from digital computers with natural graphics and externally acquired coded and uncoded alphanumerics. They will store information using codes optimized for the particular application at hand. Low cost replicas of these masters can be manufactured at these facilities and disseminated physically, in one form of micropublishing (which will, of course, also have other, simpler forms descended from such activities on XEG's UMI micropublishing).

If the archival document thus generated contains photograhic symbols representing efficient data encoding, high speed transmission of these records by straightforward facsimile means will be cost-effective. This could reduce the requirement for hybrid facsimile - OCR devices as inputs to data transmission links.

Color Image Storage

Archival storage of color images may become commercially feasible before or during the 1980's. Color information can be encoded in a great variety of ways. Some, such as those used in color television, are quite economical of time-bandwidth product in scanning systems.

It seems likely that optimally encoded color images will need roughly double the storage space required by monochrome ones of similar resolution. The increase is this modest only because most of the color information need not itself be of high resolution.

As in all cases,either magnetic or optical storage technologies can be used successfully. For archival purposes it seems unlikely that the popular tripack color emulsion (e.g. Kodachrome, Agfachrome, etc.) will be appropriate for three reasons. First, the dye images produced by these emulsions are less stable than silver images. Second, both their considerable thickness and dye diffusion effects severely limit the resolution and information capacity of such emulsions. Third, the cost of both materials and processing is substantially higher for color than for black and white, and quality control is less reliable. The net result is likely to be a cost/bit for color films that is at least two orders of magnitude higher than for black and white materials.

Digital storage of color information should be straightforward, with a cost increase proportional to the true increase of information stored, i.e., about a factor of two. Analog storage of color information might best be done by color encoding on ultra-high resolution monochrome materials. A large number of schemes exists for doing this, such as the one used in the G-E Light Valve TV systems, or the Tech-Ops color system. They are not ideally efficient, but should in general, require only about one order of magnitude greater off-line cost/bit than monochrome storage at the same resolution level. On-line cost increases may be similar as a result of the more complex viewing equipment required.

Acoustical Storage

The recording and storage of acoustical information is relatively straightforward. Since such information is inherently one-dimensional, the scanning problems of graphical information handling do not exist. Consequently there seems little reason to store sound in analog form; digital representations, including those resulting from speech recognition or other data compression techniques, would appear to be warranted in most cases. This will probably hold true even if photo-optical media are chosen for sound storage on the basis of their low cost/bit.

Implications of Video Cassette Technology

Just as Ampex's TBM and IVC's digital tape evolved from high quality studio-type video recording equipment, new data storage technology could grow out of the rapid development of low-cost video recording technology. All major existing information recording methods are already represented in the announced video recording and/or playback systems for home and educational use,which are generically called "cassettes", whether or not they actually utilize cassette holders. Of these, only magnetic tape catridge equipment offers read-write capability. The others are read-only; they are essentially dissemination or publishing media. Two of these are optical: CBS's EVR, a highly refined

photographic movie system, and RCA's SelectaVision, a relatively advanced holographic concept. The Teldec system is the only one using a mechanical transducer and a disk rather than tape format. Both SelectaVision and Teldec use mechanical replication for generation of release copies; EVR uses optical printing, either on silver halide or diazo materials. Both replication and optical printing are parallel information copying techniques, approached in magnetic technology only through the use of the new contact printing of tapes, recently refined by Ampex among others. Of these, only replication promises negligible information loss in the reproduction step.
The great significance of all these new systems is that they represent highly developed archival storage technologies which are readily adaptable to uses outside TV-type motion pictures. Their enormous information storage capacity can be utilized for such areas as micropublishing. Tradeoffs between frame rate and resolution will permit storage of high resolution images. Addition of appropriate redundancy could make the systems useful for digital data storage.

Cost estimates are even more uncertain in this field, but seem to be about as follows (based on projected retail prices) in cents/bit:

	On-Line	Off-Line
Magnetic tape	3.0×10^{-7}	1.5×10^{-8}
EVR	4.5×10^{-7}	1.5×10^{-8}
Selectavision	1.6×10^{-7}	2.7×10^{-9}
Teldec	$.8 \times 10^{-7}$	1.3×10^{-9}

Thelow cost of mechanical replication is already reflected by the off-line costs of SelectaVision and Teldec. Still lower costs can be envisioned by the 1980's. Thus it may be quite feasible to disseminate information for a replication cost of less than 10^{-9}¢/bit. This is almost three orders of magnitude less than paper alone.

Appendix II

Teldec Disk

Moreover, the disk format of Teldec could lend itself to relatively rapid access. With at least 2 x 10^{10} bits of information on every disk, and with a simple random access device capable of accessing blocks of data in some tens of millisconds, archival storage on Teldec may open up some interesting possibilties. For example, in a search made, data can be "scanned" at 10^{12} bits/second. Itis possible that wear will be a problem with Teldec, but unlikely that it would be more serious than with present magnetic tapes (Appendix II).

Some Predictions

The remarkably low costs attainable by use of mechanically replicable video playback technologies will assure that these technologies have a role in information dissemination (other than video) in the 1980's.

It is quite possible that large central archival files will be kept on access magnetic tape (or other erasable) systems. These will be remotely accessed via broadband communications. The information on them will be updated frequently by central computers, and will be largely in encoded form. Decoders can convert this to human readable form at relatively"intelligent" local or remote terminals. In order to further economize on transmission costs, local archival stores using adapted video technologies will contain most of the working data base of each terminal. This will be updated on a periodic basis by low-class mailing (e.g., weekly) of large segments of the data base. More rapid update will be accomplished automatically by transmission of supplementary information from the central file to local auxiliary magnetic files, which are so indexed as to permit searching them automatically whenever the archival store is interrogated. Additional information not included in either the local archival file or its read-write auxiliary can be obtained by direct interrogation of the central file through the communication link.

The particular division of information among read-only local archival stores, read-write local auxiliary stores, and central files will be determined by the relative costs of storage techniques and of transmission badwidth prevailing in the 1980's. It will remain in a state of flux for many years, as contending technologies continue to evolve. Successful systems will probably be those which are sufficiently flexible to adapt to changing balances among the relevant costs.

Considerations for Future Office Systems

A Summary

J. G. Mitchell

This report examines hardware and software features of possible offices of the future. A view of an office as a system of processors (human and otherwise) communicating knowledge to one another is espoused, and a set of principles is developed in the context of current offices to be applied to the study of such systems.

The examination of future offices encompasses man-machine interaction, personal terminals for using the office, functions available to the office's human processors, and the scope of a software technology sufficient to support the system. Access to shared information and privacy considerations for such accession are also discussed along with the possibilities for networks of offices. Finally, a starting point for developing a sequence of future office systems and its present-day and projected 1980 economics are outlined.

Considerations for Future Office Systems
James G. Mitchell

Current Model of an Office System

Current office practices revolve about the use of many individual information processors, most of which are versions of the family Homo Sapiens. These processors appear in the guise of managers, clerks, secretaries, typists, and others. "Automating" this system of communicating processors has, in the past, focussed on speeding up the communications channels between the people in the system: typewriters, telephones, Xerox copiers, dictation equipment, telecopiers, and the airline system all do this.

These are all simply means to an end: it is really knowledge which needs to be transmitted from person to person. Information must be assimilated (understood) by the processor receiving it in order to become knowledge which can then be applied to problems. The remainder of this section will discuss how this definition of knowledge affects the ways in which information is represented, flows, and is stored. Since the transmission of knowledge presupposes a flow of information, we will deal first with the representation and movement of information in current office systems.

Information

For information to flow requires a physical medium such as paper or a human's mind in which to be represented, and a channel such as the postal service or the atmosphere (in the case of person to person voice communications) over which to be transmitted. The primary medium for information is in the memory of the human processor, and the act of transcribing that information to some physical medium is called "generation".

Generation of Information

Humans can generate information by writing, by typing, or by voice and visual means. Non-human processors may generate it by various display methods, punched holes in cards or paper tape, or as electronic signals on a wire. However, the ease of generation is dependent on both the capabilities of the human and the properties of the generator: a processor-generator combination which operates smoothly must effect compromises between the speed of the two entities, and must pay special attention to the capabilities of the processor for controlling the generation equipment. One need only see a hunt-and-peck typist in action to understand the importance of this matching. Such "balancing" of processor capabilities, channel bandwidth, and information representation will appear again and again as a strong consideration in the effectiveness of any office system, present or future.

Transformation and Transmission of Information

Information which has been generated becomes useful insofar as it can be transmitted from processor to processor. Transmission techniques in current offices range from the physical motion of people to digital and analog signals over wide band communications links; the bulk of the load, sadly, is more likely borne by the former method than the latter. And, inside a given office, most of the information load is carried around in people's heads and on 8 1/2" x 11" sheets of paper. Since these same people constitute the primary processors which operate on that information, paper and brains work well as media: paper because the characters used are human readable, and brains because they constitute the primary memory in which humans manipulate information to extract knowledge from it.

One other important feature of many offices is the intercom or internal telephone network, an example of which is the PBX system offered by the telephone utility. It acts as a transducer (or transformer of information) and transmitter of audio data between two or more parties. Moreover, it is one of the office's "ports" to the external world and can therefore be used to transmit information between geographically separate offices. Its use in man-computer communication is one of the noticeable departures from information storage on paper which currently exists -- namely, digital storage in a computer system.

The heavy use of travel, by far the most expensive, time and energy consuming means of knowledge transmission is a comment on the lack of good techniques for man to man communication over distance and the importance of speech, gestures, presence and immediacy to humans for knowledge transfer. Any system aspiring to (even partially) displace travel will have to meet this problem of the flexibility, interaction, bandwidth and medium provided by physical proximity head on. Audio contact alone has had a chance and has not been successful; audio with video may have better luck, but audio/video plus the ability to manipulate, transform and display information dynamically has by far the best chance of impacting this problem.

