DOCUMENT RESUME

ED 146 900 IR 005 282

AUTHOR	Paisley, William; Butler, Matilda
TITLE	Computer Assistance in Information Work. Part I: Conceptual Framework for Improving the Computer/User Interface in Information Work. Part II: Catalog of Acceleration, Augmentation, and Delegation Functions in Information Work.
INSTITUTION	National Science Foundation, Washington, D.C. Div. of Science Information.
PUB DATE	31 Aug 77
CONTRACT	C76-05489
NOTE	105p.; Project Title: Computer Assistance in the Use of Scientific and Technical Information
EDRS PRICE	MF-$0.83 HC-$6.01 Plus Postage.
DESCRIPTORS	Automation; *Computer Oriented Programs; Computers; Computer Science; Cybernetics; *Information Processing; *Information Science; Information Systems; *Information Theory; *Library Automation

ABSTRACT

This study of the computer/user interface investigated the role of the computer in performing information tasks that users now perform without computer assistance. Users' perceptual/cognitive processes are to be accelerated or augmented by the computer; a long term goal is to delegate information tasks entirely to the computer. Cybernetic and psychological theories help to identify twelve perceptual/cognitive processes that underlie information tasks: scanning, fixating, feature extracting, decoding, comparing, deciding, inducing, deducing, retrieving, selecting, transforming, and producing. Functions that the computer may perform to accelerate, augment, and delegate these processes are exemplified by displaying, analyzing, simulating, and editing. In the late 1970's, computer research and development can increasingly shift from system-oriented problems to user-oriented problems. The communication functions shared by most users are displaying, commanding, inputting, editing, outputting, and transmitting. It is neither necessary nor desirable that totally new information systems be designed to accommodate these functions. Four types of existing systems (information storage and retrieval, teleconference, instruction, decision support) should be regarded as extendable with respect to new functions. Since existing systems permit low-cost evaluation of new functions, the sequel to this study should be a program of acceleration, augmentation and delegation experiments using existing systems. (Author/JAB)

COMPUTER ASSISTANCE IN INFORMATION WORK

A Report to the

Division of Science Information,

National Science Foundation

PART I: CONCEPTUAL FRAMEWORK FOR IMPROVING THE COMPUTER/USER INTERFACE IN INFORMATION WORK

PART II: CATALOG OF ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS IN INFORMATION WORK

William Paisley and Matilda Butler

Applied Communication Research, Inc.

Palo Alto, California

COMPUTER ASSISTANCE IN INFORMATION WORK

A Report to the

Division of Science Information,

National Science Foundation

PART I: CONCEPTUAL FRAMEWORK FOR IMPROVING THE COMPUTER/USER INTERFACE IN INFORMATION WORK

PART II: CATALOG OF ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS IN INFORMATION WORK

William Paisley and Matilda Butler

Applied Communication Research, Inc.

Palo Alto, California

This report is based upon research supported by the Division of Science Information, National Science Foundation, under contract C76-05489 (project title: "Computer Assistance in the Use of Scientific and Technical Information"). Opinions, findings, conclusions, and recommendations contained in this report are those of the authors and do not necessarily reflect the views of the National Science Foundation.

On-line users of this report: access WYL.KK.C69.CAIW in WYLBUR on PUB004 of the Stanford 370/168.

August 31, 1977

ACKNOWLEDGEMENTS

This project benefited from the criticisms and suggestions of many colleagues in the Stanford area and elsewhere. We want to acknowledge the specific influence on our thought of the following consultants: John Bennett (IBM Research Laboratory, San Jose); Douglas Engelbart (Stanford Research Institute); Richard Miller (Applied Communication Research); Edwin Parker (Stanford University); and Frances Spigai (Lockheed Information Systems).

At our request, the NSF Division of Science Information secured several reviews of the draft final report from specialists in subject fields that the project required us to travel through without visas, so to speak. These reviews brought corroboration of some of our points and led to revision of other points. We are grateful to NSF-DSI and to the reviewers for this assistance.

ABSTRACT

This study of the computer/user interface investigated the role of the computer in performing information tasks that users now perform without computer assistance. Users' perceptual/cognitive processes are to be accelerated or augmented by the computer. A long-term goal is to delegate information tasks entirely to the computer.

Information work (the production, distribution, transformation, storage, retrieval, and use of information) is analyzed in terms of information tasks that are more generic than each type of information work itself. Sequences of information tasks are often named after the focal tasks that they contain. For example, "decision making" is an information task in itself, but it also names a sequence of tasks that includes formulating a problem, determining information needs, searching for information, selecting and processing relevant information, comparing alternative decisions, and making the decision.

Cybernetic and psychological theories help to identify twelve perceptual/cognitive processes that underlie information tasks: scanning, fixating, feature extracting, decoding, comparing, deciding, inducing, deducing, retrieving, selecting, transforming, and producing. Functions that the computer may perform to accelerate, augment, and delegate these processes are exemplified by displaying, analyzing, simulating, editing, etc.

In the late 1970's, computer R&D can increasingly shift from system-oriented problems (e.g., memory size, processing speed) to user-oriented problems (e.g., establishing an optimal interface for each type of information work). Priorities can be set for computer R&D and the implementation of new functions by estimating aggregate user benefits (number of users benefiting X average benefit per user) and aggregate costs. The communication functions shared by most users of computer-based information systems (displaying, commanding, inputting, editing, outputting, and transmitting) have high priority according to this estimation procedure.

It is neither necessary nor desirable that totally new information systems be designed in the next decade to accommodate these functions. Four types of existing systems (information storage and retrieval, teleconference, instruction, decision support) should be regarded as extendable with respect to new functions. Since existing systems permit low-cost evaluation of new functions, the sequel to this study should be a program of acceleration, augmentation, and delegation experiments using existing systems.

CONTENTS

Summary 1

PART I: CONCEPTUAL FRAMEWORK FOR IMPROVING THE COMPUTER/USER INTERFACE IN INFORMATION WORK

1. Conceptual Framework 18

2. Scientific and Technical Information Work 33

3. Increasing the Quantity and Quality of Information Work 41

PART II: CATALOG OF ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS

4. Preconditions for Acceleration, Augmentation, and Delegation: Generic 1977 Hardware/Software and Extendable Systems 54

5. Acceleration, Augmentation, and Delegation Functions Implemented Chiefly through Hardware . . 63

6. Acceleration, Augmentation, and Delegation Functions Implemented Chiefly through Software . . 79

7. Indications for 1977-1980 Research and Development 88

Bibliography 95

SUMMARY

Outline of Points

S.1. Conceptual Framework 2

S.2. Scientific and Technical Information Work 3

S.3. Increasing the Quantity and Quality of Information Work 8

S.4. Preconditions for Acceleration, Augmentation, and Delegation: Generic 1977 Hardware/Software and Extendable Systems 10

S.5. Acceleration, Augmentation, and Delegation Exemplified in the Extension of Existing Systems . 14

S.6. Indications for Research and Development 16

S.1. CONCEPTUAL FRAMEWORK

PURPOSE. The purpose of our research on the computer/user interface is to expand the role of the computer, including computer-driven peripherals, in performing tasks that information workers now perform without computer assistance. Information workers' perceptual/cognitive processes are to be accelerated and augmented by the computer. A long-term goal is to delegate information tasks entirely to the computer.

GUIDING QUESTIONS. What are the information tasks that groups of information workers (e.g., researchers, developers, managers, planners, practitioners, students) now perform? What are the perceptual/cognitive processes that underlie each information task? For a target year such as 1985 and the probable computer power of that year, what is a productive scenario of acceleration, augmentation, and delegation functions that the computer can perform? What new configurations of hardware and software will these functions require? What kinds of research and development on hardware, software, and users will be required to make these functions available?

GROWTH OF THE "KNOWLEDGE SECTOR" IN THE AMERICAN ECONOMY. Information economists state that roughly half of national income and GNP now originates in information work. Research and development (R&D) expenditure exemplifies the growth of the knowledge sector. In 1941, R&D expenditure from all sources (e.g., government, industry, higher education) was $900 million; in 1971 it was $27 billion (National Science Board, 1975).

The "first industrial revolution" was founded on material-transforming technologies that shifted physical effort from people to machines. The "second industrial revolution" is being founded on information-transforming technologies that shift perceptual/cognitive effort from people to machines.

As information becomes a dominant commodity in itself and a key to other commodities, the literature of information on information grows. Many researchers contribute to this literature. Of particular relevance to this project is the study of perception, cognition, motivation, etc., as processes in the information user that determine the extent and effect of information use.

INFORMATION WORK. Information work can be defined as the production, distribution, transformation, storage, retrieval, and use of information. Information can be defined structurally as an encoding of symbols into a message of any form, propagated through any medium, and processed by any sensory receptors. Information can also be defined functionally as any stimulus that modifies cognitive structure in the information user.

INFORMATION TASKS. Information work consists of sequences of information tasks that are more generic than each type of information work itself. A sequence of information tasks is often named after the focal task that it contains. For example, "decision making" is an information task in itself, but it also names a sequence of information tasks that includes formulating a problem, determining information needs, searching for information, selecting and processing relevant information, comparing alternative decisions, and making the decision.

TASK SEQUENCES AND "PLANS." The tasks that make up information work are best understood in the framework of "plans" that combine them in sequences. Miller, Galanter, and Pribram (1960, p. 16) define a plan as "any hierarchical process in the organism that can control the order in which a sequence of operations is to be performed." The information elements that guide a plan are called "images" by Miller et al. (after Boulding, 1956); they are also known in the literature as "cognitive maps," "personal constructs," etc.

INSIDE THE PLAN. The simplest formulation of a plan by Miller et al. is the TOTE unit, which describes how an organism moves toward a goal by testing-operating-testing-exiting its way through each phase of a problem. In a complementary formulation, Newell and Simon (1972) describe the adaptive information processing system or IPS in terms of receptors, processor, memory, and effectors that enable an organism to solve a problem through a sequence of "elementary information processes" and motor behaviors. Related elements of the Miller et al. TOTE and Newell-Simon IPS theories are brought together in Figure 1.

PERCEPTUAL/COGNITIVE PROCESSES UNDERLYING INFORMATION TASKS. There are many theories of human perception and cognition; their concepts range from the chemical (e.g., rhodopsin-retinene cycle in the retina) to the social (e.g., group suggestibility in autokinetic perception). The most productive concepts for our purposes derive jointly from cybernetics and cognitive psychology. A minimum set of perceptual/cognitive processes can be defined as those that make the test and operate steps of the Miller et al. TOTE unit executable. Perceptual/cognitive processes of the "T" or test step are those that a plan requires procedurally for its execution. Without those particular processes there would be no test, and without the test there would be no plan. The perceptual/cognitive processes of the "O" or operate step are determined by the goal of the plan. It makes a difference in the "O" step whether the goal is to gather routine data, perform a crucial experiment, diagnose an illness, create a taxonomy, build apparatus, plan a program, etc.

Each perceptual/cognitive process of the "T" and "O" steps can also be located within the Newell-Simon IPS according to the locus of its execution. A minimum set of perceptual/cognitive processes is thus shown in Figure 2.

S.2. SCIENTIFIC AND TECHNICAL INFORMATION WORK

STI PRODUCTS AND SERVICES. Scientific and technical information (STI) is embodied in products and services that are produced, distributed, and used by information workers. These products and services have attributes such as "form," "content," and "context" that affect judgment of information value and probability of use. Judgment of information value involves inferred dimensions such as specifiability, locatability, acquirability, usability, relevance, timeliness, comprehensiveness, and authoritativeness.

CATEGORIES OF STI USERS. Efforts to improve STI systems are limited by the assumption that STI users are scientists and technologists only. There is an array of other users whose overall requirements for STI may equal those

FIGURE 1. RELATED ENTITIES AND PROCESSES IN THE IPS AND TOTE THEORIES.

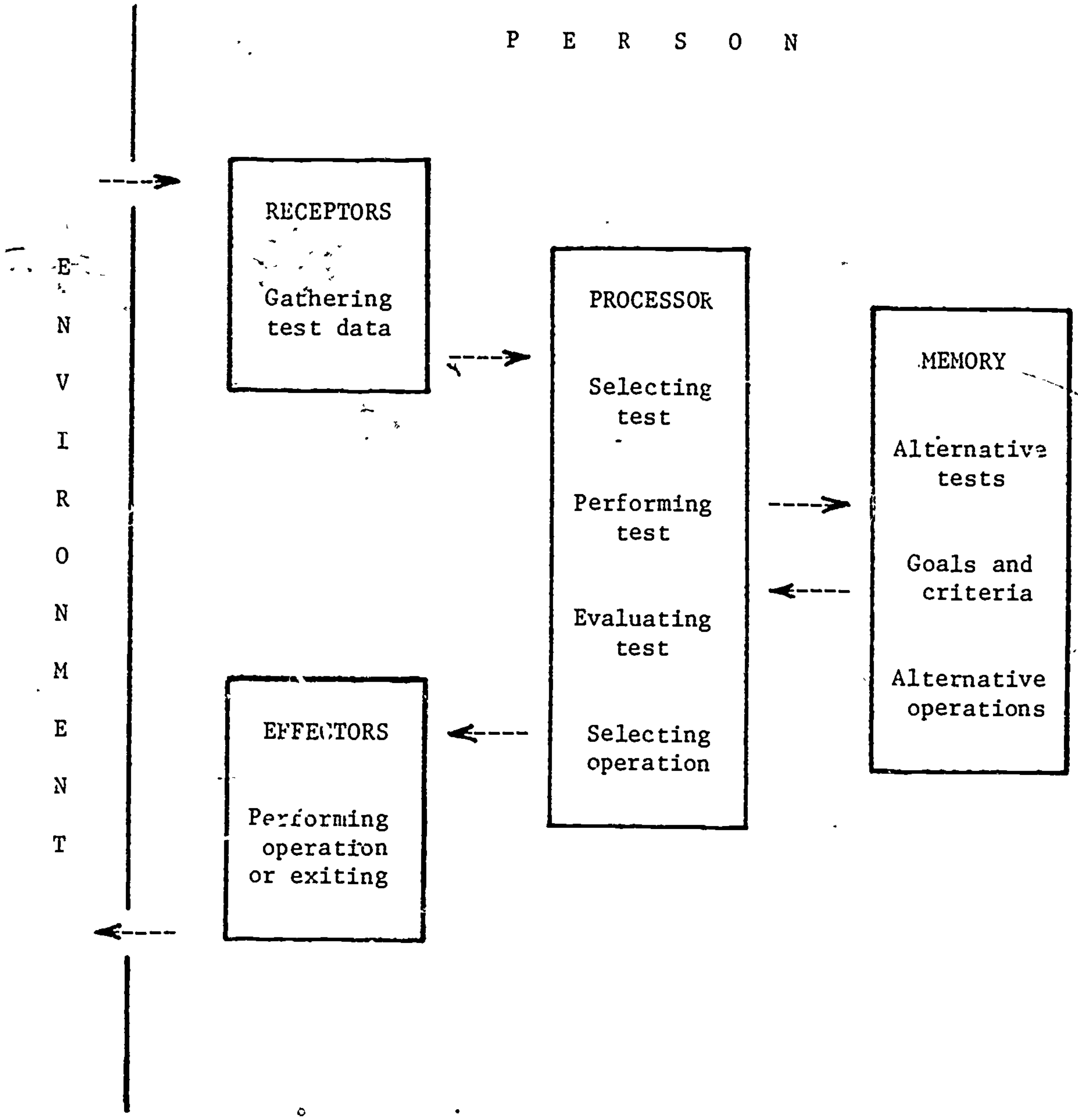


FIGURE 2. PERCEPTUAL/COGNITIVE PROCESSES IN INFORMATION WORK.

RECEPTOR LOCUS

Scanning

Fixating

TRANSACTED BETWEEN RECEPTOR AND PROCESSOR

Feature extracting

Decoding

PROCESSOR LOCUS

Comparing

Deciding

Inducing

Deducing

TRANSACTED BETWEEN PROCESSOR AND LONG-TERM MEMORY

Retrieving

Selecting

Transforming

TRANSACTED BETWEEN PROCESSOR AND EFFECTOR

Producing

of scientists and technologists. Twelve groups of STI users are identifiable: scientists, technologists, professionals, administrators, policymakers, editors and reviewers of STI, teachers, students, the public, librarians and other information specialists, publishers, and manufacturers of STI hardware and software. The first nine groups are substantive users of STI. The last three groups are procedural users; they manage, transform, and distribute STI.

THE STI SYSTEM/USER INTERFACE. The focus of our research is the system/user interface. Like other complex systems, STI systems have internal strengths and external weaknesses. The system/user interface is the weak link in most STI systems.

On the system side of the interface, information products and services "face" the user with attributes of form, content, and context. The user transforms these attributes into judgments of information value. On the user side of the interface, more attributes affect STI use than our twelve-fold grouping of users implies. The literature of "STI use studies" focuses on attributes of the user (e.g., demography, training, beliefs related to work), the work environment (e.g., work teams, communication networks), and the task (e.g., basic versus applied, rate of obsolescence of relevant information). Figure 3 summarizes attributes of STI systems and users affecting transaction at the interface.

ELECTRONIC STI SYSTEM/USER INTERFACES. Electronic distribution of STI is as old as the telegraph. The advent of each new electronic medium has shifted additional STI distribution from written to electronic forms. Prior to the computer, each new electronic medium supplemented an existing oral or written medium. The computer is a revolutionary rather than supplementary medium because of its transformational power. Alone among media, it can give back more than it is given, in the form of new information patterns.

It may be self-evident that the computer creates the most responsive STI system/user interface, but in fact few computer-based STI systems have outlived their development phases. Do such systems fail because their resources (databases) are insufficient, because they are too costly for the information markets they compete in, because they provide an unsatisfactory interface for users, because users are not adequately trained to use them, or because of other factors?

Until now, computer-based STI systems have been designed to supplant existing technologies, within the limitations of those technologies (e.g., nontransformability of content). What would a computer-based STI system look like and how would it function if previous conceptions of STI systems yielded to a new conception that exploits the information-transforming power of the computer?

The analysis of past STI system failures and the design of future interfaces should begin with the types of information tasks that STI users perform and the perceptual/cognitive processes that underlie these tasks. When suitably specified, the perceptual/cognitive processes should indicate

FIGURE 3. ATTRIBUTES OF STI SYSTEMS AND USERS.

PRODUCTS AND SERVICES	INTERFACE	USERS AND USE CONTEXTS
FORM Medium Format Periodicity	Some, not all, products and services are available at a given interface. Some, not all, attributes of these products and services are encoded.	INDIVIDUAL Demography Training/background Role/function Beliefs re work Beliefs re information
CONTENT Subject matter Breadth/depth of treatment Facts/inferences Style		WORK ENVIRONMENT Organizational demography Work teams Communication networks
CONTEXT Authorship Sponsorship Refereeship Publication/distribution Availability Cost	Perceptual/cognitive processes of users are affected by attributes of products and services, by attributes of the interface, and by the user's own background and tasks.	TASK Basic versus applied Diffuseness Obsolescence Phase Completion criteria

not only the most effective interface functions to retrieve information but also new functions to accelerate, augment, and delegate post-retrieval information tasks. The functions in turn should imply configurations of computer hardware and software as well as computer-driven peripherals (e.g., audio and visual displays) to be incorporated in the interface. These design considerations are interrelated in Figure 4.

S.3. INCREASING THE QUANTITY AND QUALITY OF INFORMATION WORK

THE MEMEX QUEST. Information scientists have been guided by a remarkable "image of potentiality" for more than three decades. Bush (1945) imagined "memex" to be a desk-sized electronic and micrographic information resource, capable not only of displaying vast documentary files at the user's command but also of merging the user's personal annotations and "trails" with the documents they describe. Exciting as the memex concept is, however, we can recognize its limitations: lack of networking or communication capability; support of exploration and learning tasks but not of analysis and decision making tasks; lack of transformative power over the symbols in its store.

ACCELERATION, AUGMENTATION, AND DELEGATION. The purpose of an information system is to perform information tasks that users cannot perform, or prefer not to perform, themselves. Simple information systems, such as books of facts or constants, merely save users' time. Rediscovery and recomputation are alternatives that users can resort to if an information system is not available.

Complex information systems perform tasks, such as multivariate simulation, that seem beyond users' power to rediscover or recompute. However, the systems' algorithms derive from human reasoning, and they too are dispensable "had we but world enough and time" to work through the algorithms manually.

Presumably, more information work can be accomplished with the support of information systems than without their support. Moreover, if information systems take over tasks that users find tedious or difficult to do, then users will enjoy their work more even though (or partly because) their productivity is greater. Productivity and user satisfaction are the information system benefits that offset information system costs.

The simplest role for an information system to play, and therefore the role played by the simplest systems, is that of accelerating the user's information task. Acceleration changes the time frame in which perceptual/cognitive processes occur but not the processes themselves.

A more complex role for an information system to play is that of augmenting the user's information task -- that is, assisting the user in the substance of his or her task and not just in the pace of its execution. There are two related senses in which information tasks are augmented and not just accelerated: (1) if the information system is more than a few orders of magnitude faster than the user in performing a task, such that the unassisted user would forego the task; or (2) if limitations in human perception/cognition (e.g., high-level pattern recognition) that make a task almost unperformable are overcome by the information system.

FIGURE 4. DESIGN CONSIDERATIONS AT THE STI COMPUTER/USER INTERFACE.

STI USERS	PRODUCTS AND SERVICES	INTERFACE
For the several groups of STI users, what information tasks comprise their information work?	What products and services are required as information resources for these tasks?	What configurations of hardware and software effectively interface STI users with products and services?
What are the perceptual /cognitive processes that underlie these tasks?	In what storage media should the products and services be stored?	What configurations of hardware and software effectively perform acceleration, augmentation, and delegation functions?
Which perceptual/ cognitive processes are relatively invariable (e.g., are delegatable but not acceleratable or augmentable) and which are relatively variable (e.g., are acceleratable and augmentable)?	Through what display media should the products and services be displayed?	How generic are these effective configurations across user groups?
	What attributes of products and services should be encoded for access at the interface?	What attributes of users and their tasks affect interface effectiveness?

In the most complex role that we project for an information system, the user's information task is entirely delegated to the system. The decisions by which the user guides an augmentation function are now made by the system itself using programmed criteria. If artificial intelligence principles enable the system to learn from experience in performing the delegated function, then its decisions can rival or surpass those of the user.

ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS IN STI USE. Although these functions can be introduced wherever computers and users are interfaced in information work, we restrict our attention to situations in which information workers turn to scientific and technical information with the anticipation that their plans can be advanced by STI use. Returning to the terminology of Section 1, we define the use of STI as the execution of a plan for searching, solving or deciding, and producing. The question to be answered, therefore, is how the perceptual/cognitive processes that underlie searching, solving or deciding, and producing can be accelerated, augmented, and delegated.