Information Processors

At the moment, the primary processors of all information are humans, and while they are very well suited to such tasks as decision making; it must also be admitted that the abilities to do rapid numerical calculations, or to quickly and accurately graph and smooth information are not generally considered their forte.

The fact that humans often err in arithmetic calculations and the decreasing costs of electronic circuitry have made numerical calculators common adjuncts to many office workers. Such devices "augment" the capabilities of the human. Similarly, typewriters enhance the clarity of documents and the speed with which they are produced; office copiers increase the speed and accuracy of document reproduction -- and therefore transmission -- and dictation equipment decreases the time spent mechanically handwriting initial drafts of documents.

Humans augment their talents and abilities using other processors in many ways: both by enhancing existing functions and by decreasing the "overhead" to perform some task, thus providing more time and energy for the human to spend on those tasks at which he excells. Moreover, decreasing the time taken to perform such tasks helps the human interact more closely with the problem which he is attacking and increases his effectiveness with respect to the quality of the results as well as the time needed to arrive at them.

Note: there has been research which substantiates this statement. See, for instance, [Gold67].

Augmentation of one's capabilities using other processors is closely allied with the notion of balance earlier described: one's effectiveness can be increased by the manner in which information is presented as well as by facilities for operating on the data.

Information Storage and Retrieval

The existing filing systems in most offices are a direct consequence of the prevalence of paper as "the" information medium. In general, very primitive retrieval mechanisms are used for accessing this storage with little use made of the content of the stored documents to structure the filing system. Even the application of microform technology alone has not helped this situation because that information is held in man-readable form; is not, therefore, easily assimilated by computer-like processors; and hence is not amenable to machine manipulation which could augment the human processor's abilities. The representation of information and its accessibility to any processor which could profitably use it to acquire knowledge ranks in importance with the notions of balance and augmentation already discussed. Of course, not all information need be manipulable by all processors, so this principle does not preclude analog forms of storage where desirable.

Thus far, three principles about office systems in general have emerged:

Balance:

The flow, medium and form of information affects how well processors which use it can extract knowledge from it: imbalance breeds bottlenecks and inefficiency.

Augmentation:

Processors should do those tasks for which they are well-suited and employ other processors to aid them in their own performance. This applies equally well to the augmentation of humans by computers and to the augmentation of computers by humans.

Representation:

Information, to be useful, should be manipulable by any processor which can potentially gain knowledge from it: this is closely connected with the above principles since inaccessible or badly represented data suppresses possible augmentation and can cause imbalances with respect to information flow.

The following represent some implicit assumptions which have been made about such systems:

Economy:

Any system which meets the other constraints but is uneconomical is probably not viable: hardware and software costs both must be considered for economy.

Feasibility:

The technology to support an office system must be solid enough to ensure reliability of the resultant system and to have a salutory effect on its economy: here again, both hardware and software technologies must be considered.

Rewards:

Any system used by humans which rewards their use of the system with obvious gains in capabilities, increased flexibility over previous means of doing similar tasks, or with the removal of tasks which they find difficult will itself be rewarded by being used. This is especially critical since these same people may be the "generators" of much of the information amenable to processing by computer.

The next section will begin to probe possible future office systems, and these principles should be used as a filter through which to view the landscapes presented. Although Economy and Feasibility are better covered by the other appendices, they will surface from time to time in the discussion.

Future Office Systems

Textual Facilities

As the cost of logic and memory decrease and as the economy and availability of good computer terminal devices increase, digital computers and personal access to them will become standard in offices. Hence, a large portion of the information in an office will be represented in some digital medium: it is then accessible by the computer but can still be displayed for processing by humans.

This information will be largely textual and numerical, but will also include diagrams, computer-generated graphics and raw visual images. The human can then be augmented in a number of straightforward but highly valuable ways. Filling out forms can be done with source error checking and validation, and the computer could fill in standard parts of the forms to relieve the human processor of some error prone drudgery.

Memos, reports, letters - in fact any textual information - can be composed (with spelling correction on input), restructured, edited, critiqued, distributed, or simply studied without the necessity for many "drafts" and retypings of the material.

Indeed, this overview has been made in just such a manner, using a system which is already available at Stanford Research Institute's Augmented Research Center (ARC) with whom PARC is collaborating on some of these issues.

Moreover, because the text is manipulable by a computer, one can cause it to be presented in a variety of different ways while studying it: detail can be suppressed or expanded, tabular information presented graphically, or cross references and internal references followed for short memory refreshing before continuing with the body of the text.

The Local Office of the Future

Information may be either private or shared among a group. If each person has access to shared files through a personal terminal plus access to computing power, then groups of people can collaborate on documents, or a reader can ask the author of a report to amplify some sections.

That is, there will be a new communications network in the office besides the internal telephone system. Unlike the telephone, however, this network will have manipulative capabilities as well as being a simple transmission network. Combining the two networks into one with the addition of video (see the discussion of display terminals below) can allow people to communicate and manipulate information simultaneously, without the necessity of physical proximity and with processing augmentation available to help in presenting, viewing, and discussing the information. This escape from the tradition of physical proximity for valuable interaction will partly dissolve the boundaries of the current office and provide much greater response to problems from geographically dispersed groups, as well as making inroads in the problem of personal travel.

The storage and processing facilities of such a network could also aid in a number of smaller ways in the office: telephone messages (even the raw audio or video) could be stored and then be selectively "scanned" by the callee; agendas and notification of calendar events could be realized (a fancy alarm clock) and probably most importantly, statistics on information flow and processing requirements could be gathered as an aid to balancing the office system or to understanding its dynamics.

A variant of this idea could yield project management techniques which could control and schedule working groups: PERT/CPM methods could use up-to-date information to govern and predict progress and point out potential bottlenecks before they occurred; or, a history of the project's progress could be kept for later study or as material with which to bootstrap new group members into the project.

Networks of Offices

The notion of a local network of memory devices, processors, information transducers, etc. clearly extends to non-local networks of local networks; indeed, the gains from such office systems may lie more in the realm of these non-local networks than within individual offices. The economics and availability of bandwidth over distance is the primary difference between the two. Locally, one can simply string coaxial cable through buildings in the same fashion as telephone wires nowadays; non-local communication, however, raises questions of cost, government regulation and availability. At this level, it is probable that shared knowledge and processing ability in remote processors will be used to decrease the amount of raw bandwidth necessary for some forms of communication, although certainly not all.

The Personal Terminal

What has been described suggests strongly that much of the current "paper pushing" in today's offices will be replaced by people spending a large portion of their time using a computer via some personal terminal. The issues with regard to time-sharing a central computer as opposed to a computer in every terminal are much better handled in the Appendix "Some Notes on Logic and Non-archival Memory for Computer Systems of the 1980's" and will not be discussed here. The form of the human's interface to this augmentation facility will, however, be discussed in some depth.

This terminal (and the augmentation tools accessible through it) must be as much a delight to use as possible. No eyestrain allowed! The information must be presented with clarity, crispness, and the aesthetics of good book quality typesetting. Its information rate must be at least that of normal television bandwidths to accommodate rapid changes in the user's "view" of displayed information. The "picture" must be accessible to the user by some easy pointing mechanism. Normal textual input (via keyboard) and other entry devices must be available and well human engineered (much research is needed here); the ability to draw simple curves is also desirable. Audio input and output should be allowed, with retention of the audio in the terminal's storage facility so that the terminal can act as a dictaphone or a message receiver. The device should be portable and useable in a stand-alone fashion so that at least some minimal level of augmentation is available at all times without needing access to any other computing facility; this means, in particular that it probably should have some processing power and enough memory, (both directly accessible and secondary, such as tape cassettes) that the user can perform many of his normal functions with the terminal alone. For further amplification of the terminal design, see the appendix: "Display Transducers".

Archival information, such as books, catalogs, or past accounting records could be stored in an analog (microforn, video disk, etc.) or mixed digital/analog form since it may not be so necessary to change such data, except for study or viewing purposes, or occasional updates. Certainly, some minimum digital information is necessary simply to allow retrieval of the information. Once retrieved, however, the information could be piped to an individual display by scanning the analog record, converting it to signals suitable for the terminal device, and transmitting it to the user's screen. Indeed, the bandwidth question could be effectively bypassed in this instance by mailing copies of the information to local offices where devices could be stationed to automatically retrieve pages for display to the user, using a TV camera to generate video for his terminal.

Analog to Digital Information Conversion

What if archival information needs to be changed or made more malleable? Some means must be available to convert the analog form to digital. If the data is textual, an OCR device will suffice. If the information includes graphs or simple drawings, much more sophisticated techniques will be required to map the structure of the information into digital form. And, if the information is represented as images or raw audio or video, the system may have to resort to simply digitizing it with sufficient resolution to retain the information content for the use to which it is to be put.

In general, the analog to digital conversion problem can be expected to be somewhat costly (depending on the type of the information) and non-trivial; therefore, unless there are clear economic gains for analog storage, or if there is no advantage to keeping it in analog form, it should be retained as digital data. Indeed, some of the memory technologies detailed in the two appendices on memory technologies suggest that digital storage may be very cheap and will compare favourably with some forms analog storage. Nevertheless, the office must interface with the outside world, and information will arrive in analog forms, so the system must be able to ingest it as much as possible. Hence, good, cheap OCR techniques, and the ability to at least digitize pictorial information will definitely be necessary.

Digital to Analog Conversion of Information

For many of the same reasons just outlined, the ability to move digital information to media such as paper, microform, film or video will be highly desirable. Happily, this problem is somewhat better understood than its analog to digital counterpart, and hardcopy devices under development within Xerox (see the appendix: "Advanced Output/Printing Devices") will prove very useful.