S.4. PRECONDITIONS FOR ACCELERATION, AUGMENTATION, AND DELEGATION: GENERIC 1977 HARDWARE/SOFTWARE AND EXTENDABLE SYSTEMS

GENERIC 1977 HARDWARE. The decade from 1965 to 1975 belonged to the "maxi" computer. When integrated-circuit computers of the IBM 360 and the CDC 6000 series began to replace their discrete-circuit predecessors, it was generally believed that large multi-purpose computers permitted the greatest computing efficiency. These computers became the central devices in educational and business computing systems that grew to serve thousands of users daily, including a high proportion of interactive and remote batch entry terminal users.

However, the same miniaturization and integration of devices that made large computers possible also made small computers inevitable. By 1975 the concept of "distributed computing" was undermining centralization. Physically small on-site computers were being installed at major nodes of large computer utilization, eliminating not only the line charges but also the service interruptions that large computers are susceptible to. The physical size of small and "mini" computers is misleading, moreover. Not only can their core memories be expanded to exceed those of almost any computer prior to 1965, but their greatly increased processing speeds permit interactive cycles that include repeated accesses to external memory without degraded performance from the user's perspective.

Undoubtedly the most-discussed developments in 1977 hardware are "smart" and "intelligent" terminals. Smart terminals are equipped with software or "firmware" that is programmed by the manufacturer for switchable flexibility with respect to communication speeds, character sets, display configurations, etc. Intelligent terminals are user-programmable for even greater flexibility and for data entry and management (e.g., editing) functions that otherwise burden the central processor.

GENERIC 1977 SOFTWARE. The decade from 1965 to 1975 saw less change in software than in hardware. Computer operating systems designed for the IBM 360 and CDC 6000 series introduced concepts of time sharing, virtual memory allocation, multiprogramming, and multiprocessing that continue to structure new operating systems. High-level programming languages such as COBOL and FORTRAN continue to generate most applications software.

Thousands of software packages for business and research applications were developed between 1965 and 1975. Because many of the packages were machine-dependent, little convergence and standardization has taken place. The most popular packages are those that are IBM 360/370 compatible and/or those that require minimum support in an untrained-user environment (e.g., SPSS in a university computing center).

The advent of small computers has led to the subsetting of high-level programming languages and software packages rather than the redesign or invention of languages and packages. Subsetting is a valid procedure according to the "median rule" that half of the capacity of a system (e.g., computer memory, programming language, software package) generally suffices for a high percentage of all demands placed upon it.

TESTING ACCELERATION, AUGMENTATION, AND DELEGATION BY EXTENDING EXISTING SYSTEMS. In Section 3 we asked the question of how the perceptual/cognitive processes that underlie information tasks (see Figure 2) can be accelerated and augmented by the computer or delegated to the computer entirely. Corresponding to each perceptual/cognitive process is one or more acceleration, augmentation, or delegation functions. A list of such functions -- undoubtedly incomplete from a future perspective -- is presented in Figure 5.

With some risk of trivializing them, we can compare acceleration, augmentation, and delegation functions with accessories on automobiles that perhaps make the automobiles more efficient and satisfying to use. The accessories do not have much application or value apart from their use in automobiles. Acceleration, augmentation, and delegation functions must similarly be incorporated into either new information systems or existing systems. A number of factors -- including cost, development delay, user acceptance, and opportunity for evaluation -- argue for incorporating these functions into existing systems whose hardware and software are capable of being extended in such ways.

INFORMATION STORAGE AND RETRIEVAL SYSTEMS. Four types of existing information systems are extendable to accommodate acceleration, augmentation, and delegation functions. The most common of these in the environment of STI use is the information storage and retrieval (ISR) system. Proprietary ISR systems such as DIALOG, ORBIT, and BRS have attracted the largest amount of use by making multiple databases (e.g., more than 50 databases in the DIALOG system) available simultaneously. Unfortunately, because of the multiservice character of these systems and a certain amount of user training that they require, most searches are performed by librarians

FIGURE 5. ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS AT THE STI COMPUTER/USER INTERFACE.

RECEPTOR LOCUS

Retrieving

Selecting

Displaying

PROCESSOR LOCUS

Transforming

Comparing

Analyzing

Simulating

Deciding

EFFECTOR LOCUS

Commanding

Inputting

Storing

Editing

Outputting

Transmitting

and other information specialists; thus the end-user is frequently not present at the interface to benefit from acceleration, augmentation, and delegation functions.

TELECONFERENCE SYSTEMS. A second type of existing and extendable information system in the environment of STI use is the teleconference system, exemplified by FORUM, the FORUM-derived PLANET, NLS, and EIES. Typically, these systems permit users to compose and transmit messages to other users. In some cases the composition of messages is assisted by a personal file storage capability and by a text editor. When the intended receiver of a message is not active on the system at the time of transmission, the system holds the message in an "electronic mailbox" and prompts the receiver to check the mailbox when he or she rejoins the system. Individual teleconference systems have extended functions that support simulation, gaming, group decision-making, distributed authorship, opinion polling, etc.

INSTRUCTION SYSTEMS. Computer-assisted instruction is still rare in environments of STI use, although open-line CAI is available from vendors at the same terminals that are also used for searching and teleconferencing in technical libraries, laboratories, researchers' offices, etc. State-of-the-art CAI systems, exemplified by PLATO and TICCIT, have two features that distinguish them from earlier systems: (1) they present material to the user in audio and/or visual formats as well as printed text; (2) they adapt to the user's strategy and style of learning via "learner-controlled courseware" (Bunderson, 1972), extending the concept of response-contingent branching taken over from programmed learning by earlier CAI systems. Although user-adapted software is the major contribution of CAI to the progress of information systems in general, PLATO's plasma terminal and TICCIT's color television are examples of innovative CAI hardware.

DECISION SUPPORT SYSTEMS. Still in their laboratory and field-trial phases of development are systems that bring numerical analysis and estimation to bear on decision making and assist the user in predicting and visualizing the outcomes of decision alternatives. One carefully studied system is IBM's GADS, which represents certain kinds of decision spaces topographically on a high-resolution CRT terminal. In a typical application, an educational administrator prepares for the decision of closing a required number of schools in a district with declining enrollment by redrawing the attendance areas of the remaining schools. A database of student and staff data is used to project the teacher load, student demography, facility utilization, and other variables for each alternative. A school district map on the CRT screen shows the new attendance boundaries topographically, with overlays of data as desired. Of course, decision support systems also project and display alternatives for decisions (e.g., production, inventory) that do not have a topographic dimension.

Each of the four types of existing and extendable information systems offers one or more capabilities that are not as fully developed in the other systems. That is, information storage and retrieval systems are capable of storing large files of nonsequential and primarily textual records with many access points (indexed attributes) per record. These systems also assist in the definition of a search by tabulating the number of records linked with single attributes or combinations of attributes, thus describing the file in detail without displaying records unnecessarily.

Teleconference systems have a unique capability for interconnecting on-line users. Messages exchanged in a teleconference differ from the terminal-to-terminal "bulletins" permitted by some general interactive systems in the fact that they can be composed in advance of transmission and retrieved asynchronously from an "electronic mailbox" by receivers. Teleconference systems also provide the most flexible text editing and personal file creation of the four types of information systems described here, although superior text editing and personal file systems (such as WYLBUR, on which this text is being written and stored) have been implemented independently of information systems.

Computer-assisted instruction systems are unique in their response-contingent branching and their user-adapted sequencing and pacing of information. They also represent the highest development of multimedia presentation among these four types of systems.

Decision support systems enter further than the other types of systems into a user-defined problem, taking in user-supplied data and projecting the outcomes of alternative decisions. They have the most highly developed numerical analysis and estimation procedures.

S.5. ACCELERATION, AUGMENTATION, AND DELEGATION EXEMPLIFIED IN THE EXTENSION OF EXISTING SYSTEMS

Acceleration, augmentation, and delegation can now be exemplified in a small number of extensions of existing information systems.

DISPLAYING, a computer function that interfaces with the perceptual processes of scanning and fixating, can be accelerated and paced for more efficient and satisfying presentation of information. Pacing, which was not defined above, is the concept of an externally regulated scanning rate. Perception studies indicate that human visual processing is a lazy behavior most of the time. Except when engaged in fast-moving activities such as sports, we do not use our full capacity for visual input. Self-pacing of input, as in reading, can be fast or slow; it usually remains at the low rates we learn in school. Rapid self-pacing generates fatigue, apparently not as much from the increased perceptual effort as from the concentration that rapid self-pacing requires.

Through the design of displays, scanning can be accelerated and/or externally paced. Even if static (unpaced), a large high-resolution display may be scanned more rapidly than a small low-resolution display. If a large high-resolution display is also paced (e.g., by scrolling) so that it presents new information without prompting from the user, then the user's scanning rate may rise still further. It is likely that the user's scanning rate is positively correlated with presentation rate up to the threshold of information overload, which varies according to the visual processing skills of the user and the subject matter being presented, beyond which scanning rate is negatively correlated with presentation rate.

Thus far we have discussed accelerated scanning with an implicit restriction to visually processed text. However, text is only one stimulus that can be presented to the visual receptors, and there are other sensory receptors whose input can be accelerated. Whether "a picture is worth a thousand words" depends on the subject matter and on the cognitive style of the user. Subject matter involving spatial relationships, dynamic relationships, relative size, form, color, etc., should be visualized rather than verbalized in a display. More subject matter should be visualized for some users than for others, according to ability to process verbal versus pictorial representation. Kropp et al. (1967) found that students who were less verbal learned pictorially represented mathematical theorems faster than they could learn the same theorems in verbal representation, relative to students who were more verbal.

Auditory scanning can be accelerated as well as visual scanning, as experiments with compressed speech have proved for more than a decade. However, the most promising form of acceleration -- multisensory presentation of the same information -- has scarcely been conceptualized, much less tested.

DECIDING is an example of a cognitive process that can be augmented and not just accelerated. One form of augmented deciding involves the presentation of alternatives for the user to compare and choose among. The dimensions of comparison among the alternatives are attributes on which each alternative has been assigned a figure of merit. When the attributes themselves are weighted according to the emphasis that each receives in the decision, then a summed figure of merit can be computed for each alternative decision:

Criterial Attributes	Alternative Figures of Merit			Attribute Weights	Weighted Figures of Merit		
1	X1	Y1	Z1	w1	w1X1	w1Y1	w1Z1
2	X2	Y2	Z2	w2	w2X2	w2Y2	w2Z2
3	X3	Y3	Z3	w3	w3X3	w3Y3	w3Z3
.	.	.	.	.	.	.	.
k	Xk	Yk	Zk	wk	wkXk	wkYk	wkZk
Sum					w.X.	w.Y.	w.Z.

When the computer performs these steps without user intervention and tells the user which alternative is indicated by the weighted figures of merit, then the function shifts from augmentation to delegation.

INPUTTING and EDITING are two of several functions that correspond to the cognitive/motor process of producing, which in fact has a long history of technological assistance. In the computer era, assistance in production goes far beyond the typewriter and dictaphone. Text-editing systems facilitate expansion and improvement of text. Although text editors only accelerate and augment production at the present time, delegated spelling and other conformance checks would be possible with a small elaboration of text-editing software.

Optical character-recognition hardware eliminates an additional keyboarding of previously keyed text. Voice-to-print converters eliminate the keyboard itself as a requirement in production. Graphic systems convert rough light-pen sketches into geometrically correct drawings. The number of such accelerations and augmentations can be explained by the importance of text in an "information society."

S.6. INDICATIONS FOR RESEARCH AND DEVELOPMENT

SYSTEM-ORIENTED R&D. In the early years of a new technology, research and development follow an agenda that the technology itself dictates. All technologies of the "first industrial revolution," from the steam engine to the spaceship, bear out this premise. When a technology reaches its initial development plateau (i.e., fulfills purely technological criteria of performance), R&D then begins to be guided by nontechnological criteria of market competition and user preference. "Human factors" R&D is the intermediate phase of this progression. As first directed by engineers, human factoring responds to technological criteria even if less satisfactory to users. As later directed by marketers, human factoring responds to user preferences even if less than technologically optimal.

Computer R&D has been technology-dictated or system-oriented for the past three decades. Current developments in miniaturization and integration as well as in new memory and display media indicate that R&D in this field could continue to be system-oriented for another decade or more (at the same time, the stabilization of many computing concepts and devices indicates that syst oriented R&D will not go on indefinitely unless technological discontinuities occur).

USER-ORIENTED R&D. System-oriented R&D is never allowed to "run its course." No technology is perfectable, and the later gains of system-oriented R&D are not as cost-beneficial as the earlier gains (except, of course, when technological discontinuities occur). In previous eras, the corporate ledger determined when system-oriented R&D would give way to production and marketing. The voice of the ledger is still heard, but social and environmental criteria of "appropriate technology" are now sometimes heard first. For example, system-oriented R&D on the SST has largely been halted in the United States by the belief that the benefits of Mach 2 travel do not equal its social and environmental costs.

In the case of computer technology, user-oriented R&D can focus on hardware and software that are "on the shelf" while system-oriented R&D continues to refine the size, power, and cost of devices. Although we would like to say otherwise in order to get on with user-oriented R&D -- specifically the acceleration, augmentation, and delegation of information work -- there is not enough hardware and software on the shelf to support these functions, at least not according to indications from psychological research on levels of perceptual/cognitive processing that are both desirable and possible.

Although separate implementations of acceleration, augmentation, and delegation functions can be found in the laboratory and even in environments of STI use, we cannot rigorously evaluate one function in isolation from others. For example, the combination of powerful retrieval and powerful transformation of retrieved content may have multiplicative rather than additive effects on information work. Similarly, a keyboardless voice-directed terminal may have little effect on information work unless powerful analysis, decision making, and production functions are being directed.

A few laboratories in the United States, perhaps best exemplified by the Augmentation Research Center at the Stanford Research Institute, test configurations of functions. Some of these laboratories are reaching the end of the system-oriented R&D phase and can proceed to user-oriented R&D. Blueprints of system-oriented R&D have ignored user's pscyhological processes or represented them at the computer/user interface as "black boxes" that would adapt to a large but unknown extent to technology-dictated system hardware and software (e.g., the low-resolution CRT displays in wide use). Blueprints of the user-oriented phase of R&D should center on the fact that information work consists of sequences of perceptual/cognitive processes whose user-satisfying performance, productivity, and potential are held in check at the interface.

PART I: CONCEPTUAL FRAMEWORK FOR IMPROVING THE COMPUTER/USER INTERFACE IN INFORMATION WORK

1. CONCEPTUAL FRAMEWORK

Outline of Sections

1.1.	Purpose	19
1.2.	Guiding Questions	19
1.3.	Growth of the "Knowledge Sector" in the American Economy	19
1.4.	Information Work	21
1.5.	Information Tasks	21
1.6.	Task Sequences and "Plans"	21
1.7.	Inside the Plan	23
1.8.	Perceptual/Cognitive Processes of the "T" Step	27
1.9.	Perceptual/Cognitive Processes of the "O" Step	28
1.10.	Physiological Reductionism	30
1.11.	A Note on Cognitive Style	32

1.1. PURPOSE

The purpose of our research on the computer/user interface is to expand the role of the computer, including computer-driven peripherals, in performing tasks that information workers now perform without computer assistance. Information workers' perceptual/cognitive processes are to be accelerated and augmented by the computer. A long-term goal is to delegate information tasks entirely to the computer.

1.2. GUIDING QUESTIONS

1. What are the information tasks that groups of information workers (e.g., researchers, developers, managers, planners, practitioners, students) perform?

2. What are the perceptual/cognitive processes that underlie each information task?

3. For a target year such as 1985 and the probable computer power of that year, what is a productive scenario of acceleration, augmentation, and delegation functions that the computer can perform?

4. What new configurations of hardware and software will these functions require?

5. What kinds of research and development on hardware, software, and users will be required to make these functions available?

1.3. GROWTH OF THE "KNOWLEDGE SECTOR" IN THE AMERICAN ECONOMY

We have entered the fourth decade of what Price (1963) calls "big-science." The war-time emergence of big science was a striking occurrence in the history of humanity. It signaled a different approach to control of the environment, manufacture of products, provision of services, planning for economic and social change, etc. Industries that had been labor-intensive became knowledge-intensive. New "knowledge industries" were born. Most indicative of all, the pre-war model of small-scale individual research yielded to large-scale organized research with teams of scientists, specialization, and division of labor.

The term "knowledge industry" was introduced by Machlup (1962) to encompass work in research and development laboratories, educational institutions, manufacturing organizations, publishers, libraries, mass media, etc., all of which produce and distribute "knowledge." The extent of U.S. investment in this sector was described by Drucker (1969, pp. 321-322):

"The 'knowledge industries,' which produce and distribute ideas and information rather than goods and services, accounted in 1955 for one-quarter of the U.S. gross national product. This was already three times the proportion of the national product that the country had spent on the 'knowledge sector' in 1900. ... In the late 1970's it will account for one-half of the total national product.

"Since the knowledge worker tends to be a good deal better paid than the manual worker, and also to have much greater job security, knowledge has already become the central cost of the American economy. The productivity of knowledge has already become the key to productivity, competitive strength, and economic achievement."

Porat (1976) has produced a current and comprehensive updating of Machlup's 1962 data. Porat's tabulations show that more than half of national income and nearly half of GNP now originate in the "production, processing, and distribution of information goods and services" (p. 1). The shift in terminology from "knowledge" to "information" avoids unnecessary dispute over the connotations of knowledge.

Further evidence of the growth of the knowledge sector, or shall we say the information sector, can be found in the funding of research and development (R&D) by the federal government, industry, and other sources. In 1941, a total of $900 million was expended from all sources for R&D in the United States (Machlup, 1962, p. 157). In 1971, more than $27 billion was expended from all sources for R&D (National Science Board, 1973, p. 109). Some of the thirty-fold increase in funding in three decades must be discounted to inflation, but R&D's share of the gross national product has increased nine-fold over that time.

An economy of goods, unprecedented in its productivity, was founded on material-transforming technologies of the first industrial revolution (ca. 1750-1950). In their early development, the machines and processes of the first industrial revolution required high levels of human effort. As the technologies evolved, human effort gave way to human monitoring. Even so, the transition from "power-assisted people" to "people-assisted power" occupied two centuries.

An information economy, also unprecedented in its productivity, is founded on information-transforming technologies, the majority of which have been invented since 1900. Machines and processes of the first industrial revolution were the prerequisites of this second revolution, but most of the information-transforming technologies themselves are still being invented in the historic present. The computer, the greatest information-transformer in the history of humanity, is only three decades old.

As information becomes a dominant commodity in itself and a key to other commodities, the literature of information on information grows. Researchers of many disciplines contribute to this literature. Policy researchers study the management of information and its benefits.

Information scientists design and test systems for information storage and retrieval. Sociologists study the production of information in organizations. Communication researchers study information dissemination through media and personal networks. Economists study information markets. Of particular relevance to this project, psychologists study perception, cognition, motivation, etc., as processes in the information user that determine the extent and effect of information use.

1.4. INFORMATION WORK

Information work can be defined as the production, distribution, transformation, storage, retrieval, and use of information. Information itself requires both structural and functional definitions. Structurally, information can be defined as an encoding of symbols (e.g., letters, numbers, pictures) into a message of any form, propagated through any medium, and processed by any sensory receptors. Functionally, information can be defined as any stimulus that modifies cognitive structure in the receiver (i.e., information user). Cognitive structure can be defined as a pattern of memory traces of stimuli previously processed by sensory receptors, together with relations established among the memory traces by the brain through processes of comparison, decision, induction, and deduction.

Information work has connotations of prestige and uniqueness that are not always merited by the work itself. As Bush pointed out in 1945 (p. 104): "The scientist, however, is not the only person who manipulates data and examines the world about him by the use of logical processes." Engineers and other technologists, managers and other administrators, physicians, lawyers, brokers, planners, teachers, librarians, and other professionals also perform information work. They are supported by cadres of office workers, data processing personnel, etc., who spend part or all of each day performing information work.

1.5. INFORMATION TASKS

Information work consists of sequences of information tasks that are more generic than each type of information work itself. These common denominators of information work are keys to improvement in the computer/user interface insofar as acceleration, augmentation, or delegation of an information task benefits all information workers who perform the task. The cost of each improvement in the computer/user interface can therefore be spread across large groups of information workers.

A sequence of information tasks is often named after the focal task that it contains. For example, "decision making" is an information task in itself, but it also names a sequence of information tasks that includes formulating a problem, determining information needs, searching for information, selecting and processing relevant information, comparing alternative decisions, and making the decision. To name a sequence of tasks after the focal task is an excusable synecdoche, just as the phrase "driving home from the office" implies entering the car, starting the engine, parking, shutting off the engine, and exiting the car as well as the actual behavior of driving.

Each type of information work consists of sequences of information tasks qualified by content and context. For example, information work in medical practice consists of decision making sequences qualified by the content of patients' medical needs and by the context of individual or group practice in an area with ample or meager medical resources. "Diagnosis" and "treatment selection" are two forms of medical decision making. They differ from other forms of medical decision making (e.g., choosing a practice locale, hiring staff, identifying resources, making referrals) insofar as their content and context differ. Medicine as information work consists of these various decision making sequences together with learning sequences (in which the focal task is learning, not decision making, although some steps in both sequences are identical), instrumentation and data gathering sequences, patient feedback sequences, etc.

1.6. TASK SEQUENCES AND "PLANS"

The tasks that comprise information work are best understood in the framework of "plans" that combine them in sequences. Miller, Galanter, and Pribram (1960, p. 16) define a plan as "any hierarchical process in the organism that can control the order in which a sequence of operations is to be performed." Miller et al. further define a plan as the action consequence of an "image," which they define as "all the accumulated, organized knowledge that the organism has about itself and its world" (p. 17).

The image and related concepts (e.g., "cognitive maps," Tolman, 1948; "personal constructs," Kelly, 1955) have important implications for information work. They represent the dissent of some cognitive psychologists from what Miller et al. describe as "nickel-in-the-slot, stimulus-response conceptions of man" (1960, p. 2). Tolman stated in "Cognitive Maps in Rats and Men" (1948, p. 193) that the brain:

> "...is far more like a map control room than it is like an old-fashioned telephone exchange. The stimuli which are allowed in are not connected by just simple one-to-one switches to the outgoing responses. Rather, the incoming impulses are usually worked over and elaborated in the central control room into a tentative cognitive-like map of the environment. And it is this tentative map, indicating routes and paths and environmental relationships, which finally determines ... responses."

Kelly (1955) formalized aspects of the cognitive map into measurable "constructions of the world" that differ among individuals. As Kelly described these "construction systems" (pp. 8-12):

"Man looks at his world through transparent patterns or templates which he creates and then attempts to fit over the realities of which the world is composed. ... Let us give the name constructs to these patterns that are tentatively tried on for size. They are ways of construing the world. ... Constructs are sometimes organized into systems, groups of constructs which embody subordinate and superordinate relationships."

Only if the brain characteristically transforms stimuli into "maps," "constructs," or "images" does the subtlety of computer transformation of information relate to comparable subtlety in the brain. Just as there is a plausible connection between stimulus and response at the level of reflex behavior, there is a plausible connection between images and plans at the level of cognitive processes.