Analog to Analog Conversion of Information

Transforming microform held information to hardcopy is achievable by a number of the same devices under development for digital to hardcopy transduction. From hardcopy to microform might best be handled by simply digitizing the information and then using a COM device for digital to analog conversion. While this requires an extra (though automatic) step, it uses facilities already needed in the system, thus obviating the need for a separate paper to microform facility. On a small to medium scale of use, this is certainly tolerable.

The Retrieval Problem

The problem of retrieving information contained in some digitally accessible storage medium has three subcases: personal files, local, shared files, and global data bases. A directory of personal files will give one access to that level of information simply by naming the file desired. Since such files tend to be small, exhaustive scanning of the file for some class of information is quite acceptable, especially if the user's terminal can allow rapid display of the data.

For medium size files which may be shared within a local office system, slightly more sophisticated techniques may be necessary to access files of interest. A set of keywords attached to the file and a simple keyword accession scheme to present files of potential interest could possibly suffice. Variations of the same technique would also be useful for looking inside such files to find items with certain characteristics.

For very large (and possibly geographically distributed) data bases, much more sophisticated representations of the information and accessing methods will be necessary, not only to guarantee a reasonable level of recall, but also to control the cost of such a facility. There is currently research going on in this area by a number of groups, and the main problem by the 1980's may be an over-abundance of different representation and accession schemes rather than a lack of them. This and other related problems of software technology are discussed in the section on software technology below.

Protection of Information

Controlling the access to stored information is closely allied with the retrieval problem. For personal files which are contained at the owner's terminal or in his office, one can simply lock the terminal so it cannot be used (possibly by voiceprint, since the terminal is a processor anyway) or lock his office. There are a number of schemes for protection and access control of locally and globally shared information, an excellent example of which is contained in a paper by Lampson [La69]. Such protection mechanisms have one decidedly useful side effect: attempted illegal access to information can be recorded by the system, including who (or what) made the attempt, and what the form of the attempt was.

Numerical Augmentation

Numerical information can be processed in a number of ways. Statistical reductions and summaries can be prepared. The result of numerical or statistical analyses can be presented graphically, tabularly, or as perspective views of three-dimensional objects. Analog images can be digitally enhanced with computer generated information. Operations research functions such as linear programming, dynamic programming and other optimization techniques can be made available. Software tools for simulation of production, or for forecasting inventories, or local performance improvements can be used. And, the users can construct their own packages for manipulating and displaying numerical (and textual) information. The facility with which the latter can be accomplished, and the extent to which similar offices may exchange and use each others' software depends to a large extent on advances in software technology.

Software Technology in the Office of the Future

The proposed view of future office systems relies heavily on software for its operation, yet of all the technologies so far discussed, software engineering is probably the least well developed. Above all, the systems programs for the office of the future must be reliable. They also need to be as tolerant of hardware errors as possible in order not to succumb to the occasional hardware fault, and the functions provided by software must be easily and cleanly expandable so that Xerox may avoid locking itself into a dead-end of functional capabilities in such a product line.

Because the office system can interface with the external world via communications links such as the telephone utility, software products could be installed, updated, or "repaired" from a central service center. This has large payoffs. The number of sophisticated personnel needed in the field for software maintenance can be kept very low. Changes to the software products to upgrade performance or correct errors can be broadcast from the service center to the installations, thus reducing the time needed to disseminate such fixes. Xerox can use the installations as free sources of valuable information on system usage and performance under load. The quality and experience of the personnel at software service centers can be kept very high because of the limited number needed and because they will see almost all problems of consequence first-hand. And, lastly, Xerox may use the system to provide automatic billing for services as well as for information which the sales force could use to help an installation tailor its system to its needs.

The issues of the construction of "zero defects" software and of software engineering principles and techniques are current topics of research within Xerox PARC. The ability to maintain inventories of software components which can "plug together" in clean and reliable ways would enable Xerox to tailor (and even construct) software functions for individual installations while still maintaining reliability of the programs and the capability for future modification of functions as needs dictate.

Such techniques will also enable users to augment product software for their own uses; this phenomenon is highly preferable to the current practice of building large, late, unwieldy systems "designed" to have all the features any user will ever need. Any user of such a monolithic system can only use a small subset of the large assortment of features provided and one of the features he needs will probably not have been anticipated by the designers of the system. For the office of the future, it will be better to provide

(1) a small set of known, useful functions, and

(2) the capability of quickly and reliably constructing new, specialized functions as the user requires them.

The ability to transport programs from one type of processor to another, error-checking and correcting techniques in the software, and fault-tolerant data structures would also contribute greatly to the reliability and life of any future office systems. The ability to move software with ease and grace from one type of processor to another will allow changes and advances in to the hardware to be made without the overhead of recreating voluminous amounts of software and without sacrificing the reliability of software which has already been "wrung out" over much use in the field. The development of fault-tolerant programs and data structures is a hedge against the occasional vagaries of hardware and software to raise the reliability of the system as high as possible. Anything less than a mean time between failures of one week on such a system is probably intolerable as a central resource for an office.

How to get there from here

The technologies exist to allow a limited system for textual operations plus personal file storage (on tape cassettes) and local file storage on 2314-type disks. Such a system currently would cost about $3000 to $4000 per station. This assumes a display terminal with keyboard, pointing mechansim, cassette reader/writer, a central computer with 2314-type disks and magnetic tapes, and a number of SLOT-type hardcopy devices (say one for every 10-15 terminals). This does not include hardware or software development costs! Most of the cost of such a system is in the individual terminals: cheaper displays and input devices and more logic and memory in the terminals would significantly decrease the cost per person.

By the 1980's such a basic system should cost about $500-$600 per person. The addition of more functional capabilities is then a software problem with decreases in performance at a given cost level (or increases in cost at a given performance level) mainly due to file accessing requirements placed on the central storage facility. With enough processing power and memory in the terminals, strict computational load cannot saturate the overall system as it might if a time-shared central computer had to handle all processing.

Further developments of such a system along the lines of improved hardcopy devices, management information tools for massaging large data bases, and other functions for the local office are hard to pinpoint in terms of development sequence or market acceptance. The important thing is that the initial system does not limit such additions.

Conclusions

It should be clear from this overview that the development of "smart", cheap, and elegant display terminals, of software technology, and of various input/output devices should be prime areas of concentration in order to be able to supply functions such as those described to the marketplace.

Bibliography:

[La69] Lampson, B.W. "Dynamic Protection Structures", AFIPS 1969 FJCC Proceedings; Vol. 35: 27-38.

[Gold67] Gold, M.M. "Methodology for Evaluating Time-shared Computer Usage", Ph.D. Dissertation, M.I.T.; 1967.

Advanced Output/Printing Devices

G. Starkweather

Output/printing devices will have to have more features in the future. Collation, sorting, forms and font variability are some of the required features. Speed will be less important than binding, stapling, etc.

I. Device Location

The output locale will be local (office, etc.) only if processes are simplified. On the basis of features and today's technology, the central (department, etc.) device will probably be dominant. The office environment may demand hybrids (e.g. multiple outputs on one processor).

II. Process

The xerographic process will continue to dominate. Electrographics and offset will have to have major breakthroughs to compete. PEP and SLIC processes may be beneficial. Small scale use of impact printing will gradually disappear.

III. Information Generation

Laser scanning holds great promise. OCP type devices will handle text only, and the mandatory graphics requirement will eventually force these devices out of the major business.

IV. Processors

Current processors and those under development will suffice for the 1970's. New paper handling and hard copy manipulation as well as colored output will be required by the 1980's. Every processor must be able to accept and print information supplied in electrical form, perhaps only as an option. Local information storage and manipulation capability will be provided in the printer.

Advanced Output/Printing Devices

In the past and over the next few years, reproduction or output devices are or will be notably passive. They process what is given to them in rather simplistic fashions. Copiers for example only reproduce what is fed into or onto them. While they perform this function well and rapidly, the environment of the 1980's may not be so tolerant of this limited capability.

The 1980's will most likely need devices for hard copy such as demand publishing, etc. While soft copy may be the ultimate answer, the transition from hard to soft copy may be more likely to take place at the end of the century or later, rather than in the 1980's. The terminal will be considerably more active such as variable stored font, forms storage, collated output graphics, binding and/or stapling, etc. The output device in essence will be much more an integral part of an active data manipulation system, rather than a straightforward reproduction device as it is today.

I. Output Locale

Two locations for the output device will be discussed. These locations are local (home, office, portable, etc.), and central (department, facility, etc.). Both local and central devices will no doubt be required for the foreseeable future.

A. Local

The office of the future should be as free and unencumbered as possible. The local printer seems to violate this immediately by placing an additional device in already crowded offices.

Printer servicing could be a problem; however, typewriters can be operated and cleaned by almost any operator. Unfortunately, nothing in current imaging technology promises to be as simple. It is likely that a soft display may be best for the general user. However, even this should have provision for optional hard copy generation. Certain specialists such as accountants, librarians, etc., may justify a dedicated hard copy local device of low to medium capacity. Such local devices, whether they be soft or hard output, should probably have a factory cost of less than $1,000 or so.

B. Central

As opposed to local device, a central output/printer can be quite expensive; perhaps a factory cost in excess of $25,000 will be acceptable. Such a device can provide duplex output, sorting, editing, local collation, stapling, binding, etc. Additionally, the office is divested of extra "stuff" and clutter. A skilled or semi-skilled operator can maintain the device optimally in a special room. The central device can also run at very high speed. Conversely, a central system failure deprives many people of their output. Proper system design must provide enough redundancy to permit alternate or non-zero output during maintenance periods.

II. Copy Process

A. Xerographic

For the next several years, it is difficult to envision a serious competitor to xerography. The simplicity of image generation and the relatively advanced state of the hardware available or under development should provide a solid base for many years. An additional big plus is that much off-lease equipment might be rejuvenated to provide substantial revenue using old processors like 813's, 914's, 24's, 36's, etc.

B. Electrographic

This process appears to have a limited future due to the electronics and stylus technology required. Toners are still needed and fusing is required. For small low speed devices, electrographics may be important, however. Character rates of up to several thousand per minute can be realized. This implies a few pages per minute. Font quality realized with electrographics (2-3 cycles/mm) and resolution may not be adequate. Electrographic stylus technology may not permit more than 100 to 150 elements/inch.

C. Printing

New printing technologies for micropublishing may emerge around the AMCD concept of a xerographically generated master and offset generated copy. The complexity of auto-collation may inhibit general offset practices, however, Offset techniques with automatic collation would require a "casette" of masters or a circulating set of master, etc. IBM and others have abandoned this idea as unworkable. Xerox would probably do well to steer clear of such techniques fruitlessly prusued by able competitors. The approach taken by Spectrum seems to be the right direction to go. The 1980 processors might use electronic intermediates instead of film, but the philosophy is nearly identical. Short and medium run impact printing will probably die out in the next ten years but not sooner. Long run impact printing will remain strong for high quality and color publishing at minimum cost. Letterpress will give way to increasing use of offset and gravure processes in the 1970's and 1980's. Direct computerized typesetting will become nearly universal by the 1980's.

D. Micropublishing

1. Microfilm - dry microfilms and photo processes may render minified documents more readily obtainable. Microfiche reader/printers, etc., may be relatively important. Reader printers should have a factory cost of less than $100 on today's scale. These reader/printers will have to be at least as good as soft displays. Some real progress is needed here since nothing is currently available of any real quality in imaging performance.

2. Xerography - xerographic techniques can produce resolution of several hundred cycles/mm with liquid developers. Cost should be no greater than current techniques with the possible exception of consumables handling (liquids). Little has been done to explore these areas in a product oriented fashion, however.

III. Information Generation

Essentially two types of information are considered here, viz., alphanumerics and graphics. Such capabilities as variable font, variable font size, etc., are considered. Many variations of data presentation may be desirable such as 2X characters on credit balances, etc. In the office of the future, a very large part of the information will be electronically stored and/or generated. As discussed briefly above, this can be used to advantage in forms and font.

A. Alphanumerics Only - Alphanumeric output only will have limited use in the 80's. Such needs as demand publishing, etc., almost imply some graphics. However, not all persons will need graphics.

1. Electrographic - This system provides a straightforward approach but is limited in quality as discussed earlier.
2. OCP Device - The 3600 OCP type system will provide excellent quality and plenty of speed. System complexity may be an economic and operational limitation.
3. Holographic - Holographic character generation is a variation of the OCP but with much simpler mechanics and no moving font. Such a system might be a follow-on to the OCP. The cost of such devices will or can be quite low and should be less than almost any other character printing system of comparable speed and quality. Speed is comparable with OCP devices and quality is just as good.
4. Electronic Analog - Such devices as the Printicon and Matricon may be interesting but the 5 x 7 Matrix type quality and a minimum of several hundred dollars generator cost may be a serious deterrent to their use.
5. Electronic Digital - This would permit a reloadable font in digital form. Cost scales as the bits/character. 5 x 7 bit characters are no doubt too poor for the 80's but what is needed is not clear either. 16 x 24 matrix characters

seem to be a lower limit to shoot for. This would cost about $100-200 for a 200 character computer selectable reloadable font, by 1980.

B. Graphics

Graphics will play an ever-increasing role. Any devices contemplated for graphics output could be coupled with alphanumerics generators as discussed above. Quality alphanumerics require more resolution than graphics (about 2X - 3X). Line drawings, etc., demand less quality than the notes beside them, for example. This has been previously discussed but warrants careful study since storage (and cost of storage) increases as the square of the resolution. Forms storage and overlay will be a real feature of graphics devices of the 1980's.

1. Laser Scanning

This technology (SLOT) provides perhaps the greatest potential. Laser radiance is adequate for almost any required exposure. A one milliwatt laser has a radiance of 2×10^4 watts/cm^2-sr. This is far higher than any other conventional sorce. A 1980 SLOT package for 2400 through Gamma range processors would probably cost $3K to $5K over and above processor cost. Lower speed devices such as 660's, etc., could cost less than $500-$1000 to modify. Beam manipulation technology is moving ahead rapidly and commercial modulators are presently capable of 25 to 50 Megahertz bandwidths. This bandwidth translates to about 2-3 copies a second of Gamma quality. Low power lasers (few milliwatts) are satisfactory for high speed xerography.

2. <u>LED's and Laser Diodes</u>

These junction semiconductors emit light when forward biased. Since the junctions can be made small or made to appear small, they can be combined into arrays. Instead of scanning as with lasers, several thousand LED's might be combined into a line array and individually pulsed. LED radiance (0.03 watt/cm^2-sr typical) is low compared to the laser, but they can be modulated at high rates and since they can be combined into arrays, each LED can be considerably less radiant than a laser. For local terminals or output devices, LED's may be the answer since they are compact and require a simpler optical system.

3. CRT's represent an amazingly agile technology. Their radiance now approaches 50-100 watts/cm^2-sr. This is far below the laser but far from useless also. Witness the Omega printer at 3 pages/second using a CRT. The CRT is, however, resolution limited. While certainly a serious competitor in the near future, the $2,000 to $3,000 cost of the high brightness CRT will not decrease much (2X maybe) in the future since processes are well established. Resolution of more than 3 x 10^6 bits on the face of the CRT is not easily obtained and hence SLOT-quality documents (10^7 bits) are not realizable now or probably in the future.

4. <u>Other</u>

Other exposure sources appear to be of questionable importance. Electron beams require vacuum and compact arcs cannot approach the smallest gas laser in brightness.

IV. Processors For Hard Copy

A. 1970's - For the near future hard copy devices should use existing processor mainframes. Gamma will provide 2 copies/ second at 8 cycle/mm (1.6 x 10^7 bits on 8-1/2 x 11 document). Until many output devices are constructed and utilized (this will take a few years), detailed processor specification for the future office environment cannot begin.

B. 1980's - Specify new processors using xerography, PEP (possibly more expensive), offset printing (AMCD), etc. Perhaps a video version of Spectrum would be ideal here. Such a device could be composed of one or more SLOT inputs. Such a processor could provide for OCP type alphanumerics only and graphics generation could be optional or selectable. The electronic intermediate could be sorted and collated electronically, thus facilitating "intermediate" or even original handling with much greater simplicity than with current "hard" intermediates. Document editing and creation features will also be important in such a device. Paper handling problems will have to be dealt with more effectively than in the past. Paper color, sorting, etc., may have to be highly automated with an accompanying increase in reliability. The use of XDM intermediates, ruticons, etc., may also make these processors very flexible. One feature of paramount importance will be reliability. The more dependent we become on the envisioned devices the less we can tolerate a down condition. Xerox must concentrate much effort on reliability in document and/or output handling if the goals of the 1980's are to be realized.

C. Color - Several technolgies provide black and white output. Xerography and PEP permit color to be realized. Only xerography promises reasonably low cost/copy in large volume. (PEP being hampered by the cost of consumables.) Any future systems should anticipate color capability. Laser scanning, CRT's, etc., coupled with computer processed images can produce very good color output. Such a system will (with the possible exception of EPIC) require completely newprocessors, however.

Some Notes on Logic and Non-Archival Memory for Computer Systems of the 1980's

Richard G. Shoup

This paper contains a discussion of the various technologies which we believe will be prevalent in computer systems of the 1980's. However, new system organizations and techniques will, for many applications, result in greater gains in computing power than will technological improvements.

I. Memory

The principal factor driving memory technologies is overall cost. Magnetic core memories seem to be bottoming out at .5μsec cycle time and 1¢ per bit. Cores will be nearly-non existent in new designs in the '80's.

Continued progress in semiconductor memories can be expected for at least 10 years, but at a somewhat slower rate than previously. Prices of less than .01¢ per bit for even small random access memories with internal speeds of less than 50 ns can be expected by 1980. Electron-beam pattern definition promises significantly higher densities (2 orders of magnitude) within a few years and, more importantly, increased yield over larger areas will be feasible. Higher levels of integration (as distinguished from higher densities) will be very prevalent by the 1980's. High speed IC memory will probably be available at .1¢ per bit and have 10 ns or less cycle time. It seems likely that MOS memory will overtake bipolar memory if not in speed, certainly in cost/performance.

High densities achieved by Bell Lab's magnetic bubble memories (2.5×10^6 bits/in^2 today) are not likely to increase a great deal more without a significant materials breakthrough. Although Bell's predictions of a few millicents per bit in 2 years is optimistic, bubbles will probably be at least 1 or 2 orders of magnitude cheaper than ICs by the 1980's.

Charge transfer devices are inherently faster than bubbles and denser and cheaper than MOS memory. It is quite possible (although too early to predict) that CTDs will eclipse bubbles for sequential memory applications.

II. Logic

By 1980, today's medium to large scale CPUs will be available on a single chip (slice) for less than $50. Propagation times of less than 1 ns per gate will be readily available. High levels of integration, new processor organizations, more parallel processing and extensive use of automated design will characterize these systems.