Plans elicit what Miller et al. call "searching and solving" behavior. Searching and solving behavior yields information, which in turn changes images: "The meaning of a message is the change which it produces in the image" (Boulding, 1956, p. 7). Changed images lead to new plans. With new plans, the behavior cycle begins again.

Miller et al. further state that planful behavior is often the execution of hierarchically related subplans, each of which yields information that changes images governing subsequent subplans. The fact that outcomes of prior subplans can affect subsequent subplans reveals stochastic as well as hierarchical dependencies among subplans. Although a "master plan" determines the hierarchy of subplans that have some probability of being executed, information yielded by each subplan in turn affects the probability that a subsequent subplan will be executed.

1.7. INSIDE THE PLAN

As stated in the previous section, Miller et al. (1960, p. 16) define a plan as "any hierarchical process in the organism that can control the order in which a sequence of operations is to be performed." In the computer era it is not incongruous to liken human plans to computer programs, which control the sequence of operations to be performed by the computer. However, the computer's program is not the computer's action, and the human's plan is not the human's behavior. How the computer acts out the instructions of the program can only be explained with reference to entities (e.g., registers, input/output devices) and processes (e.g., storing, cumulating, comparing) that are not made explicit in the program itself. How the human behaves in accordance with the plan can only be explained with reference to entities (e.g., sensory receptors, the cerebral cortex) and processes (e.g., perceiving, remembering, inducing, deducing) that are not made explicit in the plan itself.

One goal of this project is to identify developments in computer hardware and software that can accelerate or augment information tasks, or to which the tasks can be delegated entirely, with special application in the use of scientific and technical information. However, just as we cannot increase the computer's capacity for programmed action through the program itself but only through the entities and processes by which the computer executes the program (e.g., it doesn't help to declare more memory in the program if the computer doesn't have more memory), similarly we cannot accelerate, augment, or delegate human information tasks through the plan itself but only through the entities and processes by which the human executes the plan. We must enter inside the plan, so to speak, in search of these entities and processes.

Two complementary formulations of the entities and processes are the adaptive information processing system or IPS (Newell and Simon, 1972) and the TOTE unit (Miller et al., 1960). IPS places greater emphasis on entities and TOTE places greater emphasis on processes.

The Newell-Simon theory of human problem solving defines an IPS as follows (1972, pp. 20-38 and 791-809):

1. At a minimum, an IPS consists of receptors that make it cognizant of its environment, a processor (further defined below), a memory, and effectors by which it can operate on its environment.

2. The processor consists of elementary information processes (further defined below), a short-term memory that serves the elementary information processes, and an interpreter that determines the sequence of elementary information processes to be executed according to information stored in short-term memory.

3. Elementary information processes consist of discrimination, tests and comparisons, symbol creation, symbol structure writing, external reading and writing, symbol structure designation and storage. "The entire behavior of the IPS is compounded out of sequences of these elementary processes."

4. The IPS also has a long-term memory and generally has access to an external memory.

5. The IPS has a program that is goal-directed, "where a goal is a symbol structure with certain characteristics: (1) a goal carries a test to determine when some state of affairs has been attained...; (2) a goal is capable of controlling behavior under appropriate conditions...."

Miller et al. (1960) describe the basic TOTE unit as "an alternative to the classic reflex arc" (p. 26). It is a recurring four-step cycle in an organism's behavior:

1. Given a plan and a goal state or success criterion embedded within the plan, the organism tests its environment to determine where it stands, so to speak, relative to the goal state. It may test conditions external to itself via sensory receptors as well as conditions internal to itself via proprioceptors. The test datum is simply one of congruity or incongruity with the goal state.

2. When the test reveals incongruity with the goal state, the organism operates on its external or internal environment in a way that its images indicate will reduce the incongruity. Such operation may take the form of motor behavior (e.g., manipulation), perception (e.g., searching the environment for a more successful approach to solving the problem); cognition (e.g., thinking it over), or combinations of the three.

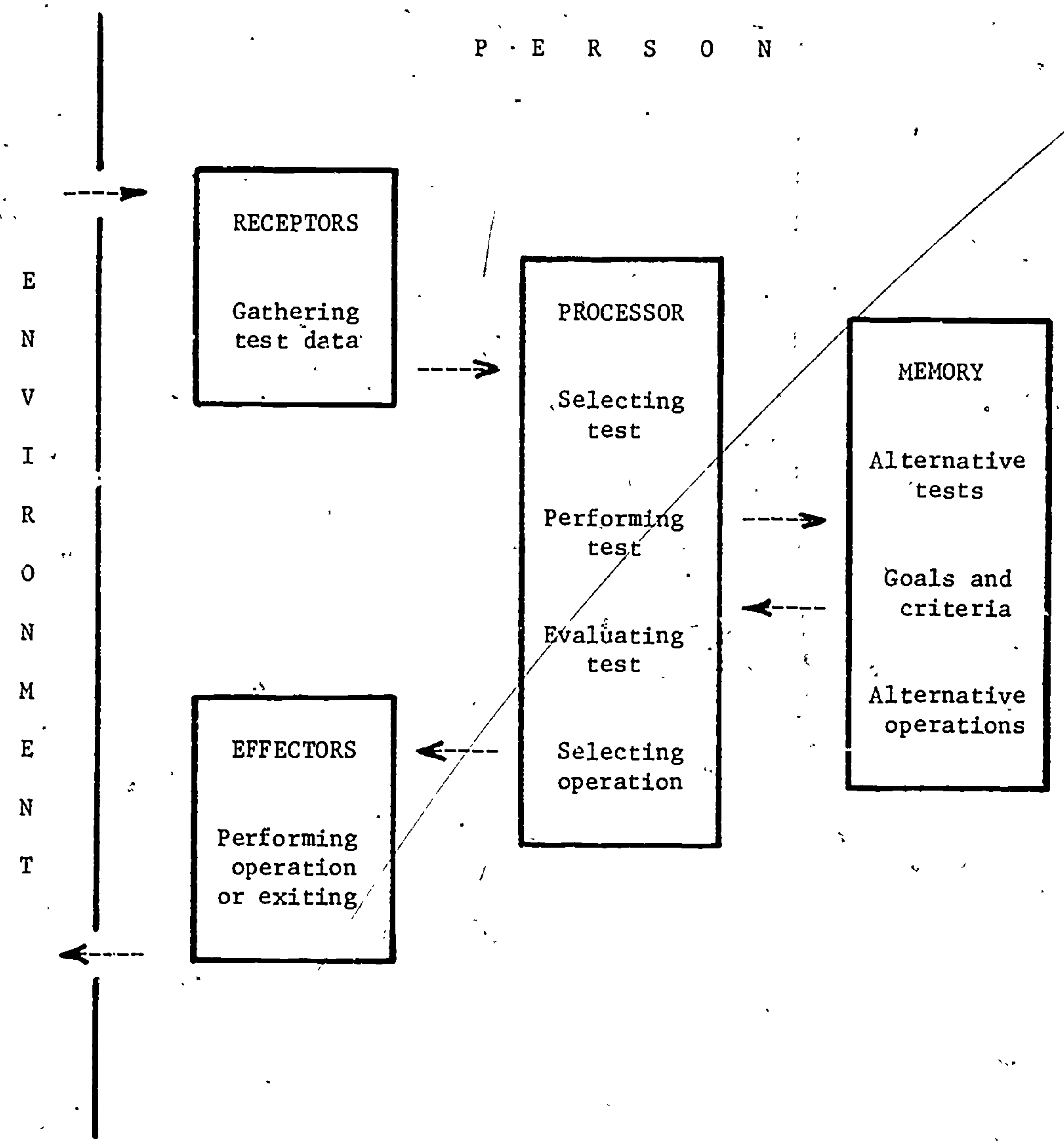
3. Following the operation, the organism again tests congruity with the goal state.

4. When the test finally reveals congruity, the organism exits from the TOTE cycle, which may also be represented as a subplan, and continues on to another subplan.

A simple integration of the Newell-Simon IPS and the Miller et al. TOTE theories is presented in Figure 1. Newell and Simon further state (1972, p. 822): "plans are structurally identical to programs ... symbolic structures, available in long-term memory (or in external memory), that are used to guide action in exploring the problem space."

The test-operate-test-exit or TOTE unit occupies a useful middle ground between information tasks and the perceptual/cognitive processes that underlie them. "Plans for searching and solving" (Miller et al., 1960, pp. 159-175) can be analyzed as sequences of information tasks. Subplans can be analyzed at several levels of hierarchical reduction. For example, the "information input" subplan within a "decision making" plan includes the tasks of determining information needs, searching for information, and selecting and processing relevant information. One level down, the subplan for a single task, such as "selecting relevant information," includes TOTE units for testing incoming streams of information against a relevance criterion, sampling more deeply into the more relevant streams, and selecting information items for further processing. Another level down, the TOTE step of testing information against a relevance criterion includes perceptual processes of scanning,

FIGURE 1. RELATED ENTITIES AND PROCESSES IN THE IPS AND TOTE THEORIES.



fixating, and feature extracting as well as cognitive processes of transforming, comparing, and deciding.

1.8. PERCEPTUAL/COGNITIVE PROCESSES OF THE "T" STEP

In the simplest case, a mechanism like a household thermostat has fixed sensory input for the tests it performs. Signals come in a fixed form and from a fixed direction to a "comparator" that juxtaposes the sensory input with criteria derived from the goal state. We derive the term "comparator" from Campbell's description of a "pattern comparator" that juxtaposes incoming information with a stored criterion (1966, pp. 93-94).

The action of a "decoder" is presupposed by the action of the comparator. In the case of a household thermostat, temperature indications embodied in the activity of gas molecules surrounding the thermostat are decoded by the action of a bimetallic strip into a consequent gap at the electrical contacts.

When the comparator has juxatposed incoming information with a stored criterion, such as a preset gap at the electrical contacts of the thermostat, action shifts to a "decider." Unlike the thermostat, a human decider can override the indications of its comparator by calling for more information and/or by changing the stored criterion. A human decider can also choose which of several subplans to execute next; it is not limited to on-off decisions.

The sequence of decoder-comparator-decider describes only the simplest case, a mechanism with fixed sensory input. When sensory input is not fixed, signals needed by the decoder may come in many forms and from many directions. Campbell (1960) borrows cybernetic concepts from Ashby (1952) and later researchers to postulate "systematic sweep scanning" processes in human perception that help the human to cope with unpredictability in the form and direction of sensory input. When TOTE tests are to be performed on unfixed sensory input, the action of the decoder presupposes the action of a "scanner" to find signals needed by the decoder.

In the cybernetic analogy, a scanner is useless without a "fixator." The scanner locates sensory input; the fixator holds sensory receptors on the located input so that signals can be brought to the decoder. Campbell (1960, p. 383) asserts that echo-location organs in bats permit a substitute search process in which the organism uses "economical" sound waves rather than its own locomotion to fix the location of objects in its environment. In Campbell's view, human "visual perception seems interpretable as a substitute search process of similar order." Campbell describes a simplified model of human perception in which "brightness contours can be located and fixated by continual crossing, as in the 'hunting' process in a mechanical servosystem."

The term "signal" implies an unambiguous stimulus that provides the decoder with a clear indication of a condition. Often, however, the stimulus is not unambiguous, and a process of "feature extracting" must intervene between fixating and decoding. An example of an unambiguous stimulus would be a traffic signal at a country crossroads where no other red or green lights occupy the same visual field. In contrast, a traffic signal at a city intersection is often an ambiguous stimulus; it is surrounded by other red and green lights from which its features of "traffic signalness" must be extracted.

The six perceptual/cognitive processes that are implied by the "T" step of the TOTE unit, then, are scanning, fixating, feature extracting, decoding, comparing, and deciding. Three of the processes -- scanning, fixating, and feature extracting -- are primarily perceptual, although perception itself is subject to cognitive control. Three of the processes -- decoding, comparing, and deciding -- are cognitive.

1.9. PERCEPTUAL/COGNITIVE PROCESSES OF THE "O" STEP

The sequence of perceptual/cognitive processes that comprise an operate or "O" step are not as predictable as those that comprise a test step. Perceptual/cognitive processes of the test step are those that a plan requires procedurally for its execution: without those particular perceptual/cognitive processes there would be no test, and without the test there would be no plan. However, the perceptual/cognitive processes of the operate step are substantively determined by the goal of the plan. It makes a difference in the "O" step whether our goal is to gather routine data, perform a crucial experiment, diagnose an illness, create a taxonomy, build apparatus, plan a program, etc.

All of the perceptual/cognitive processes of a "T" step may appear in an "O" step as well, since the plan itself, and not just the test step within the plan, may be one of searching for information and testing the information against criteria. What distinguishes an "O" step from a "T" step, in addition to motor behaviors that an operation might require, are perceptual/cognitive processes that transform information into more than it was before -- that is, more than sensory receptors reported to the brain. The additional information consists of relationships that are established among existing information elements by the cognitive processes of "induction" and "deduction."

A common-language definition of induction is that of imputing a relationship to two entities (e.g., objects, concepts) on the basis of one or more attributes that they share. Induction is functional; we ignore many attributes that entities share (e.g., weight, color, shape, common origin, colocation) and focus only on attributes that are useful in our images or constructions of reality.

Unlike the simple cognitive processes of decoding, comparing, and deciding, inducing is a complex cognitive process that can be defined as a plan composed of hierarchically related comparing and deciding subplans. In induction, the comparator processes the attributes of two or more objects; the decider then says "similar" or "different." Further comparisons follow the decision to group objects or to separate them; decisions follow these comparisons, etc. Names given to groups of objects by the decider are supplied on candidate lists by the comparator after similarities and differences are noted between attributes of the unnamed groups and attributes of groups previously named by the person or by others.

A common-language definition of deducing is that of arriving at a particular conclusion from general premises. Etymology misleads us if we regard deduction as the inverse of induction. The superficial contrast of induction versus deduction as "up the ladder of abstraction" versus "down the ladder of abstraction" ignores the reliance of induction on associational logic and the reliance of deduction on causal logic. In the simplest induction:

> X's attribute A makes it a case of Y,
> the group defined by attribute A.

whereas in the simplest deduction:

> If Y is true, then X is also true.

In the cognitive process called "reasoning," inductive and deductive plans intertwine. Since induction organizes images while deduction explains them, we execute an inductive plan until the stage is set for deduction, and we execute a deductive plan until further induction is needed. "Analogizing" is a common form of induction used to facilitate deduction, and "hypothesizing" is a common form of deduction used to facilitate induction.

Like induction, deduction is a complex cognitive process that can be defined as a plan composed of hierarchically related deciding and comparing subplans. In deduction, the decider states an "if ... then" rule; the comparator then checks a perceived or remembered condition against a criterion to determine whether the "if" is fulfilled.

As studied by psychologists like Wason and Johnson-Laird (1972), reasoning is a plan that governs the execution of several perceptual/cognitive processes. Speaking of the solution of syllogisms, these researchers say that "the answers to such problems are not, strictly, valid deductions. They depend upon additional and unstated premises" (p. 98). An "internal representation of the premises" has to be set up. In some cases, the terms of a premise have to be "converted." In other cases, the premises themselves have to be "re-ordered." The transitivity of an asserted relation (e.g., "is the father of") has to be checked against general knowledge in memory (pp. 98-100).

Additional cognitive processes to be accounted for in the "O" step are those of "retrieving," "selecting," and "transforming." Just as sensory receptors scan the environment for information that will be of use to the processor after fixating, feature extracting, and decoding, a similar scanning is transacted between the processor and long-term memory to retrieve information that will be of use to the processor after selection and transformation. Although analogies are limited by differences in the information being processed (stimulus versus memory trace), there is correspondence between the two ways in which the processor obtains the information it needs for comparing, deciding, inducing, deducing, etc. That is, retrieving traces from long-term memory is analogous to a combination of scanning and fixating stimuli in the environment. Selecting is analogous to a combination of fixating and feature extracting. Transforming memory traces into symbolic structures that are useful to the processor in the context of a particular problem is analogous to decoding stimuli into similar symbolic structures for similar purposes.

A final cognitive process to account for in the "O" step is that of "symbolic production" -- encoding verbal, numeric, and graphic messages. In most information work the "O" step requires a product from the information worker. Encoding or "producing," as we shall call it, is a cognitive process that is assisted by, and requires the skilled use of, motor behaviors such as speaking, writing, drawing, typing, etc.

Figure 2 summarizes the perceptual/cognitive processes that have been been described in Sections 1.8 and 1.9.

1.10 PHYSIOLOGICAL REDUCTIONISM

Theories of perception without the retina? Theories of cognition without the cortex? It is evident from terms used in the above sections that the Newell-Simon IPS and Miller et al. TOTE theories are analogistic rather than reductionistic. That is, these theories explain information work by analogy to the entities and processes of cybernetic machines like the computer. They do not reduce the perceptual/cognitive processes of information work to physiological concepts -- organs, neural connections, etc. Reduction (see, for example, Hempel, 1966, pp. 101-110) is science's way of anchoring higher-order concepts to lower-order concepts that can be measured more reliably and validly. It is often held that reduction from psychology to physiology and ultimately to chemistry and physics is psychology's best hope for laws or general propositions explaining perception, cognition, and behavior.

However, physiological reduction assists psychological explanation less than might be predicted by analogy with older fields of science. The lower-order concepts in reduction chains such as geology down-to chemistry down-to physics can account for much of the variance in higher-order concepts, but physiological concepts account for little of the variance in human perception, cognition, and behavior.

FIGURE 2. PERCEPTUAL/COGNITIVE PROCESSES IN INFORMATION WORK.

RECEPTOR LOCUS

Scanning

Fixating

TRANSACTED BETWEEN RECEPTOR AND PROCESSOR

Feature extracting

Decoding

PROCESSOR LOCUS

Comparing

Deciding

Inducing

Deducing

TRANSACTED BETWEEN PROCESSOR AND LONG-TERM MEMORY

Retrieving

Selecting

Transforming

TRANSACTED BETWEEN PROCESSOR AND EFFECTOR

Producing

An important exception to this truism concerns limits. Physiology explains why the average human cannot lift 200 kilograms, cannot detect flicker in a light flashing more than 50 times per second, cannot hear a 20 hertz tone at intensities of less than 60 decibels, etc. Limits and their opposites, optimal ranges of performance, are concepts for which we need data if acceleration, augmentation, and delegation of information work are to approach optimal ranges and avoid limits.

1.11. A NOTE ON COGNITIVE STYLE

Speaking of the information work that goes on in classrooms, Cronbach and Snow say that "the learner brings abilities, information-processing habits or styles, and mental sets to the scene. These prove to be well or badly aligned with the task..." (1977, p. 411). Cronbach and Snow note that various studies measure the "conceptual complexity" of learners, their "field independence," "serialist/holist" thinking, "rigidity" in processing information, etc. (pp. 376, 382, 389, 393). Our later discussion will assume that individual differences do interact with presentation variables and that the optimal presentation for one information system user may not meet the needs of another user.

2. SCIENTIFIC AND TECHNICAL INFORMATION WORK

Outline of Sections

2.1. STI Products and Services 34

2.2. Categories of STI Users 35

2.3. The STI System/User Interface 36

2.4. Electronic STI System/User Interfaces 37

2.1. STI PRODUCTS AND SERVICES

Humanity has been producing and distributing scientific and technical information since antiquity. Ancient treatises on philosophy, natural history, mathematics, and medicine were the STI of their day. The earliest distribution of STI was oral, since preliterate civilizations required plans for their engineering and architectual feats. Written distribution of STI has a history of about 30 centuries, with beginnings in China, Sumer, Greece, etc.

At the point of production, scientific and technical information consists of facts and relations in the information worker's head, augmented by what can be seen in a notebook, on a blackboard, on a computer display, on instrument dials, etc. Information workers encode what they wish others to know in conversations, memoranda, letters, conference presentations, articles, technical reports, books, and occasionally audiovisual films and tapes. Experimentally now but with the promise of broad application in the future, information is encoded into computer text for access by any number of users at near and distant locations. In the future flow of STI, these users may be collaborators in the information work; they may also be reviewers, editors, or subscribers to an "electronic journal."

Conventionally, STI products enter information systems, where they are joined by services -- abstracts, indexes, bibliographies, etc. -- provided by information specialists. These services are simply transformations of information that are intended to make the content, location, and other attributes of STI products more obvious to the user.

Although we speak of "information" available to the user of STI, in fact information systems distribute only products and services. Whether the products and services convey information to the user depends on what is encoded in them and on the user's cognitive structure.

STI products and services have attributes such as "form," "content," and "context," all of which affect the user's perception of their value. Form attributes include medium (oral, print, electronic, audiovisual), format (presented paper, symposium, article, book, etc.), and periodicity (on-demand, daily, weekly, monthly, etc.).

Content attributes include subject matter, breadth and depth of treatment, ratio of facts to inferences, style, etc. Context attributes include authorship, sponsorship, refereeship, publication and distribution procedure, conditions of availability, etc.

The user perceives these attributes of STI products and services not separately but in conjunction with each other. Products and services are sought for their information value -- in the terminology of Section 1.6 of this report, the user seeks products and services to advance his or her plan -- and not for attributes of form, content, and context in themselves.

According to the different experiences of each user, different amounts of information value are judged and anticipated from combinations of product and service attributes. Judgment of information value involves such dimensions as:

1. Specifiability (distinctness of representation);
2. Locatability (distinctness of physical location);
3. Acquirability (ease of acquisition);
4. Usability;
5. Relevance;
6. Timeliness;
7. Comprehensiveness;
8. Authoritativeness.

These dimensions are not attributes of products and services -- for example, a journal article has no relevance or timeliness in itself. They are attributions by the individual user to particular products and services. Only to the individual user, with his or her own background, resources, task requirements, etc., do particular products and services have relevance or timeliness.

2.2. CATEGORIES OF STI USERS

There is a tautology in the literature on scientific and technical information. Users of STI are assumed to be scientists and technologists only. Efforts to improve STI systems are limited by this tautology. Although it is true that each STI system exists to serve what may be called its primary users, there is an array of secondary users whose overall requirements for STI may equal those of the primary users.

Twelve groups of STI users are readily identified:

1. Scientists (e.g., physicists);
2. Technologists (e.g., engineers);
3. Professionals (e.g., physicians);
4. Administrators;
5. Policymakers;

6. Editors and reviewers of STI;

7. Trainers (e.g., professors);

8. Students;

9. The public (as consumers, voters, etc.);

10. Librarians and other information specialists;

11. Publishers;

12. Manufacturers of STI hardware and software.

The first nine groups are substantive users of STI. The last three groups are procedural users; they manage, transform, and distribute STI.

2.3. THE STI SYSTEM/USER INTERFACE

The focus of our research is the system/user interface -- the line of transaction between information system and information user. Like other complex systems (e.g., health care, social services, transportation), STI systems have internal strengths and external weaknesses. Internal processes of STI systems, such as information classification, run efficiently. External processes, such as packaging of information for users, are marked by criticism and poor utilization. The system/user interface is the weak link in most STI systems.

On the system side of the interface, information products and services "face" the user with attributes of form, content, and context. The user transforms these attributes into judgments and anticipations of relevance, timeliness, etc.

On the user side of the interface, more attributes affect STI use than our twelve-fold grouping of users implies. The literature of "STI use studies" indicates that differences in STI use are correlated with such user attributes as:

1. Demography (e.g., age, sex, nationality, language);

2. Training and professional background;

3. Organizational role and function (i.e., what the user is and does professionally);

4. Beliefs related to work and profession;

5. Beliefs related to the value of information.

In addition to individual attributes, STI use is correlated with attributes of the user's work environment:

6. Organizational demography (e.g., type and size of organization, prominence in field);

7. Work teams (e.g., size, composition, mode of functioning);

8. Communication networks within and beyond the organization (e.g., professional associations, "invisible colleges").

STI is used to perform information tasks. Attributes of tasks that affect STI use include:

9. Basic (concept-oriented) versus applied (decision- or product-oriented) requirements of the task;

10. Diffuseness of information topics relevant to task;

11. Rate of obsolescence of information relevant to task;

12. Phase reached in task (e.g., start up, full effort, wrap up);

13. Criteria of satisfactory completion of task (e.g., "quick and dirty" versus thorough).

Figure 3 summarizes our discussion thus far of the STI system/user interface.

2.4. ELECTRONIC STI SYSTEM/USER INTERFACES

Electronic distribution of scientific and technical information is as old as the telegraph. The advent of each new electronic medium, notably the telephone and the audiotape recorder prior to the computer era, has shifted additional STI distribution from written to electronic forms.

The computer is a revolutionary rather than supplementary medium because of its transformational power. Each prior electronic medium supplemented an existing oral or written medium. Thus the telegraph permitted faster correspondence; the telephone permitted distance between speakers; the audiotape permitted storage of the spoken word; etc. Each prior electronic medium could transmit or save only the messages it was given. The computer, alone among media, can give back more than it is given, in the form of new information patterns.

It may be self-evident that the computer creates the most responsive STI system/user interface, but important design questions remain to be answered. These fall into two categories:

1. Many computer-based STI systems have been built in the past, but few have outlived their development phases. Do such systems fail because their resources

FIGURE 3. ATTRIBUTES OF STI SYSTEMS AND USERS.

PRODUCTS AND SERVICES	INTERFACE	USERS AND USE CONTEXTS
FORM Medium Format Periodicity	Some, not all, products and services are available at a given interface. Some, not all, attributes of these products and services are encoded.	INDIVIDUAL Demography Training/background Role/function Beliefs re work Beliefs re information
CONTENT Subject matter Breadth/depth of treatment Facts/inferences Style		WORK ENVIRONMENT Organizational demography Work teams Communication networks
CONTEXT Authorship Sponsorship Refereeship Publication/distribution Availability Cost	Perceptual/cognitive processes of users are affected by attributes of products and services, by attributes of the interface, and by the user's own background and tasks.	TASK Basic versus applied Diffuseness Obsolescence Phase Completion criteria

(databases) are insufficient, because they are too costly for the information markets they compete in, because they provide an unsatisfactory interface for users, because users are not adequately trained to use them, or because of other factors?

2. Computer-based STI systems have been designed to supplant existing STI technologies, within the framework of those technologies and accepting many of their limitations (e.g., nontransformability of content). What would a computer-based STI system look like and how would it function if previous conceptions of STI systems yielded to a new conception that exploits the information-transforming power of the computer?

Underlying the second question is the most intriguing set of variables that researchers studying computer-assisted information work could ask for. For thousands of years, humanity has been performing information work against obstacles that information technology has begun to clear away only in this century. Studies of psychological processes such as memory and motivation indicate that delays and obstacles may be quite aversive to the progress of information work. If actual information work were simulated in a laboratory, the frustrations of receiving and producing information would be reflected in poor performance. But what if the computer minimizes these frustrations and allows the information worker to maintain "cognitive momentum" through input that is constantly available, transformable, analyzable, etc., and output that can be encoded and transmitted as readily as ideas can be spoken to oneself? The impact of such changes on the conduct of information work may be more profound than any other change in information work since the invention of writing.

These remarks are visionary, but many technological visions of this century have become everyday facts before their time. The question is not whether the computer will create a new era of information work but only how we can effectively plan for that era. It is logical to begin with an analysis of the failures of computer-based information systems (e.g., STI systems) that information workers now use.

The analysis of past STI system failures and the design of future interfaces should begin with the types of information tasks that STI users perform and the perceptual/cognitive processes that underlie these tasks. When suitably specified, the perceptual/cognitive processes should indicate not only the most effective interface functions for information retrieval but also new functions that accelerate, augment, and delegate the information tasks that follow retrieval. These functions in turn should imply configurations of computer hardware and software as well as computer-driven peripherals (e.g., audio and visual displays) to be incorporated in the interface.

Figure 4 interrelates some of these design considerations.

FIGURE 4. DESIGN CONSIDERATIONS AT THE STI COMPUTER/USER INTERFACE.

STI USERS	PRODUCTS AND SERVICES	INTERFACE
For the several groups of STI users, what information tasks comprise their information work?	What products and services are required as information resources for these tasks?	What configurations of hardware and software effectively interface STI users with products and services?
What are the perceptual /cognitive processes that underlie these tasks?	In what storage media should the products and services be stored?	What configurations of hardware and software effectively perform acceleration, augmentation, and delegation functions?
Which perceptual/ cognitive processes are relatively invariable (e.g., are delegatable but not acceleratable or augmentable) and which are relatively variable (e.g., are acceleratable and augmentable)?	Through what display media should the products and services be displayed?	How generic are these effective configurations across user groups?
	What attributes of products and services should be encoded for access at the interface?	What attributes of users and their tasks affect interface effectiveness?

3. INCREASING THE QUANTITY AND QUALITY OF INFORMATION WORK

Outline of Sections

3.1. The Memex Quest 42

3.2. Acceleration, Augmentation, and Delegation . . 44

3.3. Acceleration, Augmentation, and Delegation Functions in STI Use 46

3.1. THE MEMEX QUEST

Scientists and technologists are guided by "images of potentiality" -- the untested theories, unanswered questions, and unbuilt devices that they view as their agenda for five years, ten years, and longer. In "The Double Helix" (1968), Watson describes the image that dominated his agenda in 1951:

> "DNA was still a mystery, up for grabs, and no one was sure who would get it and whether he would deserve it if it proved as exciting as we semisecretly believed. ... DNA was the most golden of all molecules." (pp. 13, 21)

Information scientists have been guided by a remarkable image for more than 30 years. Its potential for changing the quantity and quality of human information work is enormous, yet its own properties are so amorphous that information scientists construct it in their imaginations in many different ways. To some information scientists, it is elegant hardware. To others, it is information processing software whose algorithms rival those of the mind itself.

Perhaps it was Bush's intention only to stimulate and not to constrain the imagination of information scientists when he sketched the appearance and functions of "memex" in 1945 (p. 105):

> "Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name. To coin one at random, 'memex' will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it can be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory. What does it consist of?
>
> "It consists of a desk. Presumably, it can be operated from a distance, but it is primarily a piece of furniture at which an individual works. On its top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard, and sets of buttons and levers. Otherwise, memex looks like an ordinary desk.
>
> "In one end is its stored reference material. The matter of bulk can be well taken care of even by present-day miniaturization. Only a small part of the interior of the memex is devoted to storage, the rest to mechanism. Yet if the user inserted 5,000 pages of material a day it would take a hundred years to fill the repository. So he can be profligate and enter material freely.
>
> "Memex has, of course, provision for consulting the record by the usual scheme of indexing. When the user wishes

to consult a certain book, he taps its code on the keyboard, and the title page of the book promptly appears before him, projected onto one of his viewing positions. Frequently used codes are mnemonic, so that he seldom consults his code book; but when he does, a tap of a key or two projects it for his use. Moreover, he has supplemental levers. By deflecting one of these levers to the right he runs through the book before him, each page in turn being projected at a speed which just allows a recognizing glance at each. If he deflects the lever further to the right he steps through the book 10 pages at a time; still further speeds scanning to 100 pages at a time."

Bush continued with a discussion of "trail-building" in the file, a procedure by which the user combines information elements in a pattern that serves a momentary purpose. The pattern can be extended, changed, or erased at any time. Any number of trails can run through the same information elements at the same time.

In 1967 Bush had the satisfaction of writing "Memex Revisited," in which he enumerated the memex-enabling technologies that had come into existence since 1945. The digital computer, mass digital and analogue (e.g., videotape) memories, interface devices, and micrographics had progressed in line with his optimistic projections. Yet memex itself remained unbuilt. Its multimillion dollar prototype cost was a barrier to industrial or governmental development.

Looking back at 1967 with our 1977 hindsight, it was best that memex not be built before the advent of certain 1970's technology. Memex without microprocessors would have been a bulky or low-capacity device. Memex without plasma screens would have crowded the user's workspace with separate electronic and optical displays. Going somewhat beyond Bush's vision, we can say that memex without computer-synthesized speech would have been a dull partner in long sessions of information work.

A plausible memex could be built in 1977, occupying the desk that Bush described and performing the functions that he envisioned. As is often pointed out by information scientists, most of the components of memex exist in separate implementations. An integrated implementation of memex in 1977 is a problem of packaging and compatibility rather than of fundamental design.

However, even the 1977 version of memex may better be left on the drawing board. We have lived with the concept of memex long enough to recognize its serious limitations. Among these are:

1. Memex has no networking or communication capability either with other information resources, which even if redundant may be valued for the trails that other users have created through them, or with other users directly.

2. Memex supports exploration and learning tasks of information work through its rapid displays, associative indexing, and other features. It does not provide equal support to later tasks of information work, such as analysis, decision making, and report production.

3. Memex has no transformative power over the symbols in its store. It cannot, for example, extract features for purposes of compression or comparison. It cannot transform verbal information to tabular or tabular to graphic.

These are almost gratuitous criticisms of a powerful information processing system proposed over three decades ago. However, they indicate some of the additional functions that a memex of the future should encompass.

3.2. ACCELERATION, AUGMENTATION, AND DELEGATION

The purpose of an information system is to perform information tasks that users cannot perform, or prefer not to perform, themselves. Simple information systems, such as books of facts or constants, merely save users' time. Rediscovery and recomputation are alternatives that users can resort to if an information system is not available.

Complex information systems perform tasks, such as multivariate simulation, that seem beyond users' power to rediscover or recompute. However, the systems' algorithms derive from human reasoning, and they too are dispensable "had we but world enough and time" to work through the algorithms manually.

Presumably, more information work can be accomplished with the support of information systems than without their support. Moreover, if information systems take over tasks that users find tedious or difficult to do, then users will enjoy their work more even though (or partly because) their productivity is greater. Productivity and user satisfaction are the information system benefits that offset information system costs.

The simplest role for an information system to play, and therefore the role played by the simplest systems, is that of accelerating the user's information task. An index or other inverted file accelerates the user's overview of an information store. Without an index, the user can probably carry out the same information task as well, but more slowly. Since an index is only a surrogate of an information store, the user's perceptual/cognitive processes are similar whether it is the index or the store that is being searched. Acceleration changes the time frame in which perceptual/cognitive processes occur but not the processes themselves.

A more complex role for an information system to play is that of augmenting the user's information task -- that is, assisting the user in the substance of his or her task and not just in the pace of its execution. There are two related senses in which information tasks are augmented and not just accelerated:

1. If the information system is more than two or three orders of magnitude faster than the user in performing a task, then acceleration yields to augmentation in the sense that the user can perform the task in a reasonable amount of time with assistance but would forego the task without assistance.

2. If limitations in human perception/cognition, other than time requirements, make a task almost unperformable, and if assistance from an information system makes the task readily performable, then the task has been augmented and not just accelerated.

Exemplifying the first sense of augmentation are simple information tasks (e.g., multiplying, adding, and subtracting numbers) that are greatly speeded by the computer. For example, matrix multiplication consists of these arithmetic steps only, but the number of times the steps need to be repeated increases exponentially with the rank of the matrices being multiplied. Large matrices are rarely multiplied without computer assistance. Therefore it is not a question of accelerating a task that would be performed anyway.

Exemplifying the second sense of augmentation are complex information tasks (e.g., some pattern recognition problems) that humans do not perform well. The interactions of more than a few variables in research or the pro's and con's of more than a few alternative decisions in administration can cause "information overload" (see, for example, Schroder et al., 1967). The computer makes these pattern recognition tasks performable through such tools as the "Automatic Interaction Detector" program (Sonquist et al., 1973).

Augmentation interweaves the user's decisions with the system's retrieval, selection, transformation, analysis, etc. The character and timing of the user's decisions distinguish augmentation from acceleration. In acceleration, the user's decisions are procedural (e.g., start - stop; go faster - slow down; continue as before - branch). In augmentation, the user's decisions are substantive; the system is involved with the substance of the user's information task and needs to be guided at decision points.

In the most complex role that we project for an information system, the user's information task is entirely delegated to the system. The decisions by which the user guides an augmentation function are now made by the system itself. These decisions are made normatively via one of three procedures: according to rules that the system itself stipulates; according to decisions that a majority of the system's users have made in similar contingencies in the past; according to decisions that the individual user has made in similar contingencies in the past. The second and third procedures require the system to learn from its users. In human systems these procedures call for intelligence; in computer systems they call for artificial intelligence.

3.3. ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS IN STI USE

Although acceleration, augmentation, and delegation functions can be introduced wherever computers and users are interfaced in information work, we restrict our attention now to situations in which information workers (chiefly in the first nine groups listed on pages 35-36) turn to scientific and technical information with the anticipation that their plans can be advanced by STI use. Returning to the terminology of Sections 1.6 through 1.8, we will define the use of STI as the execution of a plan for searching and solving. Even in what appear to be simple cases (e.g., reading a single article), much STI use is the execution of hierarchically related searching and solving subplans, each of which yields information affecting the probability that subsequent searching and solving subplans will be executed.

Miller et al. (1960, p. 159) refer to plans for searching as "preparatory subplans ... that are executed for no other reason than to pave the way for what we really want to do." There is a bias in this position -- namely, that the information searcher wants to get past the searching and on to some other activity. We do not disagree with this bias within existing contexts of information use, although we believe that future interfaces will make information use self-reinforcing, whether the user is an adult scientist sitting at memex (Bush, 1945) or a child entering a school experience dome during "Visiting Day, 2001" (Leonard, 1968).

The "solving" half of the "searching and solving" sequence deserves comment, because problem solving is exemplified narrowly, if not defined narrowly, in the psychological literature. Even the best contemporary theory and research on problem solving (Newell and Simon, 1972) equates problems with puzzles and games, a position that is probably justified for research purposes but is misleading if it reduces the apparent role of problem solving in information work. The problems that STI use addresses are extremely variable; they are continuing and episodic; their latencies from recognition to solution are long and short; they are abstract and concrete. Recurrent problems (e.g., "how to maintain competence in one's profession," "how to keep abreast of recent developments") have other labels that disguise their problematic character. Problems that can be solved with a few units of incoming information (e.g., "what is the correct expression of a chemical compound") are more likely to be recognized as such than problems that require hundreds or thousands of units of incoming information (e.g., "what is a productive taxonomy of perceptual/cognitive processes that underlie information tasks").

Problem solving and decision making are similar information tasks that should be distinguished, because each can be assisted in a different way by an information system. In problem solving the focal task is that of discovering a "solution principle" which, when discovered, seems self-evidently correct. In decision making the focal task is that of choosing a satisfactory alternative from a set of alternatives that may be balanced in their pro's and con's. The singularity of a well-made decision approaches the singularity of a well-solved problem only when the set of alternatives is rankable in such a way that the chosen alternative optimizes outcomes on the decision criteria. Often, decisions do not optimize; they only "satisfice" (Newell and Simon, 1972, p. 681).

Since decision making is an important task of STI users, the Miller et al. "searching and solving" sequence should be extended to include it. Furthermore, since the STI user is often responsible for an information product (i.e., for "producing"), a more complete sequence can be stated as "searching, solving or deciding, and producing."

Our discussion of acceleration, augmentation, and delegation functions has undergone two simplifications in this section. First, attention has been restricted to the acceleration, augmentation, and delegation of STI use. Second, STI use has been defined in terms of subplans for searching, solving or deciding, and producing. The question to be answered, therefore, is how the perceptual/cognitive processes that underlie searching, solving or deciding, and producing can be accelerated, augmented, or delegated.

The perceptual processes of scanning and fixating can be assisted by noncomputerized as well as computerized information systems. Scanning can benefit from a combination of acceleration and pacing. Pacing, which has not been discussed previously in this report, is the concept of an externally regulated scanning rate. Tachistoscopic studies of perception (see, for example, Mayzner, 1975) can be interpreted or generalized beyond their simple data to show that human visual information processing is a lazy behavior most of the time. Except when engaged in fast-moving activities, which are limited to sports in the lives of most of us, we do not use our full capacity for visual input. Self-pacing of input, as in reading, can be fast or slow according to the cognitive schedule of the moment: fast, when we are rushing through documentation to meet a deadline; slow, when the deadline does not press.

Our years of information processing experience from childhood through adulthood bring negative connotations to fast-paced visual input. We learn to read fast to take examinations in school; to find our way while driving; to get through the junk mail, the application forms, the instruction books, and other printed nuisances. As far as tachistoscopic studies indicate, the perceptual processes of scanning and fixating themselves do not account for the fatigue that we experience in fast-paced visual input; the fatigue may therefore be related to the concentration that self-pacing requires.

External pacing of high rates of visual input, or accelerated scanning as we shall call it, may have few initial connotations for STI users. One form of accelerated display (scrolling) may remind users of the way they often see credits displayed in the trailer of a motion picture. Accelerated scanning may be received positively or at least neutrally by STI users; they will probably allow the innovation to prove itself in their work.

Accelerated scanning was included in ush's description of a memex display (1945, p. 105): "...each page in turn being projected at a speed which just allows a recognizing glance at each." Bush also indicated that the user could combine acclerated scanning with page skipping (e.g., scan one, skip nine) to sample long texts quickly. Perhaps because Bush assumed optical projection, his imagination stopped short of features that can easily be incorporated in accelerated displays from digital storage: continuously variable rate control, instantaneous jump to any page of any text, montaged (split screen) pages, etc.

The process of fixating means simply that the perceiver is looking for something in the scanned field and will focus attention on it if it is found. Accelerated scanning places stress on fixating, since more pre-fixating decisions ("yes, I see it") have to be made per unit of time. Fixating is not acceleratable in the same sense as scanning. An information system cannot accelerate fixating through any procedure that is independent of the user's fixating criteria, which are based on the user's goals in executing the searching plan.

The interdependence of system and user in fixating calls for an augmentation rather than acceleration function. The information system can learn the user's fixating criteria for a broad range of searches as easily as a selective dissemination of information (SDI) profile can be compiled from the user's expressed needs and interests. When the user's criteria are held by the information system in the form of an inverted file of key words and phrases, various fixating augmentations can be added to the accelerated display. For example, the display can stop on any page containing a key word/phrase until the user says "continue." Alternatively, the display can slow to half speed on such pages without stopping, so that pacing is not interrupted unless the user actively commands the display to hold. Alternatively, all paragraphs containing key word/phrases can become montaged pages that are displayed apart from the rest of the text. Which of these augmentations provides the greatest assistance to each user is a question for user research with experimental interfaces.

To an information user, fixating and feature extracting are different perceptual processes because one focuses attention on part of the visual field while the other distinguishes among stimuli in the restricted field. It is the colloquial difference between looking and seeing. To a computer, fixating and feature extracting seem to be macro- and micro-steps solvable by the same selecting algorithm -- as, of course, they are to a machine that does not "move its muscles" any differently to fixate or to extract features.

The content analysis algorithms that an information system would use to augment fixating are generically the same as the algorithms that would augment feature extracting. Until computer time and cost per operation drop again by an order of magnitude, we should expect the fixating algorithms to lack some of the analysis depth of the feature extracting algorithms -- for example, parsing and disambiguation steps, since augmented fixating processes every unit of text while augmented feature extracting processes only the subset of fixated units. Again, to the computer this is only the difference between "rough cut" and "fine cut."

The decoder or semantic interpreter in the human IPS (see page 24) can be augmented by information transformations that are presented not directly to the decoder but to sensory receptors. To a given STI user, information may be more decodable if it is presented verbally, numerically, or graphically. Roe (1952) studied the verbal, numeric, and graphic images that scientists in several disciplines use to conceptualize their research. Miller et al. comment on similar differences (1960, pp. 164-165):

> "Some people tackle the problem verbally, symbolically; others want to manipulate the objects, to group them perceptually this way and that; a few can alternate between the abstract and perceptual strategies."

Although the common-language definition of decoding as a cognitive process is that of "ascertaining what the message means," the computer cannot ascertain; it can only transform one symbolic structure into another. A computer guided by artificial intelligence principles (see, for example, Carbonell, 1970) will choose the second symbolic structure -- whether verbal, numeric, or graphic -- from the repertory of structures that it believes the user is comfortable with. Except for the computer learning that is implied, this is not a complex augmentation; when we turn to the dictionary to define a symbolic structure (word) that we don't know, we hope to find there a symbolic structure that we do know. Some augmented decodings are dictionary look-up transformations of this kind (e.g., from one verbal symbolic structure to another). Others are computational in that transformation rules rather than look-ups effect the change (e.g., from numeric to graphic symbolic structure).

Comparing is one half of the comparing-deciding sequence of which "higher" cognitive processes like induction and deduction are composed. Augmented comparing would be the simultaneous presentation to the STI user of two or more entities (e.g., objects, concepts) with their associated attributes clarified. One of the entities may be a criterion, or, in Campbell's terminology (1966), a "pattern" or "template." Patterns may also be noncriterial; they may suggest alternatives for the STI user to consider during what Campbell calls the "pattern comparison" phase. For example, a pathologist may inspect computer-selected slides of normal and abnormal cells, with which he or she compares a tissue specimen from a patient. Particularly in research, another form of augmented comparing would be the simultaneous presentation of two or more attributes (rather than entities) to be compared, with representative entities (rather than attributes) providing data points on each. For example, the pattern of an attribute such as "political stability," scaled for nations around the world, may be compared with the pattern of an attribute such as "national income redistribution," scaled for the same nations. Patterns of other attributes such as "birth rate" and "per capita education and literacy" provide a multivariate context for the stability-redistribution comparison. Multivariate analyses of this kind exemplify the second sense in which cognitive processes are said to be augmentable on page 45.

One form of augmented deciding would be a sequenced presentation of deterministic or probabilistic syllogisms which invoke a criterion in the major premise and a test outcome in the minor premise. If decision rules are straightforward and if the user agrees with them (e.g., does not "hedge" the decision on the basis of other rules that the computer doesn't know about), then the computer can go beyond the presentation of syllogisms in augmentation of the user's decision, and the decision can be delegated entirely to the computer. For example, if an experimenter wishes to know which trials are statistically significant, the computer can go beyond this syllogistic presentation:

A. The .05 probability value for chi-square with 20 degrees of freedom is 31.41.

B. The chi-square for trial X is 33.07.

to the delegated decision:

> The difference obtained in trial X has a chance probability of less than .05, and is therefore to be regarded as statistically significant by the criteria of this study.