Some Notes on Logic and Non-Archival Memory for Computer Systems of the 1980's

Richard G. Shoup

June 9, 1971

Introduction

This paper is a discussion of the various technologies which we believe will be prevalent in the computer systems of the 1980's. Several points should be made first however:

1. The span of our predictions here is equal to nearly 1/2 of the total life history of computers as we know them. Furthermore, it is considerably greater than the entire history of at least one of the major technologies discussed here (magnetic bubbles). For this reason, it is difficult to make meaningful extrapolations from today's technologies. It is also not only likely, but highly probable that breakthroughs in materials, laser deflection techniques, etc. will occur within the prediction period and considerably change the overall picture (but only in a positive direction).
2. New organizations of computer hardware will, for many applications, result in greater gains in computing power than will technological improvements. Examples are associative memories, logic-in-memory, greater use of parallelism, redundancy for improved reliability, etc.

I. Memory (non-archival)

"A computer can never have too much main memory". Despite the wide applicability of this adage (especially with time-sharing), we would substitute the following stronger statement: "A computer would like all of its memory to be main memory". Unfortunately, there is at least one fundamental reason why this cannot be so, except perhaps for small machines.

As far as we can see into the future, there will always be tradeoffs between speed and size such that archival storage will, in general, be considerably slower (random access) than main memory technology. Additionally, archival memories are, by definition, always expanding and thus a removeable technology is almost mandatory (tapes, films, disk packs, magnetic cards, holograms, etc). The retrieval time is limited by this physical movement and thus hierarchies of memory will always exist.

Memories are discussed below in terms of speed, cost, density, power, reliability, volatility, media vs. read/write mechanism, random/sequential properties, batch fabricability, etc. But it is important to realize that the overwhelming factor which drives these technologies is <u>overall cost</u>. Traditionally, many of the inherent characteristics of a given technology tend to become subjugated to the desires of the consumer. Integrated circuit technology, for example, is no longer inherently low-yield. It is often used at a level of $<5\%$ good chips per slice, however, because this is the most <u>cost</u>-effective point for the manufacturer.

Reliability can be considered almost a constant and will not be discussed further, since every technology will be used in such a way as to give adequate reliability (or will be discarded) regardless of its inherent reliability. Volatility is not a major issue any longer because:

1. Lower power requirements of memories can be met by batteries in an emergency.
2. Requirements for higher system reliability (time-sharing) have made fail-safe power systems fairly common.
3. If one member of the memory hierarchy is non-volatile, reserve or filter capacitor power can be used to save the contents of volatile memories before information is lost.

Magnetic Cores

Cores have been the mainstay of primary memories for most of the history of computers. However, they now seem to be bottoming out at around .5μsec cycle time, 1¢ per bit, and 200 μwatts per bit. Although an order of magnitude improvement in overall cost/performance might be expected over the next 10 years, cores will quickly drop out of the picture. Cores cannot be homogeneously batch fabricated and require high-current drivers. Cores may be used for a few years yet in some mass-store applications but will be nearly non-existent in new designs in the 1980's.

Semiconductors (MOS and bipolar)

Continued progress in semiconductor memories can be expected for at least 10 years, but at a somewhat slower rate than previously. Prices of less than .01¢ per bit for even small random access memories with internal speeds of <50 ns can be expected by 1980. Larger semiconductor memories (10^6 bits and up) can be cheaper at the chip level (10^5 bits per chip or more) but packaging costs will absorb some of the economy of scale here. Advances in ICs over the past 5 years have been largely due to increasing densities. IC packages have remained virtually the same size. Over the next 10 years, however, we expect densities to increase somewhat more slowly due to physical processing difficulty, electron wind phenomena, etc. (Electron-beam pattern definition will permit significantly higher densities than at present and, more importantly, increased yield over larger areas will be feasible.) Higher levels of integration (as distinguished from higher densities) will be very prevelant by the 1980's. Propagation times due to connections and conductors plus package costs will result in large-chip and whole-slice approaches to many systems. Organizations which take advantage of this will be significantly better understood than today.

For memory optimized for speed, we can expect prices of .1¢ per bit and internal speeds of 10 ns or less for small to medium sized memories. (See the Logic section for additional comments on high speed circuits.) Shift register memory will probably remain somewhat cheaper than random access memory and slightly faster.

It seems likely that MOS memory will overtake bipolar memory if not in speed, certainly in cost/performance. MOS is simpler to manufactur (and thus is inherently higher-yield) by a factor of 2 to 3 and is inherently more dense by a factor of 2 to 3. MOS is currently somewhat slower than bipolar but this gap will be increasingly narrowed. In general, the actual memory cycle times will become more and more dominated by the decoding time, conductor capacitance charging time, etc. MOS is also inherently bidirectional which bipolar is not. This has implications for combinations of logic and memory (see sections on Bubbles and Logic).

Magnetic Bubbles

Bubbles are inherently capable of high densities (2.5×10^6 bits/in^2 being tested today) and require very low power (.5 μwatt per bit today). Densities are not likely to increase a great deal more without a significant materials breakthrough. Bell Labs predicts practical bubble memories with costs of a few millicents per bit in 2 years. Although this is quite optimistic, bubbles will probably be at least 1 or 2 orders of magnitude cheaper than IC's by the 1980's. However, bubbles are inherently slow (1 μsec today) and serial (like shift registers)

The manufacturing processes for bubble meories are much simpler than for ICs, but the basic materials used (garnets, orthoferrites) are much trickier than elemental silicon. Bubbles can be made non-volatile with the use of a small permanent magnet. This is important to the telephone company but not so much to computer designers. It should be noted that most major companies are adopting a fairly cautious wait-and-see attitude about bubbles. This will serve to retard the development of bubble technology, of course.

Due to their relatively low speed, low cost, and sequential nature, bubbles are most obviously used to replace drums and disks, etc. We can expect something like 10^7 bits or more in a 2 inch cube drawing less than 2 watts and having a bit rate of 5 Mhz and a latency of less than 200 μsec and costing less than $100.

Despite Bell Lab's claims, bubbles are not clearly better-suited to mixing logic and memory than ICs. However, computing power gained by organization usually takes emphasis off speed (by using parallelism, etc.) and adds some to cost. Even if bubbles are comparable logically to ICs then bubbles will often be preferable due to lower cost.

Charge-Transfer Devices

CTD's combine some of the best qualities of bubbles and semiconductors. They are faster than bubbles and denser and cheaper than MOS memory. The basic material is well-understood silicon and the sensing (detection) problems of bubbles are avoided. CTD's however, have the same sequential nature as bubbles and in addition, require a regeneration stage every few tens of bits. It is quite conceivable that CTD's will eclipse bubbles for serial memory applications (drums and disk replacement) in a few years. It is too soon to make 10-year predictions about CTD's and we should watch this technology closely.

Optical Memories

Optical memories are inherently capable of very high density (10^8 bits/in^2 even today) and high parallelism. The storage media can be manufactured very cheaply and made removable. For random access speed to improve much beyond .5 μsec over 10^{10} or so bits by 1980, a breakthrough in laser deflection techniques is required (not at all unlikely). Note that adding a high speed cache between such a memory and the central procession is an attractive combination.

It is highly likely that medium sized (10^6 to 10^9 bit) holographic associative memories will be practical in a few years. This can have great impact on information retrieval, catalogue searching, etc., when coupled with IC technologies.

Economies of scale will continute to be significant with optical memories. The light source (laser) deflection system, detection devices, etc. will be the dominant costs. Thus only fairly large optical memories are likely to be economically feasible at anytime in the forseeable future.

Drums and Disks

Perhaps and order of magnitude improvement is still possible in non-archival drum and disk memories through better heads, surface coatings and some improvements in mechanics. It seems likely, however, that rotating magnetic media will soon be overtaken by both semiconductors and bubbles (formally small and fast) on one hand and laser stores, etc. (formerly big and slow) on the other.

Others

Electron beam memories are similar in concept to optical memories, but promise higher densities, higher speeds, and perhaps lower cost. At present, however, a number of technologies must be stretched in order to achieve these goals and prediction is difficult.

II. Logic

Much of what has been said in the sections on IC and bubble memory is relevant with respect to logic as well. The cost of logic will continue to fall to levels where it represents a nearly negligible part of the cost of most computer systems of nearly any size. By 1980, today's medium to large scale CPUs will be available on a single chip (slice) for less than $50 (memory excluded). Almost the entire cost of logic will be in packaging and testing.

Propagation time of <1 ns per gate will be readily available in bipolar ICs and probably MOS as well. However, wiring progagation delays and capacitive charging times will be the determining factor in overall system speed. For this reason, very high levels of integration will be used. Significantly different architectures and processor organizations will be more prevalent than today, e.g. logic-in-memory arrays, distributed logic systems, systems with parallelism distributed over various levels, etc. Various types of redundancy may be included to improve reliability for large ICs. Very high speed gates will probably have propagation times of 100 ps. or less at moderate integration levels and will be used only in very close proximity to their inputs and outputs.

The real impact of increasing cheap memory and logic, of course, is that processing power can be economically put in places where it did not exist previously. It should be practical by the 1980's to have not only a terminal in the home but a very smart terminal and many smaller appliances, etc., having some computing power. A scenario might be envisioned analogous to the proliferation of small electric motors in the home in recent years.

Higher levels of integration and greater complexity in large computer systems will necessitate widespread use of automated logic design. As logic becomes exceedingly cheap, we will be increasingly willing to use more of it and to trade it for other properties we want such as higher yield, greater reliability, higher speed (via parallelism), and easier testing. This means that a single designer must be able to move easily over the domains of system design, logic design and IC design in order to take full advantage of any available logic technology.

PBX Summary

William F. Gunning

The FCC has allowed users to acquire PBX switching and terminal equipment from others than regulated common carriers. Lease or purchase arrangements are possible.

The future office can be best served by an integrated communication control system such that: (1) the user may connect his telephone and/or video terminal to one or more others for person-to-person communication; (2) he may gain access to digital, image and audio files, to computing capability and to hard copy devices; (3) he may reach distant people and machines through the use of the public network or private long haul communication services; (4) machines may originate communication to people and to other machines both local and remote.