A second form of augmented deciding would be the presentation of nonsyllogistically related alternatives for the user to decide among. It is often necessary in information work to choose among the balanced alternatives X, Y, and Z. The decision can be augmented by displaying in a matrix the figure of merit that each alternative is assigned on each criterial attribute. When the attributes themselves are weighted according to the role each is allowed to play in the decision, then a summed figure of merit can be computed for each alternative decision:

Criterial Attributes	Alternative Figures of Merit			Attribute Weights	Weighted Figures of Merit		
1	X1	Y1	Z1	w1	w1X1	w1Y1	w1Z1
2	X2	Y2	Z2	w2	w2X2	w2Y2	w2Z2
3	X3	Y3	Z3	w3	w3X3	w3Y3	w3Z3
.	.	.	.	.	.	.	.
k	Xk	Yk	Zk	wk	wkXk	wkYk	wkZk
Sum					w.X.	w.Y.	w.Z.

When the computer performs these steps without user intervention and tells the user which alternative is indicated by the weighted figures of merit, then the decision has been delegated entirely.

As discussed on page 30, the cognitive processes of retrieving, selecting, and transforming are counterparts of the perceptual processes of scanning, fixating, feature extracting, and decoding. However, because these cognitive processes are transacted between the processor and long-term memory, an information system's access for acceleration, augmentation, and delegation is limited. The possibility of intervening in the retrieving, selecting, and transforming processes depends on the STI user's willingness to transfer substantial information from his or her long-term memory to an external memory, such as the computer's, where acceleration, augmentation, and delegation functions can have access to it. Although we cannot imagine that users would attempt to "tell" the external memory everything that they know, we can imagine that, in the course of several years of preparing articles, reports, memoranda, etc., on the computer via a text editor, a user would commit most of his or her most-used symbolic structures to the external memory. In such cases, even existing software such as the General Inquirer (Stone et al., 1966) could augment retrieval, selection, and transformation of the user's own ideas.

Encoding, or producing as we have referred to it, is an acceleratable, augmentable, and delegatable process with, in fact, a long history of technological assistance. Whereas the printing press entered information work in assistance of distribution and provided little help to the information worker at the time of producing (despite writers like Balzac who regarded galley proofs as rough draft to the despair of publishers), the typewriter entered information work in assistance of production as well as distribution and remains, together with the dictaphone or tape recorder, the primary production assistant that most information workers have at their disposal.

In the computer era, assistance in production goes far beyond the typewriter and dictaphone, which can only preserve the writer's and speaker's words as they were, without expansion or improvement. Text-editing systems, such as WYLBUR on which this report is being written, facilitate expansion and improvement of text. Although text editors only accelerate and augment production at the present time, delegated text-editing functions such as spelling and punctuation conformance checks would be possible with software development that is a small elaboration of the text editor as a whole.

Optical character-recognition hardware eliminates an additional keyboarding of previously keyed text. Voice-to-print converters eliminate the keyboard itself as a requirement in production. Graphic systems convert rough light-pen drawings into geometrically correct drawings. While these devices and systems provide macro-assistance by converting or improving entire products, other devices at the computer terminal (e.g., "mouse," "joystick") provide micro-assistance in editing text. Of great usefulness now, they will probably yield to voice-directed text editors within ten years.

In this section we have discussed the acceleration, augmentation, and delegation functions that parallel the perceptual/cognitive processes listed in Figure 2 (page 31). Other functions can be cited: analyzing, simulating, commanding, storing, transmitting. Analyzing and simulating functions, which can be either augmentations or delegations depending on application area and software complexity, support the cognitive processes of comparing and deciding, but in more specialized ways than the functions discussed earlier in this section. Commanding is the function of telling the information system what other functions are desired; commanding was formerly regarded as a software ("command language") provision, with only a standard keyboard for expressing the commands. Increasingly, hardware provisions speed the user's command; for example, the "mouse" and "joystick" are controls that position the cursor on the screen faster than standard keyboard controls and command language can do so.

Storing and transmitting are functions that involve the user's product during and after production. In current implementations (e.g., magnetic and micro-optical storage, computer teleconferencing), these functions mostly accelerate information work with little augmentation or delegation. Storing permits more rapid structuring and filling of the user's personal file or information store. Transmitting permits more rapid communication between the user and others whom he or she wishes to inform; in computer teleconferencing the speed of a telephone call is combined with the depth of displayed text.

The functions discussed in this section are summarized for convenience in Figure 5.

FIGURE 5. ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS AT THE STI COMPUTER/USER INTERFACE.

RECEPTOR LOCUS

Retrieving

Selecting

Displaying

PROCESSOR LOCUS

Transforming

Comparing

Analyzing

Simulating

Deciding

EFFECTOR LOCUS

Commanding

Inputting

Storing

Editing

Outputting

Transmitting

PART II: CATALOG OF ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS IN INFORMATION WORK

4. PRECONDITIONS FOR ACCELERATION, AUGMENTATION, AND DELEGATION: GENERIC 1977 HARDWARE/SOFTWARE AND EXTENDABLE SYSTEMS

Outline of Sections

4.1. Generic 1977 Hardware 55
4.2. Generic 1977 Software 56
4.3. Extendable Systems 57
4.4. Information Storage and Retrieval Systems . . . 57
4.5. Teleconference Systems 58
4.6. Instruction Systems 59
4.7. Decision Support Systems 59
4.8. Extended versus Conventional Features 60

4.1. GENERIC 1977 HARDWARE

The decade from 1965 to 1975 belonged to the "maxi" computer. When integrated-ciruit computers of the IBM 360 and CDC 6000 series began to replace their discrete-ciruit predecessors, it was generally believed that large multi-purpose computers permitted the greatest computing efficiency. These computers became the central devices in educational and business computing systems that grew to serve thousands of users daily, including a high proportion of interactive and remote batch entry terminal users.

The large computer made interactive computing possible for the majority of users who did not have access to dedicated computers or minicomputers. A combination of features introduced in several lines of computers around 1965 made the innovation of remote, interactive, time-shared computing a revolutionary rather than evolutionary development for users. The speed of integrated-circuit processors gave each time-sharing user the immediate response that had formerly been experienced only in dedicated systems. Large internal memories and almost unlimited external memories, organized hierarchically for access according to size and speed, allowed users for the first time to direct their own computing without having to know where the physical records of their programs and data were stored. Thus, for users of scientific and technical computing systems in particular, information work became the direct manipulation of symbols that sprang into existence when files were summoned at a terminal. Finally, although remote batch entry was a necessary compromise between the desire of users to compute interactively and the need of the computing system to maintain foreground and background job streams for full utilization of the computer, in many large systems the job queue was processed so swiftly that users could order a terminal display of the output of a job within minutes or even seconds of its submission.

These details have more than historical interest for us. Many of the concepts of computer-based acceleration, augmentation, and delegation arose as expectations for the next generation of large computers, conceived as extensions of "transparency," "virtual memory," "natural language programming," etc.

However, the same miniaturization and integration of devices that made large computers possible also made small computers inevitable. The concepts of "distributed computing" and "point-of-use computing" were undermining centralization by 1975. Physically small on-site computers were being installed at major nodes of the networks of large computer utilization, eliminating not only the line charges but also the service interruptions that large computers are susceptible to. The physical size of small and "mini" computers is misleading, moreover. Not only can their core memories be expanded to exceed those of almost any computer prior to 1965, but the greatly increased processing speeds of their microprocessor "chips" permit interactive cycles that include repeated accesses to external memory without degraded performance from the user's perspective.

Undoubtedly the most-discussed developments in 1977 hardware are "smart" and "intelligent" terminals. Smart terminals are equipped with software or "firmware" that is programmed by the manufacturer for switchable flexibility with respect to communication speeds, character sets, display configurations, etc. Intelligent terminals are user-programmable for even greater flexibility and for data entry and management (e.g., editing) functions that otherwise burden the central processor.

There is a stage of development at which an intelligent terminal becomes a minicomputer with memory, software, and peripheral devices capable of executing many jobs independently. Although prototypes were introduced earlier, 1977 was the first year of the "personal computer" or "home computer." Because of a manufacturers' decision to package processors, terminals, magnetic memory drives, printers, etc., as separate components, the first generation of personal computers were similar to intelligent terminals electronically but had the ill-matched appearance of the first generation of audio high-fidelity components. By mid-1977 several manufacturers sought to expand the market for personal computers beyond the technically minded consumer by packaging both processor and external memory in the terminal case. Thus the personal computers of 1978-1980 will increasingly resemble intelligent terminals but will have the features of general-purpose minicomputers, including high-level compilers.

4.2. GENERIC 1977 SOFTWARE

The decade from 1965 to 1975 saw less change in software than in hardware. Computer operating systems designed for the IBM 360 and CDC 6000 series introduced concepts of time sharing, virtual memory allocation, multiprogramming, and multiprocessing that continue to structure new operating systems. High-level programming languages such as COBOL and FORTRAN continue to generate most applications software.

Thousands of software packages for business and research applications were developed between 1965 and 1975. The size of the software market can be estimated from the finding that, in its annual survey of users of proprietary software, Datapro Research Corporation (1976) obtained ratings of 1,426 software packages. In the 1970's computer manufacturers began to "unbundle" their hardware and software offerings, a move necessitated by the often more efficient software produced for standard configurations by specialized software manufacturers. Of the 38 software packages that achieved "honor roll" status in the Datapro survey, only 2 were produced by IBM and only a handful of others by manufacturers who offer hardware as well as software.

Because many software packages are machine-dependent, convergence and standardization of software seem as far from realization in 1977 as in 1965. Drawing upon the informative Datapro survey again, we find that no software package received more than 172 of the 3,659 ratings and that only 7 packages received more than 100 ratings. The most popular packages are those that are IBM 360/370 compatible and/or those that require minimum support in an untrained-user environment (e.g., SPSS in a university computing center).

The rapid diffusion of small general-purpose computers has led to the subsetting of high-level programming languages and software packages rather than the redesign or invention of languages and packages. A high proportion of software packages now commercially available are derived from a small number of source packages. Subsetting is a valid procedure according to the "median rule" that half of the capacity of a system (e.g., computer memory, programming language, software package) generally suffices for a high percentage of all demands placed upon it.

4.3. EXTENDABLE SYSTEMS

With some risk of trivializing them, we can compare acceleration, augmentation, and delegation functions with accessories on automobiles that perhaps make the automobiles more efficient and satisfying to use. The accessories do not have much application or value apart from their use in automobiles. Acceleration, augmentation, and delegation functions must similarly be incorporated into either new information systems or existing systems. A number of factors -- including cost, development delay, user acceptance, and opportunity for evaluation -- argue for incorporating these functions into existing systems whose hardware and software are capable of being extended in such ways.

Generic 1977 hardware and software are brought together in standard configurations, many of which (e.g., commercial accounting, inventory control, travel and lodging reservations, etc.) are not found in environments of STI use. However, four types of information systems, described below, have present or future STI roles. We refer to these as extendable systems for testing acceleration, augmentation, and delegation functions.

4.4. INFORMATION STORAGE AND RETRIEVAL SYSTEMS

The most common STI information system is used for information storage and retrieval (ISR). Proprietary ISR systems such as DIALOG, ORBIT, and BRS have attracted the largest amount of use by making multiple databases (e.g., more than 50 databases in the DIALOG system) available simultaneously. Other ISR systems compared in an important "feature analysis" by Martin (1974) include BASIS, DATA CENTRAL, INTREX, LEADER, NASIS, RECON, RIQS, SPIRES, and STAIRS.

Some systems that have diffused less widely than DIALOG, ORBIT, and BRS incorporate powerful features. For example, SPIRES provides transparent access to the WYLBUR text editor, and both BASIS and RIQS permit graphs to be plotted at the terminal from retrieved records. Thus, although the flexibility and features of DIALOG, ORBIT, and BRS are impressive, they incorporate only some of the features that ISR system designers have thought of.

The fact that a family of systems, such as ISR, incorporates more features than are found on any single system complicates the definition of extendable systems. On the one hand, we think of the widely diffused ISR systems such as DIALOG as prototypes of extendable systems. On the other hand, some of the accelerations and augmentations that should be tested in a single integrated configuration can already be found on various ISR systems in the family. A first step in extending a single ISR system, then, would be to consolidate features already found in the family of ISR systems.

Use patterns of ISR systems pose other problems for their extension to post-retrieval information tasks. Because of the multiservice character of these systems and a certain amount of user training that they require, most searches are performed by librarians and other information specialists. In a survey of ISR system usage and impact, Wanger (1976) found that 77% of the "searchers" were librarians and information specialists (furthermore, because of the high number of delegated searches performed by each of these searchers, only a few searches were performed by "end users"). Even if the end user is collaborating with a librarian to refine a search, he or she is observing rather than working at the interface and cannot fully benefit from acceleration, augmentation, and delegation functions. Also, in most ISR installations the computer goes on to other tasks for other users. It does not remain at the disposal of a single user for tasks of decoding, comparing, deciding, inducing, deducing, etc.

4.5. TELECONFERENCE SYSTEMS

Large-scale teleconferencing via computer is exemplified by FORUM and the FORUM-derived PLANET, initially designed as a computerized means of eliciting responses from experts (Hardy, 1976). The geographically dispersed users of PLANET, which is made available commercially on the TYMSHARE network, communicate through computer files that they create. Message transmission can be synchronous or asynchronous. When the intended receiver of a message is not active on the system at the time of transmission, the system holds the message in an "electronic mailbox" and prompts the receiver to check the mailbox when he or she rejoins the system.

FORUM, PLANET, and other teleconference systems including NLS and EIES have several common functions (e.g., text editing, personal file, storage, synchronous and asynchronous message transmission) and a few functions that are unique to each system (e.g., simulation, gaming, group decision-making, distributed authorship, opinion polling, etc.).

Because teleconferencing has been proposed as an energy-saving substitute for travel, there has been lively interest in social and psychological differences between face-to-face and computer-mediated communication. As a result, more behavioral studies have been conducted at the teleconference interface than at the information storage and retrieval interface (cf. Hardy, 1976; Short, Williams, and Christie, 1976). The absence of nonverbal cues in computer-mediated communication is studied as a factor that affects the substitutability of communication for travel. At the least, it seems desirable to transmit an audio signal on the same line as the computer signal to provide vocal nonverbal cues that inflect the meaning of the printed messages. Video signals, or in fact a video teleconference, would deal with the expressed dissatisfaction of some computer teleconference participants, but video (except for slow-scan TV) is not an add-on capability within the transmission bandwidth normally used for computer teleconferences.

4.6. INSTRUCTION SYSTEMS

Computer-assisted instruction (CAI) was initially a computerization of programmed learning sequences. Of the four modes of instruction that CAI now combines -- tutorial, drill and practice, problem solving, and simulation -- the first two were well developed in early CAI software and the second two are accomplishments of recent software development projects.

CAI is still rare in evironments of STI use, although open-line CAI is available from vendors at the same terminals that are also used for searching and teleconferencing in technical libraries, laboratories, researchers' offices, etc. State-of-the-art CAI systems, exemplified by PLATO and TICCIT, have two features that distinguish them from the prior generation of systems: (1) they present material to the user in audio and/or visual formats as well as printed text; (2) they adapt to the user's strategy and style of learning via "learner-controlled courseware" (cf. Bunderson, 1972), extending the concept of response-contingent branching taken over from programmed learning by earlier CAI systems.

Although user-adapted software is the major contribution of CAI to the progress of information systems in general, PLATO and TICCIT are also known for their innovative hardware. PLATO's plasma terminal, in the vanguard of the first major shift away from CRT terminals, provides not only high-quality display of material from computer files but also rear projection of photographic material on the flat, translucent plasma screen. TICCIT is unique in its use both of computer-controlled television and of minicomputers for self-contained instructional subsystems.

The related technology of computer-managed instruction (CMI) is concerned with the appropriate assignment of off-line as well as on-line learning sequences, based on computer analysis of each learner's progress through a curriculum. Of analogic interest for STI system design is the distinction between CMI's macro-branching among learning sequences and CAI's micro-branching within learning sequences.

4.7. DECISION SUPPORT SYSTEMS

For about two decades management information systems (MIS) have provided decision support of a kind through printout summaries of the variables that affect decisions. Th performance of MIS systems has been sharply criticized (cf. Ackoff, 1967), so that current conversions from printout to CRT display of variables must be regarded as a cosmetic rather than fundamental change in the decision support capability of a conventional MIS.

Still in their laboratory and field-trial phases of development are systems that bring numerical analysis and estimation to bear on decision making and assist the user in predicting and visualizing the outcomes of decision alternatives. One carefully studied decision support system (DSS) is GADS, which represents certain kinds of decision spaces topographically on a high-resolution CRT terminal. Bennett (1976) asserts that such a DSS finds its special application when "management control" objectives (versus "operational control" and "strategic planning" objectives) must be met by "semi-structured" decision rules (versus "structured" and "unstructured" decision rules).

In a typical application of GADS, an educational administrator prepares for the decision of closing a required number of schools in a district with declining enrollment by redrawing the attendance areas of the remaining schools. A database of student and staff data is used to project the teacher load, student demography, facility utilization, and other variables for each alternative. A school district map on the CRT screen shows the new attendance boundaries topographically, with overlays of data as desired. Of course, decision support systems also project and display alternatives for decisions (e.g., production, inventory) that do not have a topographic dimension.

All information systems have design principles, and these principles are often stated in terms of system optimization rather than system/user optimization. Bennett (1976) presents three design principles for DSS that help us further to understand the evolutionary difference between MIS and DSS (pp. 10-15):

"1. Arrange text and graphic symbols on each presentation to establish an explicit context for user action.

2. When user process is not known in advance, concentrate on displayable data representations and then design operations to act upon these representations.

3. Design the system to provide an explicit framework for representations. The framework gives a uniformity of structure within which the user can synthesize problem solutions. This framework can be developed even though the problems themselves are unstructured."

For successful functioning, decision support systems must be designed around what Bennett calls the "user process" more so than the other systems we have reviewed in this section. DSS have a minimal intrinsic function (i.e., they do not retrieve information, mediate communication, or teach per se). Their function is to focus data, analyses, estimations, projections, etc., on the user's problem, which structures their framework of representations.

4.8. EXTENDED VERSUS CONVENTIONAL FEATURES

Each of the four types of existing and extendable information systems offers one or more capabilities that are not as fully developed in the other systems. That is, information storage and retrieval systems are capable of storing large files of nonsequential and primarily textual records with many access points (indexed attributes) per record. These systems also assist in the definition of a search by tabulating the number of records linked with single attributes or combinations of attributes, thus describing the file in detail without displaying records unnecessarily.

Teleconference systems have a unique capability for interconnecting on-line users. Messages exchanged in a teleconference differ from the terminal-to-terminal "bulletins" permitted by some general interactive systems in the fact that they can be composed in advance of transmission and retrieved asynchronously from an "electronic mailbox" by receivers. Teleconference systems also provide the most flexible text editing and personal file creation of the four types of information systems described here, although superior text editing and personal file systems (such as WYLBUR, on which this text is being written and stored) have been implemented independently of information systems.

Computer-assisted instruction systems are unique in their response-contingent branching and their user-adapted sequencing and pacing of information. They also represent the highest development of multimedia presentation among these four types of systems.

Decision support systems enter further than the other types of systems into a user-defined problem, taking in user-supplied data a projecting the outcomes of alternative decisions. They have the mc highly developed numerical analysis and estimation procedures.

As we move on to a discussion of acceleration, augmentation, and delegation functions to be developed, tested, and implemented on these four kinds of systems, we encounter the problem of defining "extension." What constitutes an extension of such systems and what constitutes only a conventional feature? Clearly the state of the art in the development of hardware and software changes the boundary between conventional and extended features from year to year. A feature conceived as an extension becomes conventional when widely available. Five years ago the feature of simultaneous on-line access to a large number of bibliographic databases was an extension; today it is conventional.

High-technology innovations diffuse at different rates along different paths from centers of research and development. Innovations that are still being tested in the R&D centers are certainly not conventional, but before they reach distant application sites they are regarded as conventional at many application sites along the diffusion path.

The problem is definitional rather than empirical, and we can solve it by saying that a conventional feature of an information system is one that is already available to a substantial number of users. We do not stipulate how many application sites are implied by a "substantial number of users." Systems that can function with simple peripherals diffuse electronically to any number of application sites; for example, the conventional features of DIALOG, ORBIT, and BRS are hypothetically available to anyone in the United States and in several foreign countries who has a basic terminal, a modem, and a telephone. Systems that rely upon complex peripherals must, in the present state of the art, bring users in to a few specially equipped application sites; this is somewhat the case with computer-assisted instruction systems like PLATO and TICCIT, and it is definitely the case with decision support systems like GADS. Thus conventional versus extended features should be defined on the basis of the number of users rather than the number of application sites.

5. ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS IMPLEMENTED CHIEFLY THROUGH HARDWARE

Outline of Sections

5.1. Introduction 64

5.2. Commanding and Inputting 64

5.3. Displaying and Outputting 68

5.4. Storing 75

5.5. Transmitting 77

5.1. INTRODUCTION

The entries that are presented below represent diverse extensions of the present state of the art in computer-assisted information work. The reader who works in a center of computer technology development may believe that some of them are conventional already, while the reader who works in one of the thousands of application sites in the United States may believe that his or her electronic work station will not be extended in such ways until the 1980's. Both beliefs may be correct, but the rate at which new computer technology is capable of being refined, packaged, and marketed has often been misjudged in the past. Developments that at first appear to be unrelated (e.g., the increasing power of minicomputers, the rising cost of telecommunication, and the declining cost of mass memory) converge to create new marketable configurations (in this case, free-standing high-capacity computers at users' work stations), while other developments are left stranded by a loss of function within the new configurations. Continuing this example, a majority of information workers may require remote access to "maxi" computing systems for another decade or longer, but such access will become less frequent and will involve a few seconds of concentrated data transmission (read into local memory) rather than hours of logged-in use of the "maxi" computer.

Hundreds of extensions of computer-assisted information work can be identified or projected from the pages of current journals of computer technology, convention proceedings, equipment catalogs, etc. Most of the extensions are variations on a limited number of themes. Our sampling of extensions attempts to represent the themes rather than the variations. Furthermore, since our commitment is to information work rather than to technology per se, this is an idea catalog and not an ordering catalog. References to individual manufacturers are not consciously balanced. Cost comparisons, which are misleading prior to the mass marketing of new technologies, are avoided.

Acceleration, augmentation, and delegation functions are more distinct in relation to the user's perceptual/cognitive processes than in relation to hardware and software. For example, commanding and inputting can be distinguished as procedural versus substantive production on the part of the user, but they are accelerated and augmented by the same hardware and software. In conjunction with a touch screen, a displayed decision matrix may contain either procedural or substantive alternatives for the user to command or input. Displaying and outputting are bound together by the same ambiguity of function.

Four abbreviations that appear frequently below refer to the four generic types of STI systems: ISR, information storage and retrieval; TC, teleconference; CAI, computer-assisted instruction; and DSS, decision support. See pages 57-60 for an overview of these systems.