Time division (not space division) switching and distribution technology will simplify installation and accomodation to change and reduce cost.

Information system storage and data compression/expansion capability must be balanced by the cost of transporting information. ATT broad bandwidth costs about 20 cents per megabit per kilomile. The cost will probably drop 50 to 1 by 1980. Today, 6 hour cross-country air shipment of magnetic tape costs less than 0.01 cents per megabit per kilomile.

Automatic information routing and transmission will be controlled by the same equipment used to automatically control information generation, manipulation, storage and display. The communication common carrier can supply only a limited class of services. The total information handling needs of an organization will be better met by equipment and services provided by a different kind of supplier.

PBX

William F. Gunning

In computer terms, the telphone network is a single, interconnected, automatic machine that allows efficient use to be made of a hierarchy of resources on a demand basis by millions of terminal users. The enormous complexity of redundant levels of switching, control, transmission facilities, automatic cost accounting, and maintenance components are faily well hidden from view.

The PBX (Private Branch Exchange) is an example of the principle of distributed control in resource allocation. It allows interconnection of geographically clustered terminals without the use of resources at the next level up that are more expensive (trunks and central office switching).

We can think of a generalization of the PBX function in the context of the future office to include interconnection of capabilities beyond the present common carrier communication trunks and internal telephone lines.

Present PBX Capability

PBX services that are technically available in present day equipment are surprisingly numerous. Not all are universally covered by regulatory tarrifs. Some examples are:

1. The familiar keyset "hold" and "comm" buttons allow the terminal user to handle interrupts according to his immediate evaluation of priorities. He is not able to disable the interrupts however.

2. Several means are available to deal with the situation when one is not at his terminal. "Call forwarding" and "follow me" allow the PBX to automatically route calls to user selected alternate destinations. The "message waiting" lamp (commonplace in motels and hotels) is another means for the system to deal with the absent addressee.

3. The "call waiting" feature places a distinctive tone on the line of a call in process to identify the fact that someone is in a queue.

4. The "priority interrupt" feature allows preemption of a busy channel.

5. Automatic dictation and phone answering devices allow filing of audio messages for deferred delivery.

6. A "do not disturb" feature allows selective deferring of incoming calls. A recorded explanation or diversion to another destination can be arranged.

7. Subscriber controlled conference calls can be established. The size of the conference is limited to a few parties.

The features mentioned are designed primarily for voice communication, but many will extend directly to video communication. Many of the more useful functions listed are very expensive to mechanize using the relay logic of presently available equipment and, therefore, are not widely used.

When the PBX is extended to become a more generalized resource allocator, it will include more than analog (voice or video) person-to-person communication. Low cost semiconductor logic can be applied and the PBX function can be coordinated with the complete information manipulating system or service. This will allow lower cost implementation of the features listed plus the use of the two-way video terminal in the office as an access device to both analog and digital files plus computer data manipulation capabilities -- that is, interactive man-to-machine communication.

Technology

For more than 50 years of automatic telephone equipment history, circuit interconnections have been made by moving metal contacts. The step-by-step, two motion Strowger switch is still being installed in many PBX situations and represents about one half of the switching capability in the total system today. The crossbar relay is substantially faster, more reliable and capable of more sophisticated control operations than "direct control" stepping switches. Electronic (ESS) offices now being installed use hermetically sealed reed relay contacts for increased speed and reliability. In both the crossbar and ESS offices the control function is separated conceptually and physically from the switching or information path making function. These are all space division switches in which a selected channel is dedicated full time to the communication needs of the interconnected terminals. Both crossbar and reed relays are capable of switching picture phone (1MHZ) bandwidth analog signals.

Switching exchange technology is heavily influenced by the venerable telephone instrument. The most demanding feature is the bell which requires about 100 volts at one watt. Phones using "tone ringers" cost about the same and have allowed solid state PBX switching systems to be built (e.g., the

IBM 2750 -- distributed in Europe). It is not clear that semiconductors would beat reeds in building a space division exchange with 1000 or more multi-megacycle video terminals even by 1980.

Time division, binary digital transmission technology is already in widespread use in the telphone system. Close to one million circuits (T1 carrier) are in place in which ordinary voice communication is handled purely digitally by sending sequential 7 bit coded samples of 24 different speakers over one pair of wires. The Bell System is in the process of conversion of all of its transmission facilities to binary digital form. This conversion will not be complete until 2000. It is less costly for Bell to use 64 kilobits per second to provide an ordinary voice communication channel in the T1 system than it is to transport the information in the conventional 3 kilohertz analog audio form. This is only one of several reasons to expect a continuing reduction of the cost of transporting binary information in electrical form. Recently authorized competition for the bit transportation market should also help. Present costs are about 20 cents to send 1 megabit 1 kilomile (50% utilization of 50KBS line). By 1974, ATT promises switched broadband digital service to 60 major cities. An order of magnitude reduction in cost seems reasonable by 1975 with another factor of five by 1980.

This should be compared with machine readable information delivery in another form. Shipment of 8 reels of video tape to New York from San Francisco in less than 6 hours,costs about $23.00 today. Each 1200 foot reel will hold over 10^{10} bits (see Urbach). The cost is less than 0.01 cents per megabit per kilomile. Bell estimates that 1 million picture phones will be in service by 1980. Each long haul picturephone circuit is a 6.3 megabit/second digital channel.

Information transportation costs will strongly influence future information system design and operation favoring multiple copies of slowly changing information files. Bandwidth compression/expansion equipment will be part of trunk signal interface function.

Standard telephone exchange twisted pair cable is used by the Bell System to carry 1.5 megabits/sec of binary information in the T1 system with simple pulse repeaters spaced about every mile. The same cables also are being used for the 1Mhz analog Picturephone video. Coaxial cable is used to hundreds of times this bandwidth in CATV and long haul telephone systems.

It will probably be cheaper to wire an office building with coax using addressed, sequential digital and/or analog messages in time-division mode (like the ARPA Network). By 1980 the office installation can use a conducting, layered floor covering (to be field tested by Dole Electro Systems in '73) that distributes both power and communication signals throughout the room and allows changes in furniture and fixture placement or type to be made with ease.

Time division transmission (distribution and collection of information) will allow time division switching to be used for the PBX function which is exactly what computer technology does best.

Regulatory Factors

The Carterphone decision led the FCC to allow a private user to supply his own terminal to terminal interconnection capabilities (PBX) and meet the common carrier at trunks. A standardized format and a protective mechanism safeguard the integrity of the public automatic switching network. This regulatory fact will allow the offering of a complete communication service capability (to be sold or leased) to a user by unregulated suppliers. The bandwidth, interconnection means and protocols, and overall technical implementation can be completely different from those dictated by the constraints (technical and regulatory) imposed on the common carrier. Appropriate conversion to the common carrier format will occur at the trunk interface.

A specialized information system designed specifically for the needs of the office or an educational setting can be freed from the technical and economical restrictions imposed on the common carrier. For example, we can use high resolution, high contrast, large area color displays which could not be justified solely for person-to-person communication needs, but which is almost certain to be necessary for most effective man-to-machine communication.

The PBX function can perhaps include improved means for handling the interrupts imposed by the present telephone system. One could record a personalized statement (audio and/or video) of the time at which he plans to reactivate his interrupt capability and request that messages be filed for delivery at that time. Letters and memos can be augmented by filing an analog (voice or video) message in a queue for later delivery. Whether it is stored internally in digital or analog form is a system designers choice.

The Xerox organization does not presently possess the capability of implementing a voice PBX system. The hardware for basic voice functions is available commercially at a cost of between $150-250 per line. The experience necessary to interface with the common carrier trunks and handle the very real problems of transmission, cross talk and wiring a facility can be acquired. They represent a small part of the total task of expanding human capability in learning or decision making by applying modern communication, storage, switching and data manipulation technology.

PBX Interfaces

The expanded PBX will provide interfaces for (1) internal terminals, (2) the public network (trunks), (3) information processors and files (analog and digital) and hard copy terminal equipment. The system will allow calls to be originated by any terminal or machine to any other terminal or machine, subject only to administrative restrictions of access authorization.

Privacy and Access Control

The questions of privacy and security of stored information has satisfactory technical solutions analogous to lock and key functions at an almost arbitrary level of safeguard. Encription ("scrambling") of data in binary digital form can guard against wiretap intrusion during transmission. Implementation requires only uncomplicated computer type logic. The problem of proper identification of the individual desiring access needs more attention. Examples of suggested solutions are: (a) an automatic thumbprint scanner, (b) voice print recognition, and (c) a memorized algorithm use by a person to generate a response to a string of random digits supplied by the computer/PBX. This last system seems to be satisfactory at Project MAC.

The more important question of determining how to decide who should and should not have access to what information is a question of enormous impact to society. Delay in finding a satisfactory solution may seriously impede full exploitation of our technical information manipulation capability.

Display Transducers

Alan Kay

The minimum acceptable display terminal in 1980 will have the following characteristics:

1. 1024 x 1024 picture elements of color/b&w, 90 ∿ 100 lines/inch.
2. 90 ∿ 100:1 dynamic range with 64 shades of grey.
3. TV compatible, picture storage for 10 minutes, selective updating.
4. Portability: flat screen and <10 lbs. Max dimension - 1-1/2" x 12" x 15".
5. Local computation and buffering provided by powerful LSI chips and cassettes.
6. I/O includes telephone, picture-phone and TV bandwidths for analog and digital data. Keyboard, pointing devices, stereo, etc.

Several thousand documents of mixed digital and analog information will be stored and used locally. Windowing and high resolution allow Xerox like quality and larger effective surface.

The super display will have more of everything, will not be portable, (but part of it might be worn) and will mainly differ from the minimum device by offering much more real time computation for TV frame rate simulations.

Today's technologies are not quite extrapolatable to 1980. CRTs have focusing problems and are bulky. The Crystalflex is slow or requires much power. The eidophor is too large and messy. LED panels are too expensive and draw much power. The plasma display is flat, but requires voltage switching and has poor modulation of grey scale. It will appear in a color/1024 x 1024 version which will allow spatial half toning. Cost will go to $10 a panel. A small modulated laser,raster scanned onto a Ruticon, using Schlieren projection, appears to be the best candidate so far. The main disadvantages appear to be power and frame rate.

The computer mediated display should be well on its way towards supplanting paper in 1980, to become the main source of <u>all</u> kinds of visual information.

DISPLAY TRANSDUCERS by Alan C. Kay

New products frequently exhibit a five year lag between first inception and appearance at the market place. Even if this is so, it means that the display technology of the 1980's need not be invented until 1975 to be a viable product. This is somewhat of a relief to the ardent crystalball polisher since current display terminal technology leaves quite a lot to be desired even for extrapolation over an entire decade.

What will be the minimum acceptable display terminal of the 80's?

1. Resolution should be a minimum of 1024 lines (or one million picture elements) in color or monochrome. There should be not less than 90 resolution elements to an inch of display surface. This is necessary both for amount of information displayed and also to supply enough resolution for good readibility.

2. Dynamic range should be 90:1 witth a minimum of 64 shades of grey scale. Minimum brightness should be 10 foot-lamberts.

3. Modes of the device should include:

- a. TV compatibility
- b. Image storage for up to 10 minutes
- c. Selective updating and erasure
- d. Cursor element display while in storage mode.

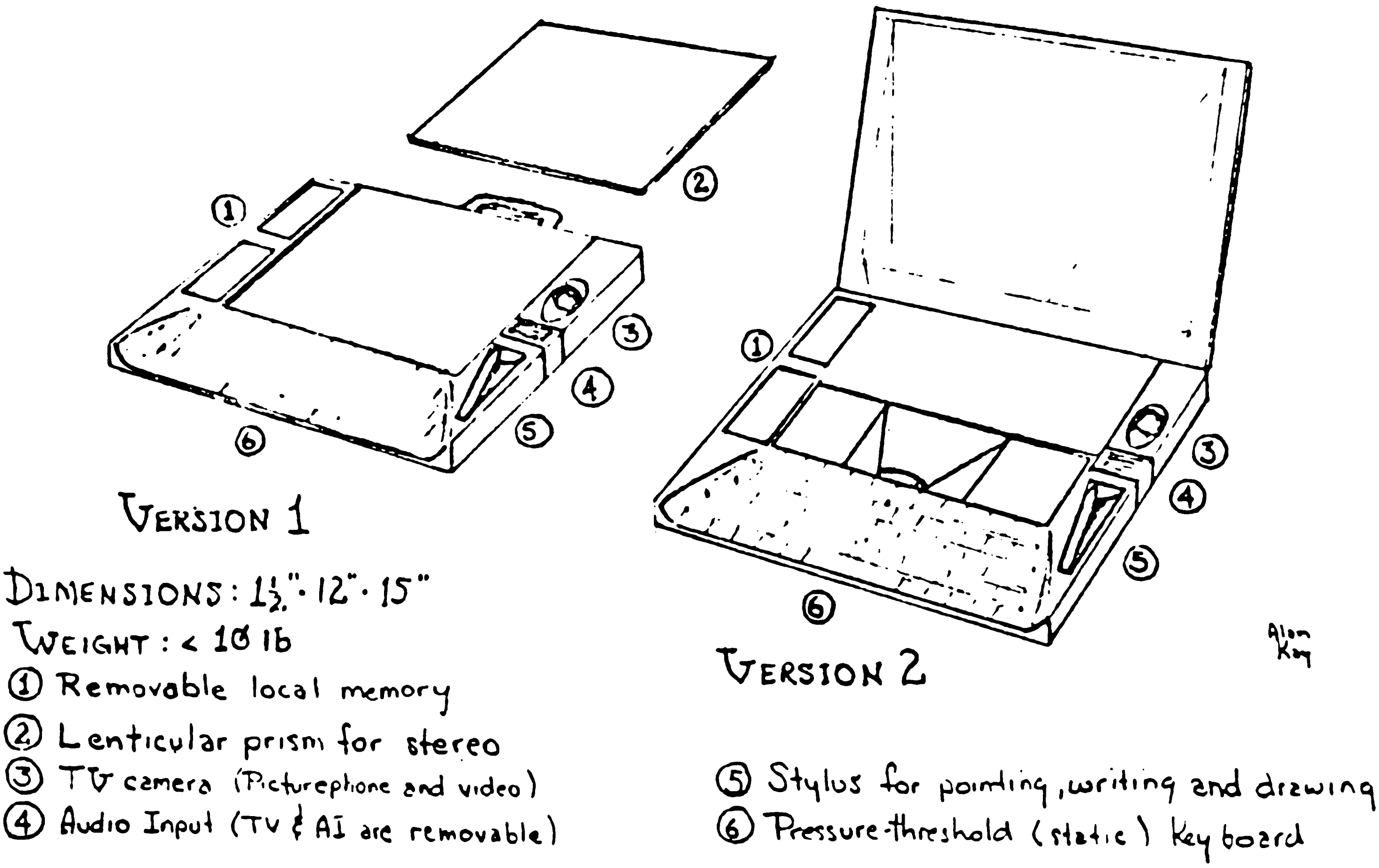
4. Portability is important. The device should require minimum space and no special handling. It should have a flat screen if at all possible and an ability to operate from rechargable nickel-cadmium batteries would allow use away from central power sources.

5. Local computation and buffering will be supplied by a chip sized processor and whatever the cheap mass storage device will be (cassettes now). This should include local font generation for characters. (See the article by R. Schoup on HW for more details).

6. Inputs and Outputs will cover a wide variety of media, including both narrow band (telephone) and wide band (picturephone and coax) transduction, as well as a static keyboard, pointing devices, and audio and TV I/O. There will be no moving parts when possible. Braille air driven tactile "wrist bands" for the blind can be provided. A simple stereo display can be made by superimposing a lenticular prism over the display and transmitting each eye point of view as every other point horizontally.

7. The size of the entire device should be such that is is convenient for executives (size of top of attache case), children (weigh less than 10 lbs), and others.

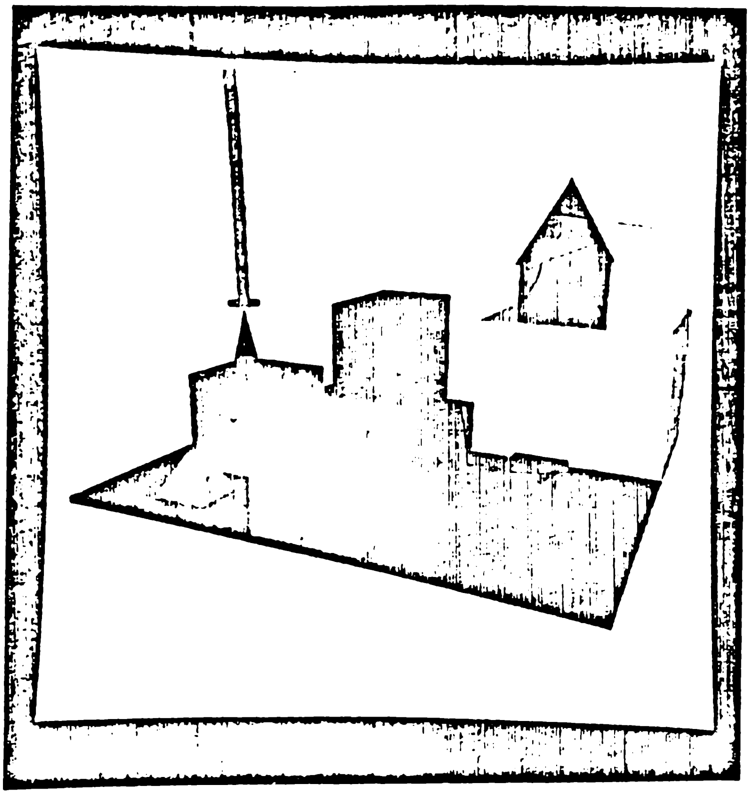
8. The cost should not be more than 110% of commercial TV sets using the same technology (about $500 in 1971).



In short, the minimal terminal of the 1980's is nothing less than a comprehensive transducer between a human being and computerized knowledge, whether used locally (by itself) or when tapped into the high bandwidth information utilities of the office and the world. The local memory will be able to store a mix of many thousands of coded documents along with straight audio and video information.