5.2. COMMANDING AND INPUTTING

TOUCH SCREEN. When a CRT screen is formatted into selectable fields or a response matrix, the customary device for selecting a field or making a response is the light pen. Multiple versions of touch screens have recently been introduced to eliminate the light pen in this application.

A photoelectric touch-screen mask contains light sources along one horizontal/vertical half of the perimeter and photoelectric cells along the complementary half of the perimeter. When the user touches the screen with a finger, one horizontal and one vertical beam of light are interrupted, providing digitizable information on the section of screen that was touched.

More precision in selection can be achieved with a touch-sensitive overlay on the screen itself. In one design, a touch-sensitive grid is composed of adhesive plastic overlaying transparent metallic strips. A low-voltage oscillating current is maintained in each strip. When the user touches the screen, finger capacitance changes the oscillating frequency in the touched strips, providing digitizable information on location.

The simplicity of touch-screen response is especially desirable in CAI and DSS applications. As touch screens become common, there will be a need for software to create more selectable fields and response matrices on CRT or other screens.

(Photoelectric: Control Data Corporation, Minneapolis, Minnesota; overlay: Information Dialogues, Inc., Minneapolis, Minnesota; others)

MOUSE. The mouse is an analogue device that permits more rapid positioning of the cursor on a CRT screen than keyboard cursor controls. Twin opposed potentiometers in the base of the hemispherical or hemi-elliptical mouse translate the mouse's motion along a work surface into horizontal and vertical analogue potentials, which are then digitized to position the cursor. A single movement of the mouse achieves the same cursor positioning as the use of four cursor-control keys (up, down, left, right) on a CRT keyboard.

(Augmentation Research Center, Stanford Research Institute, Menlo Park, California)

JOYSTICK. Like the SRI mouse (see above), the joystick uses analogue potentials from horizontal and vertical motion to position the cursor on a CRT screen more rapidly than is possible with cursor-control keys on a conventional CRT keyboard.

Comparative tests of the performance of the joystick and the mouse have been conducted by Tektronix, Inc. (Beaverton, Oregon) and Bell Laboratories (Holmdel, New Jersey) in the course of their development of the split keyboard console (see below).

SPLIT KEYBOARD CONSOLE. In this experimental terminal configuration, the standard typewriter keyboard is divided in the middle, with the key sections operated by the left and right hands offset from the horizontal plane and adjustable in four directions. Human factors research indicates that each hand can operate keys more efficiently if the key sections are more or less perpendicular to the plane of each forearm in typing position (the forearm planes converge on a point a few inches behind the keyboard, the angle of convergence depending on physical measurements of the user).

A joystick is mounted between the half-keyboards so that either hand can position the cursor.

(Tektronix, Inc., Beaverton, Oregon, in collaboration with Bell Laboratories, Holmdel, New Jersey)

REDUCED KEYSET TERMINAL. Housed in a standard pocket calculator case, the reduced keyset terminal uses a pocket calculator touchpad with keys 0-9 and two symbols. Two other keys allow combinations of numbers to form alphabetic characters. The LED display forms characters in a 5x7 dot matrix. Given the geometry of the LED display, this limits the character set to numbers and uppercase alphabet at the present time. However, the microprocessor is already programmed to distinguish between uppercase and lowercase alphabets when the lowercase alphabet becomes displayable.

Unlike most miniature terminals, the reduced keyset terminal does not transmit a single character at a time. Microprocessor memory allows a full line of input to be stored, then transmitted in a burst to the computer.

R&D on miniature terminals of this kind should be concerned with human factors. Are there STI use settings in which miniature size and one-handed operation are desirable? Are there STI transactions in which most of the user's responses can be expressed as mnemonic codes involving a small number of characters? In terms of ease of training and user satisfaction with continued use, how does the reduced keyset terminal compare with the SRI chordal keyset (see below)?

Apart from data entry, this terminal may work best in CAI and DSS applications, in which the computer prompts the user for a large number of responses to multiple-choice questions or options. In general, STI transactions that involve limited keying on the part of the user permit this reduced keyboard to take the place of a full-sized keyboard.

(Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts)

CHORDAL KEYSET. A keyset consisting of five piano-like keys is capable of generating 31 "chordal" signals when different combinations of keys are depressed. When used in conjunction with three buttons operated by the other hand, the chordal keyset produces uppercase and lowercase letters, numbers, special characters, and display instructions. The chordal keyset was designed to permit rapid inputting of editing characters with one hand while the other hand operates a cursor control like the mouse.

(Augmentation Research Center, Stanford Research Institute, Menlo Park, California)

GRAPHIC TABLETS. Many representations that an information worker would draw on paper (e.g., graphs, diagrams, models) are keyboarded out of necessity at the computer interface. With ingenious use, a keyboard can approximate many drawn representations, but the mechanical steps for doing so are tedious and lack spontaneity. A number of graphic tablets have been developed to digitize free-form drawing for storage and display on any screen or plotter that can process coordinate data.

In the more flexible of two configurations ("constrained cursor" versus "free cursor"), a tablet contains an embedded grid of horizontal and vertical wires. As the pen-like cursor passes over the surface of the tablet, the transmission of a signal to or from the grid and the cursor provides digitizable information on the location of the cursor.

An advanced graphic tablet can digitize 1,000 or more points per second with a resolution of 100 or more points per inch. Most graphic tablets are supported by minicomputers.

(Science Accessories Corporation, Southport, Connecticut; Summagraphics Corporation, Fairfield, Connecticut; others)

INTERACTIVE GRAPHIC DESIGN SYSTEM (IGDS) WITH GRAPHIC TABLET. This software package permits the user to compose original designs or modify existing designs retrieved from storage. Designs can be drawn by hand or defined numerically from the geometry of design elements.

(M&S Computing, Inc., Huntsville, Alabama)

AUTOMATIC SPEECH RECOGNITION (ASR). Automatic speech recognition begins with a microphone. In hands-off applications the microphone can be worn as a headset. The spoken signal that is picked up by the microphone is directed to an audio spectrum analyzer with bandpass filters from 200 hz. to 5,000 hz. After the signal is filtered into its frequency components, it is converted from analogue to digital form. The digital pattern of frequency, stress, and time is compared with stored patterns or templates for each phoneme. As is true of the human ear and brain, matching incoming information with stored information is a process of ranking possible matches according to the number of discrepancies noted on the dimensions of frequency, stress, and time. Once each phoneme is thus identified, additional software disambiguates various letter equivalents of each phoneme in word context.

All other methods of commanding require that the user learn to operate a device (keyboard, light pen, joystick, mouse, etc.) while voice recognition allows the computer to be commanded by a fixed vocabulary of spoken words and phrases. Recognition vocabularies of computers are not yet large, but inputting of numeric data can be accommodated as well as commanding. The ability to speak commands and numeric data frees the user's hands to work with other materials.

Until recently ASR systems have required isolated speech (i.e., separately pronounced words, not continuous sentences). The systems have also required "tuning" to dialectical differences among speakers. Moreover, they have performed poorly in settings where ambient noise was high. These limitations need to be overcome before ASR can displace some keyboard work in STI use.

Recent R&D has utilized a "Greek chorus" of many voices to create phonemic templates that are dialect-free. Faster processors also permit a more continuous and hence natural delivery by the speaker. Enlarged recognition vocabulary for limited text input (in addition to commands and numeric input) requires additional storage for the new templates, additional disambiguation software, and faster processors to keep up with the larger number of vocabulary alternatives to be recognized.

When the technology is mature, ASR will have a profound effect on the interfaces of all information systems. The number of keyboarded characters per minute is an index of how much a particular application will be affected by ASR. By this index, TC (which requires the greatest amount of user input) will be affected most, followed by CAI, ISR, and DSS, in that probable order.

About a dozen research teams have been working steadily on ASR, and about half a dozen companies market some version (chiefly isolated word recognition). Uses of ASR in business and industry include mail-sorting (clerk speaks name and address for directory look-up of addressee's department), inspection for defects on the assembly line (inspector speaks name of defective part), and account posting (clerk speaks numeric data to update account). These are good examples of applications in which the user's hands need to be free for other tasks.

(Threshold Technology, Delran, New Jersey; others)

5.3. DISPLAYING AND OUTPUTTING

AUTOMATED LABORATORY INFORMATION SYSTEM (LIS) AND DIRECT INPUT VOICE OUTPUT TELEPHONE SYSTEM (DIVOTS). These companion systems are designed to increase accuracy and efficiency in ordering, performing, and reporting hospital tests. The technology is transferrable to a number of STI system applications.

An online patient record is created at the time of admission. Each patient is assigned a unique number that serves as a key to later transactions between the patient's physician and the laboratory.

The physician requests laboratory tests via DIVOTS. The DIVOTS extension is dialed and an IBM Audio Response Unit answers with a spoken message for the physician to enter the request. The physician inserts a previously prepared patient dialer-card in the card-dialer pad attached to his or her telephone. Within 3 seconds the Audio Response Unit speaks back the identity of the patient for verification. The test is ordered by test identification number, and the Audio Response Unit verifies the test by speaking its name. Special instructions are entered by code numbers and spoken back for verification.

Test request information is collected at a laboratory terminal in the form of preprinted and prepunched test requisitions. Specimens are then collected and tests performed. Several of the laboratory analyzers report results directly to the computer; technicians enter results from other tests manually.

To obtain test results directly (although they are also entered on the patient's record), the physician can phone DIVOTS, enter the patient's number, his or her own number, and the test identification number. The Audio Response Unit spells the patient's last name for verification, states the name of the test, the day it was performed, test results, and degree of normality.

When time is a critical factor, the system has a autocall feature. As previously instructed, DIVOTS calls the ward station. When the phone is answered, a series of chimes produced by the Audio Response Unit identifies the call as coming from DIVOTS. The answerer enters the ward code number as verification that the right extension was reached. DIVOTS then states the patient's name, the test name, and the result. To ensure accurate reception of the result, DIVOTS repeats the message continuously until the phone is hung up.

In STI applications, the verification procedures described above would not be necessary, and a simpler exchange could take place between users, databases, and audio response units. As an option in selective dissemination of information, for example, a user's profile could contain instructions for the user to be called whenever certain high-relevance documents are identified in scheduled SDI updates. The cost of the phone call, using OUTWATS and involving no human labor, would be justified by the user's more rapid access to the relevant documents.

Participants in teleconferences may also value the option of an autocall feature for high-priority messages. Intended receivers of messages can thus be reached away from their terminals. If a message is brief, an audio response unit can deliver it in its entirety. If a message is long, an audio response unit can notify the receiver that the message is waiting in his or her electronic mailbox.

(Youngstown Hospital Association, Youngstown, Ohio, and IBM Corporation, White Plains, New York)

PLASMA TERMINAL. Plasma terminals have grown in a few years into a generic family of display devices, having in common only their plasma (ionized gas) screens. The best-known plasma terminal was developed at the University of Illinois in conjunction with the PLATO CAI system. The PLATO plasma screen consists of an 8.5x8.5 inch sandwich of two layers of translucent glass. Within the sandwich are 262,144 bubbles or cavities containing neon, and within each bubble horizontal and vertical electrodes cross, separated by an ionization gap. Characters or lines are formed by firing combinations of electrodes. Once one of the intersections has been ionized, it continues to glow at a maintenance voltage without refreshing from the computer.

In the PLATO configuration, the screen becomes a terminal with the addition of a keyboard and a rear-screen projector for random-access projection of microfiche color transparencies. A touch screen can be added, and random-access audio is under development.

While the PLATO configuration was developed for CAI applications, it is a prototype of the extended-function terminals that users of ISR and DSS systems would be well served by. In these applications, the auxiliary optical display and audio channel can store information that is needed by the STI user but is hard or expensive to digitize.

(Control Data Corporation, Minneapolis, Minnesota)

KODAK INTERACTIVE LEARNING TERMINAL (KILT). KILT is an integrated CAI terminal with random access audio and visual channels. Minicomputer controlled, it does not require a real-time communication channel. A 70 square-inch plasma screen permits both electronic and optical display (the latter through rear projection). Random access is provided to 128 color microfiche and 128 audio chips. A standard ASCII keyboard completes the configuration.

Although the dual-purpose plasma screen, random access audiovisual storage, free-standing operation, and student self-loading of program materials are found separately in other systems, KILT is unique in its integration of these features in one configuration. Like other small CAI systems, KILT should be tested as a means of providing "10 minute tutorials" that are often needed by the STI user in dealing with unfamiliar concepts, measures, etc. The cost of a KILT-like system would be higher per station than the cost of conventional text-only CAI -- does the instructional benefit of the integrated electronic-optical-audio display justify its cost?

While KILT itself is a CAI system, it may prove to be a useful extension of ISR systems in particular.

(Eastman Kodak Company, Rochester, New York)

SPLIT-SCREEN DISPLAY. In applications like text editing, the user would often like to work with more than one displayed file at a time.

Conventionally this is accomplished by successive "use and save" steps or by working with one displayed file in conjunction with a printout of another file.

One new intelligent terminal exemplifies a trend toward split-screen display. The full screen of 80 characters by 24 lines can be split equally or unequally to display two files simultaneously. In addition to a standard computer interface, this terminal is capable of stand-alone operation with 28K bytes of internal memory and a floppy-disk interface for external memory.

This terminal also exemplifies a trend toward human-factoring of displays and keyboards. Character-set definition, screen glare, display dynamics, cursor representation (described below), and other characteristics have been designed for efficiency and user satisfaction.

(Digital Equipment Corporation, Maynard, Massachusetts)

CURSOR REPRESENTATION. On most CRT screens the cursor is represented by a underline or rectangular block. On some CRT screens the cursor blinks rapidly to assist the user in finding it. Although the blinking feature is useful when the cursor is stationary, it may actually impede the user's effort to reposition the cursor, since the cursor repeatedly disappears and reappears as it moves across the screen.

On one new intelligent terminal, the cursor blinks whenever it is stationary but remains visible whenever it is moving.

(Digital Equipment Corporation, Maynard, Massachusetts)

LARGE SCALE LIQUID CRYSTAL MATRIX DISPLAY. Liquid crystal displays (LCD) are widely used in calculators and watches. Problems associated with enlarging them to serve as computer displays are being solved. In one experimental version, the panel has 400 horizontal and 500 vertical lines of transparent striped electrodes. Using the 200,000 intersections of these electrodes, characters can be formed in 7x9 dot matrices.

LCD offers two potential advantages over CRT and other conventional image technologies. First, the voltage and power requirements of LCD are both low enough to permit terminals using liquid crystal displays to be unwired and hand-held (the digital signal can be broadcast to a stationary unit from a hand-held terminal). Second, LCD does not wash out in high ambient illumination as does a CRT display.

R&D is needed on user response to LCD. Liquid crystal displays are thought to be "cool" or "soothing." In comparison with other image technologies, does LCD reduce user fatigue in long work sessions? In settings where CRT's are now used, is ambient illumination kept below a level that would be optimal for other reading tasks (e.g., reading data sheets at the terminal) in order to heighten contrast on the CRT screen? Is LCD more compatible with other reading tasks that require higher illumination?

LCD may become a generic extension of ISR and CAI systems. TC still relies upon hardcopy terminals, and some applications of DSS require a higher-resolution screen.

(Hitachi, Ltd., Tokyo, Japan; others)

LARGE SCREEN CRT PROJECTOR. Via a high-resolution projector, CRT images can be enlarged to 6x6 feet. The projected image has a contrast ratio of 12:1 and a resolution of more than 1,000 lines. Graphic representations of 3,500 symbols or tabular presentations of 4,100 symbols can be accommodated.

At a future time when the system/user interface relies less on the keyboard and accepts, for example, combinations of spoken commands for symbolic interaction and joystick motion for cursor control, the display screen and the user can enter into a new and more agreeable relationship. Whether implemented in a 6x6 foot version or in a smaller version (e.g., 3x3 feet), the large screen can be wall-mounted or free-standing at some distance from the user, who can execute changes in the display via the combination of speech and joystick.

The desirability of larger display surfaces for information work is self-evident, but processing efficiency and user satisfaction should be investigated across a range of screen sizes. It will also be useful to determine if large displays of computer information can contribute to the effectiveness of group problem solving, decision making, and brainstorming sessions. However, the highest-priority R&D question is the production economy of large displays using CRT, storage tube, plasma, and other image technologies.

ISR and CAI systems, in which small low-resolution displays are still standard, are the best candidates for extension via large high-resolution displays. TC usually calls for hardcopy terminals; DSS already utilizes higher-resolution displays.

(General Dynamics Corporation, San Diego, California; Mitre Corporation, Bedford, Massachusetts; others)

VOICE RESPONSE (VR). Voice response or voice synthesis provides the user with spoken verification of commands as well as spoken prompts for additional information. Older VR systems assemble a response from words or phrases stored on random-access magnetic media in analogue form. A more recent VR technology that avoids some of the choppiness of analogue VR produces a response by frequency synthesis of phonemes, with digital patterns of phonemes and stress levels stored on random-access magnetic media.

VR is well-established in some computing applications (e.g., banking). Transfer of this technology to STI use calls for analysis of the STI system responses that are best presented visually and those that are best present aurally, taking into account the average STI user's ability to process visual input several times faster than audio input, particularly when browsing is an appropriate mode of visual processing for the information task. VR is an attractive alternative to the visual display of routine system prompts. Fatigue may be reduced if the user can relax visual vigilance during the execution of a command until the system aurally prompts the next command.

If used to transform system prompts from visual to audio mode, VR will be a useful extension of all STI systems. Systems that normally involve browsing of displayed information (ISR, TC, and DSS, in that order) will benefit less from VR than systems in which every word needs to be attended to.

One version of VR that can produce speech from either analogue or digital storage is designed by IBM (White Plains, New York) to run on a System/7 minicomputer, using the 7770 and later models of the IBM Audio Response Unit. Similar technology has been developed by Scope Electronics, Inc. (Reston, Virginia), among others.

THREE-DIMENSIONAL DISPLAY (GRAPHPAK). This is a basic system for defining, projecting, and plotting two-dimensional and three-dimensional figures, using a storage-tube display and/or a line plotter. Figures can be rescaled, translated, and rotated for either of the output devices.

GRAPHPAK is an APL software package designed to operate on IBM 360 computers.

(IBM Corporation, White Plains, New York)

THREE-DIMENSIONAL DISPLAY (DISSPLA). Larger, more versatile, and more expensive than GRAPHPAK, DISSPLA is a package of 250 FORTRAN programs designed to operate on IBM, Univac, and CDC computers with a variety of output devices, including CRT displays, plotters, and computer-output microfilm recorders. In addition to three-dimensional figures, DISSPLA produces graphs, curves and curve interpolations, surface projections, maps, etc. Reference axes can be linear, semi-log, log-log, polar, and combinations of these.

User-supplied labeling can use Roman, Greek, Cyrillic, and Hebrew characters in titles, headings, legends, and subscripts.

(Integrated Software Systems Corporation, San Diego, California)

THREE-DIMENSIONAL DISPLAY WITH TRUE DEPTH AND PARALLAX. Unlike the three-dimensional display systems described above, in which the three-dimensional effect on a flat surface is achieved by means of software, this display system uses a mirror mechanism mounted on a CRT screen to provide a perception of true depth and parallax. In the previous systems, the user sees the same three-dimensional image from any viewing position in front of the screen. In this system, the user sees a different perspective of the three-dimensional image from each viewing position.

Two display processors and the specially designed terminal create unusual support requirements for this system, but it may be especially suitable for CAI and DSS applications in which the user needs to make judgments or inferences concerning three-dimensional figures by changing his or her viewing position.

(Perceptronics, Inc., Woodland Hills, California)

THREE-D PERSPECTIVE DRAWING PROGRAM. The special features of this three-dimensional drawing program include optional suppression of hidden lines in gridded surfaces, creation of pairs of perspective drawings for stereo viewing, and production of animated movies via computer-output microfilm.

(California Computer Products, Anaheim, California)

AUTOMATED SYMBOLIC ARTWORK PROGRAM (ASAP). Schematics, diagrams, plans, and other kinds of drawings that involve placement and connection of repetitive symbols can be created, updated, and edited by means of ASAP. Drawing orientation and continuity are checked and conformed by the program. Area within a defined polygon can be shaded with cross-hatching lines. Grid size, symbol size, and pen size are user-specifiable.

(California Computer Products, Anaheim, California)

PLOTPAK. This system prepares three-dimensional output for a line plotter under a high degree of user control. For example, the deformed shape of a model that results from a particular loading can be displayed.

(Encomp Systems, Inc., Irvington, New Jersey)

AUTOMATED DRAFTING SYSTEMS, ISOMETRIC PIPING AND STRUCTURAL STEEL DETAILING (ADSIP AND ADSTEEL). These related systems take as input the specifications of construction projects involving piping and structural steel. Output consists of plans, fabrication drawings, bills of material, cost estimates, etc. Drawing and lettering can be scaled independently; lettering can be projected in any of four directions; and standard symbolic representations of construction components can be called from memory to be added to the drawing.

(Suntech Computer Services, Philadelphia, Pennsylvania)

RSVP. This report-writing system processes a user-oriented report request to produce an individualized report from a data file. The report request is generated with reference to an item list that describes the contents of each data field in nontechnical terms. Against these data fields are posed tests or selection criteria that cause records to be included or excluded from a report. The format of the report as well as its substance can be specified by the user in the report request.

(National Computing Industries, Atlanta, Georgia)

5.4. STORING

° MICROFORM ULTRASTRIPS. Ultrastrips are a high-density optical storage medium suitable for computer-directed random access. Each 35 mm. ultrastrip contains as many as 2,000 pages of information. Sticks of 50 ultrastrips are mounted in 2x3x6 inch cartridges. In a new version of this storage system, 500 ultrastrips (containing 1 million pages of information) are mounted on a carousel.

Directed by a minicomputer, the ultrastrip system will retrieve and display any page within a maximum of 4 seconds after the page is selected at the keyboard. In a common application, telephone directory assistance, the user calls up a sequence of pages by keying a name. The minicomputer consults its inverted file to determine the page or pages containing the name and then initiates the display.

The possibility of storing up to a million pages of full-text literature in a random-access device should lead to R&D on related questions of copyright, filming costs, updating procedures, display transmission methods and costs, remote viewing devices, etc. The concern for display transmission and remote viewing follows from an assumption that ultrastrip systems cannot be afforded at points of STI use. At best, an ultrastrip system can be installed as an extension of the central computer of an ISR system. Pages retrieved from the ultrastrip system then require analogue or digital transmission to a remote point of use, where they can be viewed on the basic terminal screen or on an ancillary screen.

(Microform Data Systems, Mountain View, California).

COMPCARD. COMPCARD is a smaller and more affordable computer-directed microform storage system. The system's present capacity is 73,500 pages; any page can be retrieved and displayed in a maximum of 4 seconds by keying 8 or fewer characters.

Because of its significantly lower cost, the integrated COMPCARD minicomputer and storage/display station could be installed in major STI use sites (e.g., technical libraries) for rapid access to medium-size high-access files whose contents permit and justify page-specific indexing. Such files would not contain general literature (e.g., only 500 technical reports of average length could be stored) but might contain directory information, project descriptions, union lists of resources, etc. Since the same amount of text in digital form (about 200 million characters) is now commonly assigned to disk in large computer systems, the most promising unduplicated function of COMPCARD in STI use is the storage of graphic and pictorial information that requires much larger digital space per page than text.

(Image Systems, Inc., Culver City, California)

SHRINK. SHRINK compresses data files for storage on various magnetic media, averaging from 60% to 80% file compression. Files can be retrieved, sorted, and updated without expansion. An additional use of SHRINK is to accelerate CPU-to-CPU transmission of data.

Whereas SHRINK is designed to run on IBM 360/370 computers, an equivalent software package, the Bit Efficient Storage Technique (BEST), is designed to compress and expand files on the more restricted IBM System/3.

As minicomputers and microcomputers take over an increasing number of STI functions from large computers, file compression software may offer a favorable tradeoff between expensive storage media and inexpensive CPU cycles used for compression and expansion. If file compression software can be standardized, vendors may offer compressed versions of STI products on cassettes or diskettes at lower cost per record than the uncompressed versions.

(SHRINK: Informatics, Inc., New York, New York; BEST: Standard Software Company, Silver Spring, Maryland)

MAGNETIC MASS STORAGE SYSTEM. A state-of-the-art magnetic mass storage system approaches half a trillion bytes of random access read/write memory. In terms of the page images that STI systems frequently store, the mass storage system can accommodate 200 million average pages, or more pages than are contained in most university libraries.

For a number of years the technology of magnetic mass storage has progressed through a number of media and mechanical configurations. In this system, 202 magnetic cylinders are mounted in a cartridge. Pairs of cartridges are designated as mass storage volumes. Mass storage volumes are the subsets of the mass storage system that interface with the computer through the concept of direct access storage devices (DASD). DASD, a portion of the mass storage system that is used as a "staging buffer," serves the purpose of providing an addressable location for data from cylinders in each mass storage volume, just as tape drives and disk drives are computer-addressable locations for tapes and disks. Data held at a given time in a DASD is directly available to the computer. Data requested from a cylinder whose contents are at a given time not held in a DASD must be transferred to a DASD from a mass storage volume through an internal read procedure. An efficient use of the DASD buffers calls for all currently active datasets to be held in a DASD, with other DASD space left available for previously unused datasets to be called from mass storage volumes. When a DASD runs out of space, a rule of purging sends the least recently used datasets back to mass storage volumes.

This discussion of the mass storage system emphasizes allocation and management of space rather than the physical memory medium because it is the former rather than the latter set of design problems that become more severe with order of magnitude increases in memory size. This system has the capacity of nearly 5,000 packs mounted on IBM 3336 disk drives, and therefore its interface with the computer is potentially far more complex than a disk-drive interface. The concept of DASD buffers in the mass storage system reduces interface complexity.

(IBM Corporation, White Plains, New York)

HOLOGRAPHIC MASS MEMORY. A "medium-scale" read-only holographic memory contains 200 billion bits of data stored on approximately 7,000 conventional microfiche chips. Random access of any portion of the file takes less than 15 seconds. A major feature of this form of read-only holographic memory will be the cheapness of the recording medium -- presently estimated to be 2.5 cents per million bits. Archival files could be distributed in the form of holographic microfiche at a cost of 10 cents for an average book. A single microfiche, which requires no special handling because of the holographic recording, would contain four average books.

(Harris Corporation, Melbourne, Florida)

5.5. TRANSMITTING

MICROIMAGE TRANSMISSION. The cost of decentralizing microform collections is high enough to justify the development of methods for transmitting selected microimages from the central collection to remote users. When the users are geographically concentrated and therefore can be connected to the transmission source by broadband lines, analogue video transmission of the microimages is feasible. The geographical limitation of this approach is removed when inexpensive broadband communication is made possible by cable, terrestrial microwave, or satellite networks.

In the near future, however, geographically dispersed users cannot be served by video transmission of microimages. An alternative under development is the analogue-to-digital conversion of the microimage followed by narrowband transmission of the digital code and digital-to-analogue reconversion at the point of use.

One implementation of analogue-to-digital conversion and reconversion uses a specially developed scanner-digitizer, temporary disk storage of the digital code, and Tektronix 4014 terminals at the receiving stations. This system simultaneously accommodates 800 digitized pages and 100 receiving stations.

In order to improve resolution at the receiving station, cursor controls enable the user to specify that one of the four quadrants of a page is to be magnified. That quadrant then fills the screen.

(Video transmission: Project INTREX, Massacusetts Institute of Technology, Cambridge, Massachusetts; analogue to digital: EPSCO Laboratories, Wilton, Connecticut, in collaboration with Rome Air Development Center, Rome, New York)

MICROPROCESSOR BASED VISUAL COMMUNICATION TERMINAL. There are many applications for a video communication capability that allows the camera to be focused on any object or scene of interest (e.g., a scientific specimen, a page of text, a teleconferee), digitizes the video image, and transmits the digital code via narrowband lines to remote terminals for reconstruction of the image. Slow-scan images are often acceptable in these applications, if higher resolution is gained by restricting the number of video frames per minute.

In one congfiguration, a vidicon camera and a plasma display are coupled by a microprocessor which not only digitizes the video image but also calculates a synthetic gray scale for the otherwise bilevel plasma display. A new picture can be placed on a direct-wired display in eight seconds. Longer intervals between new pictures occur when dial-up telephone lines intervene.

This video communicaton system is seen as an extension of interactive interpersonal communication. It has also been used to transmit continuous tone and graphic images as well as alphanumeric characters to remote locations. Asynchronous communication is made possible by storage of digitized images in memory for later transmission.

(Bell Laboratories, Holmdel, New Jersey)

6. ACCELERATION, AUGMENTATION, AND DELEGATION FUNCTIONS IMPLEMENTED CHIEFLY THROUGH SOFTWARE

Outline of Sections

6.1. Introduction 80

6.2. Retrieving and Selecting 80

6.3. Transforming 82

6.4. Analyzing 83

6.5. Simulating 84

6.6. Deciding 85

6.7. Editing 86

6.1. INTRODUCTION

Comments made in the Introduction to Section 5 apply here as well. Some scientific and engineering users of STI systems may have used one or more of the software packages listed below more extensively than other packages that we omitted as too conventional (e.g., SPSS). However, unless the reader has previous knowledge of the software of several fields, he or she may be surprised by the specificity of packages that have been developed to solve the particular problems of each field.

Software descriptions are not as common nor as detailed as hardware descriptions in the literature of computer technology. We have gleaned descriptions from several sources, but one source, the DATAPRO DIRECTORY OF SOFTWARE (Datapro Research Corporation, 1976), was much more useful than the rest.

6.2. RETRIEVING AND SELECTING

DIALOG. Typical of a family of large general-purpose information storage and retrieval systems, DIALOG serves thousands of remote users via TYMNET and TELENET. More than 50 bibliographic and data files, proprietary (e.g., PSYCHOLOGICAL ABSTRACTS, PREDICASTS) as well as public (e.g., ERIC, NTIS), are mounted simultaneously.

Users can call DIALOG from a variety of CRT and printing terminals. After logging onto the system, the user first chooses a file to be searched and then enters a search request based on any searchable attribute of the file (files from various sources differ in indexing strategy). The user can browse thesauri and other inverted files in formulating a search request. Searching can be restricted to index fields or can involve the entire stored text (citation plus abstract). When a relevant set of documents has been identified using boolean combinations of search terms, the user can browse the set at the terminal and/or directed that the set be printed offline.

Among DIALOG's special features are provision for selective dissemination of information (SDI) in which user-generated search profiles are run periodically in batch mode against each update of chosen files; mounting of the user's personal files for DIALOG searching if desired; "search-save," private storage of the user's frequently used search formulations; and DIALIST, microfiche records of all subject indexes currently in use with DIALOG files.

An unusual interface feature of DIALOG is variable-rate terminal display of retrieved citations or citations and abstracts. Display durations of as little as 1 second can be specified by the user for browsing; longer durations can be specified for reading, note-taking, etc.

(Lockheed Information Systems, Palo Alto, California)

ORBIT. Approximately 40 bibliographic and data files can be searched by this system, which shares with DIALOG the majority of on-line ISR users in the United States, Canada, and Europe. One file unique to ORBIT lists the 10,000 patents issued weekly in 20 nations. Another file lists th nglish-language accessions of the Library of Congress. Other files that indicate the scope of the database cover the energy literature and grants programs of federal, state, and local government.

ORBIT offers two modes of searching the entire stored text of files. String search identifies file entries whose abstracts or other searchable fields contain a specified set of boolean-combined terms. Sentence search identifies only those file entries in which the terms are found within the same sentence (thus reducing the possibility of a spurious conjunction of terms within an overall field).

In formulating a search off-line, the user can consult microfiche records of the subject indexes of all databases; next to each subject term is shown the number of documents posted to that term.

(System Development Corporation, Santa Monica, California)

INQUIRE. A comprehensive file building, storing, retrieving, updating, and report-generating system, INQUIRE provides the user with a free-format command language for calling all system procedures and also allows user-written COBOL, PL/1, FORTRAN, or ASSEMBLER programs to access INQUIRE files.

Among systems in this category, INQUIRE's strengths lie in its proximity searching, KWIC/KWOC index construction, and thesaurus browsing procedures as well as data manipulation procedures prior to report generation. INQUIRE can also prestore routine sequences of commands whose execution the user wishes to delegate to the system and can individualize prompting sequences with user-entered variables.

(Infodata Systems, Inc., Falls Church, Virg. ia)

MISCELLANEOUS SPECIAL FEATURES IMPLEMENTED IN RETRIEVAL SYSTEMS. Features found in only one or a few retrieval systems are worth describing if they suggest useful extensions of other systems. Such features were mentioned in the longer descriptions of retrieval systems above, and miscellaneous other features are mentioned here. For example, whereas most retrieval systems permit numeric processing, if at all, only on retrieved records, QUERY5 (Azrex, Inc., Burlington, Massachusetts) permits retrieval to be conditioned on calculated values. ROBOT (Artificial Intelligence Corporation, Kensington, Maryland) accepts questions and search formulations in natural English rather than English-like code; the natural language is translated by ROBOT into its command language via procedures that disambiguate pronoun references, abbreviations, implicit content, etc., and check spelling. When necessary, ROBOT asks the user for clarification. QL SEARCH (QL Systems Ltd., Kingston, Ontario) computes a relevance value for each retrieved document based on its correspondence to the search request; retrieved documents are presented to the user as an ordered set from the most to the least relevant. ASPENSEARCH (Aspen Systems Corporation, Germantown, Maryland) is designed to store and retrieve full-text documents; in the output produced by full-text searching, text words that caused a document to be retrieved are printed in the margin next to their lines of appearance. REQUEST (System Automation Corporation, Silver Spring, Maryland) is more suited to management information retrieval than bibliographic information retrieval, but it merits description here because of its simulation module, which calculates solutions and projections from retrieved data. DATA/CENTRAL (Mead Technology Laboratories, Dayton, Ohio) has two kinds of features not found on most retrieval systems: instructional sequences for users and an interface for color CRT terminals.

RESTRICTED-ENGLISH QUESTION-ANSWERING SYSTEM (REQUEST). Quite different in approach from bibliographic-retrieval and data-retrieval systems are question-answering systems that provide fact retrieval. REQUEST is capable of answering a range of natural-language questions concerning a small database of business and industrial facts. The system's vocabulary and transformational grammar combine to translate natural-language questions into formal query structures, which are then processed against information in the database. For example, REQUEST is capable of answering a question like, "How large were the earnings of the companies ranking 10th through 15th in 1969 sales?", despite a certain amount of variation in question phrasing.

(IBM Corporation, White Plains, New York)

6.3. TRANSFORMING

Software in this category transforms records from one symbolic representation to another. Some kinds of transformations have already been mentioned (e.g., speech synthesis from digital information, digitizing of images for transmission).

TEXT TO STRUCTURED INFORMATION. One project seeks to restructure free text produced in a hospital setting into tables and medical reports. The bulk of the software is devoted to parsing and disambiguation of the free-text statements. Sets of core words, defined by distributional analysis of words that occur in the same syntactic paradigms, are used to resolve problems of synonymity and implicit reference (e.g., "x-ray" and "film"). Linguistic string analysis resolves ambiguity concerning the part-of-speech that a word is appearing in (e.g., "left lung" and "left the hospital").

When a sentence or sentence fragment has been mapped into a formal representation, information can be derived from it for tables and reports.

(Linguistic String Project, New York University, New York)

QUICK-DRAW AND FLOBOL. These similar transformation systems analyze the syntax of computer programs and produce flowcharts and cross-reference tables of variables and procedure names.

(QUICK-DRAW: National Computer Analysts, Inc., Princeton, New Jersey; FLOBOL: Cosmic, University of Georgia, Athens, Georgia)

EZPERT. While most graphic analysis systems begin with digital input, such input is generally supplied ad hoc by the user. EZPERT produces graphs and charts from the normal tabular output of network analysis programs, providing the network analysis user with automatic transformation from numeric to graphic format. In an application like project management, EZPERT transforms numeric data into graphs and charts detailing costs, resources, schedules, etc.

(Systonetics, Inc., Anaheim, California)

6.4. ANALYZING

CICS TERMINAL CALCULATOR (CALC). Implemented on IBM 360/370 computers, CALC operates under the IBM CICS (Customer Information Control System) monitor to provide the full range of normal calculator functions at a terminal. Whole formulas involving addition, subtraction, multiplication, division, and exponentiation can be entered and processed for terminal display of the results.

(National Systems Laboratories, Inc., DeKalb, Illinois)

CRITICAL PATH ANALYSIS. This system assists in project planning and management by analyzing activities and events of the project and producing a flow diagram showing the beginning and ending of each activity and the points at which activities converge and diverge. Beginnings, endings, convergences, and divergences are defined as the events of the project.

(Cosmic, University of Georgia, Athens, Georgia)

ANALYSIS OF DATA FROM AMINO ACID ANALYZER. Output from an amino acid analyzer, frequently on paper tape, is read onto magnetic tape. Peak and peak time occurrence are computed for each substance. Area associated with each peak is computed, leading to the proportional constant and concentration values of each substance.

(Technical Economics, Inc., Berkeley, California)

GRAPHIC ANALYSIS OF THREE-DIMENSIONAL DATA (GATD). Working at a graphics terminal, the user specifies a numerical model of a three-dimensional figure via the Problem Language Analyzer (PLAN) language. The user can then modify the figure by means of a light pen. Contour maps, perspective diagrams, cross-sections, and similar graphics are accommodated by this system.

(IBM Corporation, White Plains, New York)

SURVEY. The SURVEY system provides the land surveyor with assistance in analysis based on survey coordinates. Up to 1,000 coordinate points can be processed in the same analysis. Output from the system consists distances, bearings, curve data, etc., for an entire lot.

(Multiple Access Computing Group, Don Mills, Ontario)

RIGID FRAME SELECTION PROGRAM (RFSP). The user of this system specifies dimensions, loads, and materials via IBM's Problem Language Analyzer (PLAN) language. From these inputs RFSP calculates material requirements for different combinations of dead, live, and wind loads on the planned structure.

(IBM Corporation, White Plains, New York)

SPICIER AND FNAP2. DC and AC electronic circuits of up to 100 nodes and 250 branches can be analyzed, with some parameters supplied by the user and others supplied from device directories contained in these related systems. Beyond the flexibility of these systems, user-supplied FORTRAN programs can be introduced to meet special requirements. System commands are designed to be understood by engineers who do not specialize in computers.

(Be Electronics, White Plains, New York)

A 74. An extensive system of programs for ship design and construc ., AUTOKON-74 accesses a single database of specifications to generate plans, rolling and cutting templates, parts lists, etc. The user's (shipbuilder's) own rules for steel design become part of the database.

(Shipping Research Services, Inc., Alexandria, Virginia)

6.5. SIMULATING

INTERACTIVE SIMULATION LANGUAGE. A wide range of physical processes of interest to scientists and engineers can be simulated via the solution of differential equations in interactive mode. This program includes an optional interface to analogue computers to check out analogue simulations.

(Interactive Mini Systems, Inc., Kennewich, Washington)

TRAINER. Plastic extrusion, molding, coating, thermoforming, and other plastic processes can be studied as the output variables that are affected by a variety of input variables and processing conditions.

(Scientific Process and Research, Inc., Highland Park, New Jersey)

PROGRESS. The operations of a petroleum refinery are simulated by this program. Inputs include types of crude oil, rates and modes of operation of the processing units, etc. Outputs include yield and quantity information for fuel oil and gasoline pools. The operating conditions of the refinery can be varied to gauge effects on output.

Specialized refinery simulations, ALKYLATION PROCESS SIMULATION, MEK DEWAXING PROCESS SIMULATION, FLUID CATALYTIC CRACKING PROCESS SIMULATION, HYDROCRACKING PROCESS SIMULATION, AND CATALYTIC REFORMING PROCESS SIMULATION, are extensions of the basic PROGRESS simulation.

(Profimatics, Inc., Woodland Hills, California)

FLOWTRAN. This large system of programs helps engineers design entire chemical plants by simulating steady-state chemical processes. FLOWTRAN draws upon a database of the properties of more than 200 chemicals and provides the user with programs to model the behavior of chemicals not in the database.

(Monsanto Company, St. Louis, Missouri)

6.6. DECIDING

Software that supports decision making is presently oriented to medical decision making, as the first three entries show.

PROBLEM-ORIENTED MEDICAL INFORMATION SYSTEM (PROMIS). PROMIS is a medical decision support system containing patient records and related information. Branching displays assist the user in processing information to arrive at decisions concerning diagnosis and treatment.

A touch-screen CRT terminal allows the user to progress through from one branching display to another without keying commands. Average time from touch to fresh display is .6 seconds.

More than 700 disease entities are represented by problem-specific information in the database. Independent of displays generated from the patient's own record, more than 30,000 displays of medical information are contained in the system.

(PROMIS Laboratories, University of Vermont, Burlington, Vermont)

TECHNICON MEDICAL INFORMATION SYSTEM (MIS). MIS is similar in several respects to PROMIS. However, instead of PROMIS's emphasis on the problem-oriented medical record as a basis for decision making, MIS provides the physician, nurse, and other hospital staff with hierarchically structured order sets. These sets are presented as response matrices on the CRT screen; the user moves through the hierarchy of related orders by pointing a light pen at the chosen term in each response matrix. A new response matrix, representing the next down-branch from the chosen term, then appears on the screen. This procedure is repeated until a complete order has been entered.

(Technicon Medical Information Systems Corporation, Mountain View, California)

MYCIN. This is an experimental artificial intelligence program to assist physicians in prescribing antimicrobial therapy. The basis of an antimicrobial therapy decision is a correct identification of the micro-organisms causing the infectious disease. The rationale for computer-assisted decision making in this area is that physicians often make different therapeutic decisions from essentially the same diagnostic data (i.e., nonspecialist physicians prescribe broad-spectrum antibiotics or several overlapping drugs while specialists prescribe a specific effective therapy as indicated by their knowledge and experience). MYCIN is designed to play the role of a consulting specialist to assist nonspecialist physicians in arriving at a correct diagnosis and choice of therapy. MYCIN uses artificial intelligence rules, each of which consists of a premise or supposition concerning the diagnosis and a conclusion or action statement. In the course of interacting with the physician, MYCIN takes in information supplied by the physician and modifies its decision tree accordingly. The session terminates when MYCIN and the physician concur in identifying the micro-organism and prescribing an appropriate antibiotic.

(School of Medicine, Stanford University, Palo Alto, California)

PLANNING AND ANALYSES FOR UNCERTAIN SITUATIONS (PAUS). Uncertainty modelling is used to analyze factors in a decision. Each factor is weighted by an estimate of uncertainties and probabilities. Output provides the decision maker with a summary of the risks entailed by each decision alternative.

(Bonner and Moore Software Systems, Houston, Texas)

GENERAL APPLICATION GUIDANCE SYSTEM (GAGS). This system guides the user in defining a problem and choosing appropriate solutions. Four components of the system -- dialogue-supported methods dictionary, dialogue-supported data dictionary, dialogue-supported execution facility, and dialogue-supported system guidance -- provide the user with decision trees that provide information and structure alternatives.

(IBM Germany, Heidelberg, Germany)

6.7. EDITING

Text-editing systems are commonplace in business; minicomputers and even intelligent terminals support them. However, they are not as available at system/user interfaces where information work is being done. Two examples suffice to indicate the commands and format options that are generally found in these systems.

SUPERWYLBUR. The text-editing facility, which is one of several features contained in this system, creates and modifies texts at the character level, page level, and full-text level. Pervasive change commands operate on strings of characters found anywhere in the text. String retrieval lists lines of text for checking and sorting. Alignment, right justification, automatic hyphenation, pagination, and footnoting can be executed with single commands.

SUPERWYLBUR also functions as an interactive programming language and as a remote job entry/output retrieval controller.

(Optimum Systems, Inc., Santa Clara, California)

WORD/ONE. Text-editing, information retrieval, and telecommunication control are combined in this system. The combination of text-editing and telecommunication permits remote shared access to files that are being created and edited -- in other words, the system supports distributed authorship.

(Bowne Time Sharing, Inc., New York, New York)

7. INDICATIONS FOR 1977-1980 RESEARCH AND DEVELOPMENT

Outline of Sections

7.1. System-Oriented versus User-Oriented R&D 89

7.2. Hardware/Software 90

7.3. Users 91

7.4. Recommendations 92

7.1. SYSTEM-ORIENTED VERSUS USER-ORIENTED R&D

In the early years of a new techhology, research and development follow an agenda that the technology itself dictates All technologies of the "first industrial revolution," from the steam engine to the spaceship, bear out this premise. When a technology reaches its initial development plateau (i.e., fulfills purely technological criteria of performance), R&D then begins to be guided by nontechnological criteria of market competition and user preference. "Human factors" R&D is the intermediate phase of this progression. As first directed by engineers, human factoring responds to technological criteria even if less than satisfactory to users. As later directed by marketers, human factoring responds to user preferences even if less than technologically optimal.

Computer R&D has been technology-dictated or system-oriented for the past three decades. Current developments in miniaturization and integration as well as in new memory and display media indicate that R&D in this field could continue to be system-oriented for another decade or more (at the same time, the stabilization of many computing concepts and devices indicates that system-oriented R&D will not go on indefinitely unless technological discontinuities occur).

System-oriented R&D is never allowed to "run its course." No technology is perfectable, and the later gains of system-oriented R&D are not as cost-beneficial as the earlier gains (except, of course, when technological discontinuities occur). In previous eras, the corporate ledger determined when system-oriented R&D would give way to production and marketing. The voice of the ledger is still heard, but social and environmental criteria of "appropriate technology" are now sometimes heard first. For example, system-oriented R&D on the SST has largely been halted in the United States by the belief that the benefits of Mach 2 travel do not equal its social and environmental costs.