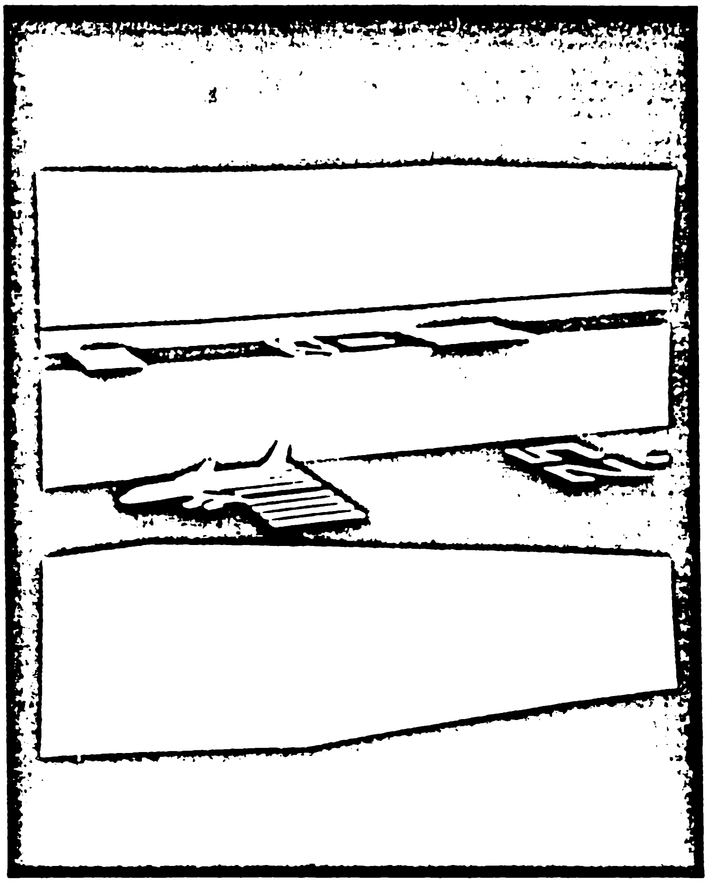
All of the user's current information may be retained in computer processable form in this portable device to be viewed and manipulated while on a plane, in a taxi, or at home. Windowing techniques and high resolution will eliminate much of the desire for paper while allowing many more documents, etc. to be at the fingertips of the user.

The device will be locally capable of generating complex simulations including "simulated video" (or continuous tone) displays. See picture, which is a simulation of a table with blocks on it. More computation and display bandwidth can be had through a coax connection to a (XEROX supplied) utility.



The "large", non-portable display of the future will resolve at least 100 points to the inch (the average performance of a Xerox machine), and will display on an area of at least 18 by 24 inches. It may be an entire desk ("working surface") top or a wall. Stereo can be provided through various means --- most of them will involve a sacrifice of resolution elements. Any item in the display may be refered to tactily by using the entire display surface as a tablet.

Color, Three-D, continuous tone, real-time simulations of moving siutations will be commonally available. Tactile inputs and outputs will be provided through feedback torque motors, modulated air transducers, joysticks, etc. See D. Damouth's paper for more. The user may even "wear" his display for complex applications. For instance, in air traffic control of the future, head-mounted displays can be used to simulated the human controller as being 2 miles tall by showing 3D simulations of radar data transformed into graphic representations of the planes.



City planners will use detailed (and changable) displays of cities to be built. Business executives can view highly complex interrelations between divisions of a corporation, and of the corporation with the outside world, then run simulations to "see" what might happen using various assumptions about the company's future.

Learning is the process of developing a model (or simulation) of knowledge in one's mind. Children will finally have a device which is at once both tool and toy, that can be used to "try out" ideas and fantasies as well as to encourage self organized and motivated developement.

TECHNOLOGY

How far are the preceding dreams from reality? One way to find out is to try and build such devices from today's technology, then "guestimate" how long it will take to remove the deficiencies.

Version 2 of the minimal transducer can be built today if the abilities of battery operation and TV frame rate can be discarded. A galvanometer-mirror, rastor scanning laser, writing on a liquid crystal ("Crystalflex") surface or on the photosensitive Ruticon using schileren optical projection will do the job.

Both devices currently demand about 150 watts of continuous power which somewhat precludes batteries. The Ruticon will allow a 10 frame/second rate which is OK for most computer usage but disallows TV. The Crystalflex display has about a 1 millisecond latency per point which requires sloth or high power.

The runners-up in this competition include other light gated amplifiers, LED's (see Starkweather) and plasma panels. The LGA's are summarized in the attachment and LED's may not come down in price to a reasonable level.

The plasma panel is the most extrapolatable display. It will appear in a 1024 * 1024 color version with about 120 resolution elements to the inch. Whether as many as 16 grey tones will ever be achieved is in serious doubt. On the other hand, the resolution provided allows spatial halftoning to be done with considerable success. An annoyance is that fairly high voltages will have to be switched concurrently in order to attain TV frame rates. The potential fabrication costs of these panels is very low and will probably go under $10.00 before long. Battery sources do not seem to be possible with plasma panels.

A solution to a number of battery storage problems can be solved if airlines could be convinced to install power sources, etc.

Many of the computer technology questions are summarized in R. Schoup's article. The costs seem to be plummeting at a still constant rate. Sony manufactures the innards for their color TV's for about $25 to $50 dollars. The use of analog and digital LSI will bring the total electronics cost of the transducer to this level.

For the large, nonportable system, the siuation is similar. High resolution projection systems such as the Eidophor (GE) and the laser scanned Ruticon (Xerox) can deliver what is needed up to about 1000 color elements and 3000 monochrome. The headmounted display is already a reality at the University of Utah although more needs to be done or sensing the position of the head. A real-time halftone simulator which runs at TV rates is due within this year. Tactile feedbacks, etc. are being studied by NASA, and Bell Labs.

A "display" technology which is lagging seriously is that of software design and engineering. If the perfect display were to materialize tomorrow, there is still woefully little than can be done in the manipulative sense. Although many design systems have been labouriously created, there are not many that would claim to be useful for more than limited, narrow applications.

How to score light-gating CRTs

To insure high performance, versatility, economy, and reliability, the ideal cathode ray tube for large-area projection display should have certain characteristics:

- Gray scale. It should display shades of gray as well as outlines. Ten shades of gray, or a minimum contrast ratio of 20:1, are desirable.
- Color. It should have a color version.
- Brightness. The tube system should be capable of a projected light intensity of 5,000 lumens for black-and-white and 2,000 lumens for color. Versions with more moderate brightness, down to about 200 lumens, should also be available.
- Resolution. In black-and-white, the CRT should resolve 1,000 TV lines, or 1 million image points. For color alphanumerics and graphics, the resolution should be the same; for color pictorial displays, it should be about 500 lines.
- Variable persistence. The duration of continuous light emission should be adjustable between several seconds and approximately 20 milliseconds. At the TV refresh rate of 30 times per second, there should be no charge build up.
- Storage time. The CRT should be able to store an image—without necessarily displaying it—for at least 10 minutes without significant degradation.
- Selective erase. It should be possible to selectively erase and replace a part of the image.
- Cursor display. An overlay of image elements requiring short persistence (like a cursor, for example) with stored image elements should be possible.
- Tube life. Life expectancy should be comparable to that of conventional CRTs, which last for several thousand hours.
- Standard optics. The projection optics and light source should be simple and straightforward. If possible, schlieren optical systems, which essentially make visible inhomogeneities in a material, or reflection-polarized light systems should be avoided, since they are relatively complex and costly.
- Standard CRT technology. The CRT, from its cathode and gun to its high voltage and deflection circuitry, should employ standard, well understood technology to maximize reliability and facilitate manufacture.
- Target technology. The underlying principles of target structure and operation should not be unique, but also be employed in applications other than the light-gating CRT, to cut cost and development time.
- Optical axis. The light-optics path should not interfere with the electron-optics portion of the tube. Usually this means using either an off-axis light-optics system or an off-axis electron beam with the unsymmetrical deflection necessary for keystone-distortion correction.
- Adjustments. Installation of the light-gating CRT package in a system should not require supernatural skill at making optical adjustments.
- Special equipment. The CRT should not require special—and expensive—auxiliary equipment like heaters or vacuum pumps.

The accompanying table is the author's estimate of the degree to which the various light-gating projection systems approach these ideal criteria. For each criterion, a system is rated as: 1—if it meets it unconditionally; 2—if it does so with reservations; 3—if it has only a 50-50 chance of meeting the criterion; 4—if it's unlikely to meet the criterion; 5—if it won't meet the criterion without a major, unforeseen breakthrough.

CATEGORY OF IDEAL TUBE STANDARDS → / TECHNOLOGY ↓	1 GREY SCALE	2 COLOR VERSION	3 IMAGE BRIGHTNESS	4 RESOLUTION	5 VARIABLE PERSISTENCE	6 STORAGE	7 SELECTIVE ERASE	8 CURSOR OVERLAY	9 TUBE LIFE	10 OPTICAL SYSTEM	11 STANDARD CRT TECHNOLOGY	12 TARGET TECHNOLOGY	13 OPTICAL AXIS	14 ADJUSTMENTS	15 SPECIAL EQUIPMENT	REMARKS
DARK TRACE TUBE	2	5	3	3	5	1	4	5	1	2	1	2	1	1	2	Demonstrated feasibility for limited application (direct view storage tube); 38 Points
POCKELS EFFECT TUBE	1	4	2	3	5	5	5	5	2	3	1	3	1	2	1	Limited application in B&W displays at TV rate; 43 Points
EIDOPHOR PROJECTOR	1	1	1	1	5	5	5	5	2	4	5	3	1	4	5	Demonstrated feasibility for limited application (large screen TV projection, B&W and color); 49 Points
LIGHT VALVE TUBE	1	1	2	1	5	5	5	5	2	4	4	3	1	2	2	Demonstrated feasibility for limited application (large screen TV projection, B&W and color); 43 Points
ELECTROSTATIC DISPLAY AND STORAGE TUBE (ESDT)	3	5	2	1	5	1	5	5	1	2	2	2	5 1	2	4	Limited application (projection storage of display graphics); transmission 45 points, reflection 41 points
ORIENTED PARTICLE TUBE	1	5	2	2	1	1	1	1	1	2	1	4	5 1	1	1	Multipurpose tube; transmission 29 points, reflection 25 points
DEFORMOGRAPHIC STORAGE AND DISPLAY TUBE (DSDT)	1	4	1	1	1	1	1	1	1	4	3	4	5 1	3	1	Multipurpose tube; transmission 32 points, reflection 28 points
ARRAY-TARGET TUBE	1	1	1	1	1	1	1	2	1	3	2	3	1	2	1	Multipurpose tube; 22 points