In the case of computer technology, user-oriented R&D can focus on hardware and software that are "on the shelf" while system-oriented R&D continues to refine the size, power, and cost of devices. Although we would like to say otherwise in order to get on with user-oriented R&D -- specifically the acceleration, augmentation, and delegation of information work -- there is not enough hardware and software on the shelf to support these functions, at least not according to indications from psychological research on levels of perceptual/cognitive processing that are both desirable and possible.

Although separate implementations of acceleration, augmentation, and delegation functions can be found in the laboratory and even in environments of STI use, we cannot rigorously evaluate one function in isolation from others. For example, the combination of powerful retrieval and powerful transformation of retrieved content may have multiplicative rather than additive effects on information work. Similarly, a keyboardless voice-directed terminal may have little effect on information work unless powerful analysis, decision making, and production functions are being directed.

A few laboratories in the United States, perhaps best exemplified by the Augmentation Research Center at the Stanford Research Institute, test configurations of functions. Some of these laboratories are reaching the end of the system-oriented R&D phase and can proceed to user-oriented R&D. Blueprints of system-oriented R&D have ignored user's pscyhological processes or represented them at the computer/user interface as "black boxes" that would adapt to a large but unknown extent to technology-dictated system hardware and software (e.g., the low-resolution CRT displays in wide use). Blueprints of the user-oriented phase of R&D should center on the fact that information work consists of sequences of perceptual/cognitive processes whose user-satisfying performance, productivity, and potential are held in check at the interface.

7.2. HARDWARE/SOFTWARE

The pace of hardware development outstrips our application scenarios. In every category of computer hardware -- processors, external memories, displays, keyboards and other input devices, printers, transmission equipment, etc. -- not one but many solutions to problems of size, speed, quality, and cost are being developed rapidly. The vigor and diversity of these solutions is well exemplified in displaying media (e.g., plasma, recording storage tube, electroluminescent, and liquid crystal alternatives to the CRT display) and in printing media (e.g., full-font and dot-matrix impact printers; ink jet, electrophotographic, electrostatic, magnetic, and thermal nonimpact printers). Typically, several solutions to each problem survive the transition from R&D to production, because user requirements are as diverse as the solutions.

In comparison, software development is burdened with several related problems. First, software is not as generic as hardware, so that a given software product cannot command as large a market as a given hardware product. Second, software development is intellectually effortful and labor-intensive. Unlike hardware, software does not spin off from technological advances in other fields such as aerospace R&D. Third, software production requires only a small fraction of the capitalization of hardware production, so that entrepreneurial motives are curbed by the awareness that competitors, even companies that did not exist a few months before, can quickly close the development gap.

However, software does get written. As is true of hardware, the development of some categories of software outstrips application scenarios. This is more true of delegatable procedures (e.g., statistics and graphics) than of procedures that are augmentations of a user's perceptual/cognitive processes (e.g., retrieving, deciding), since the latter require a directed exchange with the user.

We saw in Sections 5 and 6 of this report that software augmentations of cognitive processes such as transforming, comparing, simulating, and deciding are in short supply. The special-purpose character of the software packages that do exist leaves a majority of users unprovided for. There is a circular dilemma in the production of general-purpose software augmentations of these processes. There may appear to be no market for such software; users (e.g., of STI systems) now exit from the computer environment after retrieving information. Several cognitive steps later, they may return to the computer to analyze data. Then, after another hiatus, a small number of them may use the computer to produce reports. A market analysis that does not question their on-again-off-again pattern of using the computer might reach the conclusion that they are not customers for software that would augment the information tasks that lie between searching/retrieval, analysis, and report production. However, users have only gradually been led to use the computer for any information tasks. Those who were not trained to use the computer as students are slow to be "acculturated." Thus, if general-purpose software augmentations of cognitive processes are commercially viable only if a market of predisposed users can be identified, and if users are usually slow in shifting their information tasks to the computer, then the circular dilemma is hard to escape.

7.3. USERS

If we return to the fifth question on page 19, "What kinds of research and development on hardware, software, and users will be required to make these functions available?", our discussion is leading to these answers:

1. Hardware R&D generally stays ahead of the demands that acceleration, augmentation, and delegation functions would place upon it. Exceptions to this rule include multisensory displays, hardcopy graphics capability in an inexpensive terminal, and of course the attractive packaging of all peripheral components in an "electronic carrel" that replaces the desk as the user's everyday work station.

2. Adequate software has been developed to support chiefly hardware functions such as displaying and plotting. There is not adequate software to augment most of the cognitive processes involved in information work, with the exception of software for statistical analysis, text editing, and a few other specialized functions.

3. Most software is commercially produced, and general-purpose software augmentations of information work will not be produced unless a market of users is identified. It is through users that a demand for such software can be created. Acknowledging that users are slow to convert or "computerize" their working habits, we should investigate the incentives or disincentives of information work that may cause users to rely more extensively on the computer.

Paisley (1968) noted that "user studies" show that scientists and technologists often begin projects without conducting a literature search to determine whether identical or similar work has already been done. The probable explanation of this negligent attitude, Paisley said, was that few "sanctions for remediable ignorance" are ever levied against the scientist or technologist who unnecessarily duplicates someone else's work. Tolerance of remediable ignorance was a corollary of the post-war growth of the scientific and technical literature, which for a time grew faster than indexing and abstracting services could keep up with. The belief that "you can't find what you're looking for in the literature" outlived the actual problem, and scientists and technologists in many fields are more careless about searching the literature than the actual accessibility of the literature gives any excuse for.

There is a psychologically grounded argument that the user's careless attitude toward literature searching is part of a general attitude toward information work, That is, when the user is formulating a problem, analyzing data, making a decision, etc., the possibility that relevant factors or criteria have been overlooked is probably no more unsettling than the possibility that relevant literature has been overlooked, particularly since it is the relevant literature than can identify such factors and criteria.

Any innovation in our work pattern begins by causing us trouble. The first-time user of any technological innovation suffers from information overload and from the consequences of errors. We have a natural inclination to stay out of the "first-time user" role. The opportunities that this attitude forecloses in information work include not only the assistance of the computer but also the power of new bibliographic tools, new measurements and statistical procedures, new ways of formulating and solving problems, etc.

Yet persons who make their careers in information work are generally interested in new things, inquisitive, and adaptable. Therefore an apparent lack of interest in an expanded role for the computer in their work may be overcome by a variety of strategies, all of which serve to expose them to the possibilities and procedures of computer assistance. Several of these strategies are discussed below as recommendations for next steps in testing acceleration, augmentation, and delegation functions.

7.4. RECOMMENDATIONS

A number of specific recommendations for research and development have been made with reference to hardware and software described in Sections 5 and 6 of this report. For example, the largely unassessed potential of speech recognition and voice response in information work calls for R&D both at the system analysis level and at the user task analysis level. A revolution in computer-assisted information work may occur when these developments converge to produce the keyboardless terminal; speech-oriented information retrieval, teleconference, and instruction systems; and the multisensory electronic work station. However, not nearly enough R&D has been conducted on information work to guide these developments.

Recommendations for 1977-1980 research and development begin with the user and move outward to STI systems:

1. Our model of information work postulates a sequence of generic information tasks, each of which is performed via a plan or program that calls certain perceptual/cognitive processes from the user's repertory. Despite the reference to "sequence," our model is fragmented because research has not been done on the stochastic process underlying each sequence. In other words, the sequence that we want the computer to perform with us has many unknown parameters. Except in restricted cases such as medical decision making, for which algorithms now exist, we know less about the actual conduct of information work than about assembly line work. The traditional method of time-and-motion analysis does not extend far enough into the information worker's plan to provide full understanding of what information work consists of, but time-and-motion analysis may be a necessary first phase of research, followed by deeper analysis of the integration of perceptual/cognitive processes in the information worker's plan. Our present episodic knowledge of the conduct of information work does not measure up to the national investment that information work represents.

2. Priorities should be set for hardware and software development by estimating aggregate user benefits, which can be defined crudely as the number of users benefiting X average benefit per user. In the present context of remote access to large computers, extensions of the computer facility itself provide simultaneous benefits to all users, while extensions of terminals or other work-station peripherals benefit only those users who have access to them. Even so, an analysis of the overall balance of hardware and software in STI systems may indicate that the average terminal is a weak link in the systems, a disincentive for users to use the systems often. At least three generations of terminals, dating back to Teletype 33's, are used to access STI systems. Some of these terminals are slow enough and noisy enough to dampen enthusiasm for any extension of the central computer. Therefore, although as a rule there is greater aggregate benefit in extending the central computer, typical peripheral configurations should be surveyed to determine if they are within the tolerable to good range. Good configurations should be assmbled, demonstrated at scientific and professional meetings, and publicized in system descriptions.

3. Software in support of information work is not a market corollary of hardware in support of information work. Some software packages mentioned in Sections 5 and 6 were developed in the 1960's, and they are frequently the most recent examples of particular applications. The highest-priority software R&D for information work, whatever it proves to be, may require the stimulus of government support at first. The precedent for government involvement in STI software R&D is well laid in more than a decade of support for information storage and retrieval systems, teleconference systems, and instruction systems.

4. The pace at which innovations in computer-assisted information work diffuse can be increased by incorporating the extensions, whenever possible, into systems that are already successful and popular with users. Given the cooperation of their vendors, DIALOG and ORBIT are examples of STI systems that could be testbeds for extensions. Some extensions (e.g., simulation and decision making software) could be programmed into the systems on an experimental basis. Other extensions (e.g., transmission of microimages) are add-ons that the vendors could agree to interface with their systems. Feasibility studies should precede such experiments, and field evaluations should be arranged well before the experiments come on-line.

5. R&D in this area should not lag behind the widespread adoption of personal computers at points of STI use (see page 56). There are no technological precedents for the personal computer as a tool of information work, and we may find that STI users at first underutilize the personal computer in performing post-retrieval information tasks, just as they now underutilize the powerful retrieval systems. R&D should focus, for example, on the legal and economic implications of transferring retrieved content from a proprietary ISR search into the local memory of a personal computer for transformation, analysis, editing, etc., as well as for storage against future need. If this practice violates the access rules of proprietary ISR systems, new rules and possibly rate structures should be established to permit STI users such direct and flexible control over retrieved content.

6. "Images of potentiality" (see page 42) should be propagated around the theme that the computer can make information work more productive and more enjoyable. Demonstration systems should be conspicuous and well publicized. It may be that attention can be drawn to the potential of acceleration, augmentation, and delegation of information work through a small grants competition for investigators who have concepts, hardware, or software to test in STI use settings.

BIBLIOGRAPHY

Ackoff, R.L. "Management Misinformation Systems." MANAGEMENT SCIENCE, 1967, 14, B-147-156.

Adams, J.L. CONCEPTUAL BLOCKBUSTING. Palo Alto, Calif.: Stanford University, Stanford Alumni Association, 1974.

Allport, F. THEORIES OF PERCEPTION AND THE CONCEPT OF STRUCTURE. New York: John Wiley, 1955.

Anastasio, E.J., and D.L. Alderman. EVALUATION OF THE INSTRUCTIONAL EFFECTIVENESS OF PLATO AND TICCIT. Princeton, N.J.: Educational Testing Service, 1973.

Arnheim, R. VISUAL THINKING. Berkeley, Calif.: University of California Press, 1969.

Ashby, W.R. DESIGN FOR A BRAIN. New York: John Wiley, 1952.

Bennett, J.L. "Integrating Users and Decision Support Systems." PROCEEDINGS OF THE SIXTH AND SEVENTH ANNUAL CONFERENCES, SOCIETY FOR MANAGEMENT INFORMATION SYSTEMS. Chicago: SMIS, 1976.

Bobrow, D.G., and A. Collins (eds.). REPRESENTATION AND UNDERSTANDING: STUDIES IN COGNITIVE SCIENCE. New York: Academic Press, 1975.

Boulding, K.E. THE IMAGE. Ann Arbor: University of Michigan Press, 1956.

Brown, J.S., et al. A MODEL-DRIVEN QUESTION-ANSWERING SYSTEM FOR A CAI ENVIRONMENT. Lowry AFB, Colo.: Air Force Human Resources Laboratory, 1973.

Bunderson, C.V. TEAM PRODUCTION OF LEARNER-CONTROLLED COURSEWARE. Provo, Utah: Brigham Young University, Institute for Computer Uses in Education, 1973.

Bush, V. "As We May Think." ATLANTIC MONTHLY, July 1945, 101-108.

Bush, V. "Memex Revisited." In Bush, SCIENCE IS NOT ENOUGH. New York: Morrow, 1967.

Campbell, D.T. "Blind Variation and Selective Retention in Creative Thought as in Other Knowledge Processes." PSYCHOLOGICAL REVIEW, 1960, 67, 380-400.

Campbell, D.T. "Pattern Matching as an Essential in Distal Knowing." In Hammond, K.R. (ed.), THE PSYCHOLOGY OF EGON BRUNSWIK. New York: Holt, Rinehart and Winston, 1966.

Carbonell, J.R. "AI in CAI: An Artificial Intelligence Approach to Computer-Aided Instruction." IEEE TRANSACTIONS ON MAN-MACHINE SYSTEMS, 1970, MMS-11, 190-202.

Carlson, E.D. AN APPROACH TO DESIGNING DECISION SUPPORT SYSTEMS. San Jose, Calif.: IBM Research Laboratory, 1977.

Carlson, E.D. USING LARGE DATA BASES FOR INTERACTIVE PROBLEM SOLVING. San Jose, Calif.: IBM Research Laboratory, 1975.

Collins, A. PROCESSES IN ACQUIRING KNOWLEDGE. Cambridge, Mass.: Bolt, Beranek, and Newman, 1976.

Cronbach, L.J., and R.w. Snow. APTITUDES AND INSTRUCTIONAL METHODS. New York: Irvington Publishers, 1977

Crowder, R.G. PRINCIPLES OF LEARNING AND MEMORY. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1976.

Datapro Research Corporation. DATAPRO DIRECTORY OF SOFTWARE. Delran, N.J.: Datapro, 1976.

DeGreene, K. (ed.). SYSTEMS PSYCHOLOGY. New York: McGraw-Hill, 1970.

Drucker, P. THE AGE OF DISCONTINUITY: GUIDELINES TO OUR CHANGING SOCIETY. London: Pan Books, 1969.

Edwards, W. (ed.). DECISION MAKING. Baltimore, Md.: Penguin Books, 1967.

Eisenstadt, M., and Y. Kareev. "Aspects of Human Problem Solving: the Use of Internal Representations." In Norman, D.A., and D.E. Rumelhart (eds.), EXPLORATIONS IN COGNITION. San Francisco, Calif.: W.H. Freeman, 1975.

Engelbart, D.C. AUGMENTING HUMAN INTELLECT: A CONCEPTUAL FRAMEWORK. Menlo Park, Calif.: Stanford Research Institute, Augmentation Research Center, 1962.

Engelbart, D.C. AUGMENTING HUMAN INTELLECT: EXPERIMENTS, CONCEPTS, AND POSSIBILITIES -- SUMMARY REPORT. Menlo Park, Calif.: Stanford Research Institute, Augmentation Research Center, 1965.

Engelbart, D.C. HUMAN INTELLECT AUGMENTATION TECHNIQUES, FINAL REPORT. Menlo Park, Calif.: Stanford Research Institute, Augmentation Research Center, 1968.

Engelbart, D.C. "Design Considerations for Knowledge Workshop Terminals." AFIPS PROCEEDINGS OF THE NATIONAL COMPUTER CONFERENCE, 1973, 221-226.

Garner, W.R. THE PROCESSING OF INFORMATION AND STRUCTURE. Potomac, Md.: Lawrence Erlbaum Associates, 1974.

Hardy, A. TELECONFERENCING RESEARCH: A REVIEW. Palo Alto, Calif.: Stanford University, Institute for Communication Research, 1976.

Heidorn, G.E. "Automatic Programming through Natural Language Dialogue: a Survey." IBM JOURNAL OF RESEARCH AND DEVELOPMENT, 1976, 20, 302-313.

Hempel, C. THE PHILOSOPHY OF NATURAL SCIENCE. Englewood Cliffs, N.J.: Prentice-Hall, 1966.

Hunt, E. CONCEPT FORMATION: AN INFORMATION PROCESSING PROBLEM. New York: John Wiley, 1962.

Hunt, E. "The Memory We Must Have." In Schank, R.C., and K.M. Colby (eds.), COMPUTER MODELS OF THOUGHT AND LANGUAGE. San Francisco, Calif.: W.H. Freeman, 1976.

Kelly, G.A. A THEORY OF PERSONALITY: THE PSYCHOLOGY OF PERSONAL CONSTRUCTS. New York: W.W. Norton, 1955.

Klaff, V., and P. Handler. COMPUTER-ASSISTED INSTRUCTION OF POPULATION DYNAMICS: A NEW APPROACH TO POPULATION EDUCATION. Urbana, Ill.: University of Illinois, Coordinated Science Laboratory, 1975.

Kropp, R.P., W.H. Nelson, and F.J. Kind. IDENTIFICATION AND DEFINITION OF SUBJECT-MATTER CONTENT VARIABLES RELATED TO HUMAN APTITUDES. Tallahassee, Fla.: Florida State University, 1967.

Lancaster, F. INFORMATION RETRIEVAL ON-LINE. Los Angeles: Melville, 1973.

Leonard, G.B. EDUCATION AND ECSTASY. New York: Delacorte, 1968.

Machlup, F. THE PRODUCTION AND DISTRIBUTION OF KNOWLEDGE IN THE UNITED STATES. Princeton: Princeton University Press, 1962.

Martin, T.H. A FEATURE ANALYSIS OF INTERACTIVE RETRIEVAL SYSTEMS. Palo Alto, Calif.: Stanford University, Institute for Communication Research, 1974.

Martin, T.H., et al. A POLICY ASSESSMENT OF PRIORITIES AND FUNCTIONAL NEEDS FOR THE MILITARY COMPUTER-ASSISTED INSTRUCTION TERMINAL. Marina del Rey, Calif.: University of Southern California, Information Sciences Institute, 1975.

Mayzner, M.S. "Studies of Visual Information Processing in Man." In Solso, R.L. (ed.), INFORMATION PROCESSING AND COGNITION. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1975.

Meadow, C.T. MAN-MACHINE COMMUNICATION. New York: Wiley-Interscience, 1970.

Miller, G.A., E. Galanter, and K.H. Pribram. PLANS AND THE STRUCTURE OF BEHAVIOR. New York: Henry Holt, 1960.

Mitre Corporation. AN OVERVIEW OF THE TICCIT SYSTEM. McLean, Va.: Mitre, 1974.

National Science Board. SCIENCE INDICATORS 1974. Washington: National Science Foundation, 1975.

Newell, A., and H.A. Simon. HUMAN PROBLEM SOLVING. Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Paisley, W. "Information Needs and Uses." In Cuadra, C.A. (ed.), ANNUAL REVIEW OF INFORMATION SCIENCE AND TECHNOLOGY, VOL. 3. Chicago, Ill.: Britannica, 1968.

Paisley, W., and Parker, E.B. "Information Retrieval as a Receiver-Controlled Communication System." In Heilprin, L. et al., (eds.), EDUCATION FOR INFORMATION SCIENCE. Washington: Spartan Books, 1965.

Parker, E.B., and W. Paisley. "Research for Psychologists at the Interface of the Researcher and His Information System." AMERICAN PSYCHOLOGIST, 1966, 38, 1061-1071.

Plath, W.J. "REQUEST: A Natural Language Question-Answering System." IBM JOURNAL OF RESEARCH AND DEVELOPMENT, 1976, 20, 326-335.

Porat, M.U. THE INFORMATION ECONOMY. Palo Alto, Calif.: Stanford University, Institute for Communication Research, 1976.

Pribram, K.H. LANGUAGES OF THE BRAIN: EXPERIMENTAL PARADOXES AND PRINCIPLES IN NEUROPSYCHOLOGY. Englewood Cliffs, N.J.: Prentice-Hall, 1971.

Price, D.J.DeS. LITTLE SCIENCE, BIG SCIENCE. New York: Columbia University Press, 1963.

Roe, A. THE MAKING OF A SCIENTIST. New York: Apollo Editions, 1952.

Sackman, H. MAN-COMPUTER PROBLEM SOLVING. Princeton: Auerbach, 1970.

Schank, R.C. "Identification of Conceptualizations Underlying Natural Language." In Schank, R.C., and K.M. Colby (eds.), COMPUTER MODELS OF THOUGHT AND LANGUAGE. San Francisco, Calif.: W.H. Freeman, 1976.

Schroder, H.M., M.J. Driver, and S. Streufert. HUMAN INFORMATION PROCESSING. New York: Holt, Rinehart and Winston, 1967.

Scragg, G.W. "Answering Questions about Processes." In Norman, D.A., and D.E. Rumelhart (eds.), EXPLORATIONS IN COGNITION. San Francisco, W.H. Freeman, 1975.

Sheridan, T.B., and W.R. Farrell. MAN-MACHINE SYSTEMS: INFORMATION, CONTROL, AND DECISION MODELS OF HUMAN PERFORMANCE. Cambridge, Mass.: MIT Press, 1974.

Short, J., E. Williams, and B. Christie. THE SOCIAL PSYCHOLOGY OF TELECOMMUNICATIONS. New York: John Wiley, 1976.

Smith, L.C. "Artificial Intelligence in Information Retrieval Systems." INFORMATION PROCESSING AND MANAGEMENT, 1976, 12, 189-222.

Sonquist, J.A., E.L. Baker, and J.N. Morgan. SEARCHINC FOR STRUCTURE. Ann Arbor: University of Michigan, Institute for Social Research, 1973.

Suppes, P. RESEARCH ON USES OF AUDIO AND NATURAL-LANGUAGE PROCESSING IN COMPUTER-ASSISTED INSTRUCTION. Palo Alto, Calif.: Stanford University, Institute for Mathematical Studies in the Social Sciences, 1975.

Stone, P.J., D.C. Dunphy, M.S. Smith, and D.M. Olgivie (eds.). THE GENERAL INQUIRER: A COMPUTER APPROACH TO CONTENT ANALYSIS. Cambridge, Mass.: M.I.T. Press, 1966.

Tolman, E.C. "Cognitive Maps in Rats and Men." PSYCHOLOGICAL REVIEW, 1948, 55, 189-208.

Walker, D. INTERACTIVE BIBLIOGRAPHIC SEARCH: THE USER/COMPUTER INTERFACE. Montvale, N.J.: AFIPS Press, 1971.

Wanger, J., M. Fishburn, and C.A. Cuadra. ON-LINE IMPACT STUDY: SURVEY REPORT OF ON-LINE USERS, 1974-1975. Santa Monica, Calif.: System Development Corporation, 1975.

Wason, P.C., and P.N. Johnson-Laird. PSYCHOLOGY OF REASONING: STRUCTURE AND CONTENT. Cambridge, Mass.: Harvard University Press, 1972.

Watson, J.M. THE DOUBLE HELIX. New York: Atheneum, 1968.

Watson, R.M. "User Interface Design Issues for a Large Interactive System." AFIPS PROCEEDINGS OF THE NATIONAL COMPUTER CONFERENCE, 1976, 357-364.