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WORKSHOP ON RESEARCH NEEDS IN USER/INFORMATION SYSTEM INTERACTION

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CONTENTS

PREFACE

The Committee on Human Factors was established in October 1980 by the Commission on Behavioral and Social Sciences and Education of the National Research Council in response to a request by the Office of Naval Research, the Air Force Office of Scientific Research, and the Army Research Institute for the Behavioral and Social Sciences. In addition, its sponsors currently include the National Aeronautics and Space Administration and the National Science Foundation. The principal objectives of the committee are to provide new perspectives on theoretical and methodological issues, to identify basic research needed to expand and strengthen the scientific basis of human factors, and to attract scientists both inside and outside the field to perform needed research.

Human factors issues arise in every domain in which people interact with the products of a technological society. In order for the committee to perform its role effectively, it draws on the assistance of experts from a wide range of scientific and engineering disciplines. The committee includes specialists in the fields of psychology, engineering, biomechanics, cognitive sciences, machine intelligence, computer sciences, sociology, and human factors engineering. Other disciplines also participate in working groups, workshops, and symposia. Each of these disciplines contributes to the basic data, theory, and methods required to improve the scientific basis of human factors.

At the request of the Information Science and Technology Division of the National Science Foundation, the Committee on Human Factors organized a workshop to define the research required to improve the interaction between information systems and their users. Fifteen specialists in the fields of human factors, cognitive sciences, and information systems met for three days in Washington, D.C., in October 1983. The workshop participants were requested to consider what basic experimental research would achieve a better understanding of the effects of the characteristics of information systems on how people use those systems. The following specific objectives were set forth in the invitation to participants:

- To define the characteristics of information systems that distinguish them from other systems in terms of their purpose, function, and structure;
- To estimate the trends of future technological developments that are likely to affect the nature of information systems and their use;
- To define the significant behavioral and cognitive issues directly related to the interaction between information systems and their users;
- To explicate the effect of instrumentation on experimentation and issue development; and
- To formulate recommendations and justifications for fundamental experimental research most necessary to improve user/information system interaction.

In organizing the workshop, the Committee on Human Factors stressed the final objective--the formulation of recommendations for research--as the primary one and characterized the others as playing supportive roles. The workshop participants were asked to identify what they considered to be some of the most important issues but were not asked to rank within that set.

A background paper on the objectives was distributed to participants prior to the meeting. Each participant was asked to prepare a brief, informal paper relating to workshop objectives that also could be distributed to other participants before the meeting. This report draws from those papers as well as from discussions and subsequent correspondence among the participants.

INTRODUCTION

Information technology means computers and communication. It is the technology of processing information and of moving it from place to place. The rapidity with which this technology has been developed over the past few decades is unprecedented. Moreover, what has happened was not anticipated by even the most astute observers.

Many factors have contributed to the explosive growth of this technology, prominent among which has been a series of discoveries of how to build increasingly smaller and faster devices for storing, manipulating, and transmitting digitally encoded information. Equally important as the development of the underlying technology has been the realization of how immensely useful the ability to store, manipulate, and transmit large amounts of digital information can be. Thus the development of information technology has been propelled by two forces--the push of technical innovation and the pull of applications demand--and such development could not have occurred if either of them had been missing. The near-term future development of information technology should be no less phenomenal than its immediate past. The same two forces are still operative and likely to be for some time to come.

The impact of information technology on our lives has already been pervasive and profound, but it promises to be even more extensive in the future. Most people in developed countries are affected, at least indirectly, by the many applications of this technology. As the applications multiply in the future, the ways in which the technology impinges on people's lives will also increase. More and more functions traditionally performed by people will be performed by computers; some jobs will be abolished, and others will be created or modified as a result of further use of information technology in the workplace. A growing assortment of information services will be available to consumers. "Smart" devices and automation will become increasingly pervasive.

The number of users of information technology and information systems will also increase explosively. Computer programming is already one of the fastest growing of all professions, and many people other than computer specialists are using informations systems in their day-to-day world. They include physicians, lawyers, scientists, and engineers as well as many office workers, technicians, sales people, farmers, writers, and agents of various sorts. Many people use such systems because their jobs require them to do so, but many others use them strictly by choice. By some estimates there are currently more than 10 million personal computers in U.S. homes (Kolata, 1982), a figure that does not include the computing circuitry found in many automobiles and household appliances.

In short, increasing numbers of people are finding themselves interacting with computer-based systems for the purposes of creating, organizing, retrieving, evaluating, or transmitting information. For many of these people both quantitative and qualitative aspects of this interaction are fundamentally different from their analogues--to the extent that there were analogues--of only a few decades ago.

An obvious and often-noted reason for making information technology a focus of human factors research is the importance of designing information systems that are well matched to the capabilities and limitations of their intended users. This is indeed an important goal of research and one that has increasing economic implications, given the fact that the cost structure of information processing has changed so much in recent years that today the time of a person using an information system is often more costly than that of the system itself. There is an economic incentive therefore to focuson the problem of making efficient use of people's time.

In addition to the economics of information system use in the workplace, there are other important reasons for focusing human factors research on information technology. We want to understand the technology and its relationship to human beings well enough to anticipate and influence its impact on jobs, on organizations, on interpersonal relationships and communication, and on human values. The issues involved are complex, and effective investigation of them requires new ideas and innovative approaches. There will undoubtedly be some false starts and some trial-and-error exploration, because the territory is new and not well marked. Perhaps the most basic challenge is that of identifying the kinds of questions that should be asked. That too is likely to involve some trial-and-error search--but a search well worth making.

The main purpose of the workshop, from which this report comes, was to attempt to identify some of those questions. We expected the result to be incomplete; indeed, there was no way for it to be otherwise. Our hope was to identify some reasonable points of departure for research that will give us a better understanding of the questions that we really should be asking.

The pages that follow are organized in terms of the objectives outlined in the preface. We begin with a section describing information systems, their distinctive characteristics, and their functions. We then consider the technological developments involved and project future trends. Next we discuss behavioral and cognitive issues essential to understanding the capabilities and limitations of people who use information systems. We then discuss the equipment and methods needed to support research on user/information system interaction. The remainder of the report is a set of recommendations for research that will improve our understanding of these issues.

CHARACTERISTICS OF INFORMATION SYSTEMS

The distinctiveness of information systems is an important issue vis-a-vis the identification of research problems, because only to the extent that information systems differ from other person-machine systems will the effort to understand them require research focused on these types of systems as a class. Do information systems differ from other person-machine systems in ways that have implications for research? And if so, how?

In this report we view an information system as a system whose main purpose is to serve people's information needs. Functionally, this includes acquiring information, organizing it, manipulating it, storing it, moving it from place to place, representing it in forms suitable for human assimilation, and generally making it accessible to those who need it. Structurally, information systems that make use of computer technology to some significant degree are the focus of our attention.

Computers are qualitatively different from most machines with which we interact. We think of machines as assemblages of gears, levers, wheels, motors, and other hard components linked together so as to move in a coordinated fashion, when adequately fueled, in the performance of specific physical functions: lifting things, bending things, pushing things, pulling things. They are devices designed to change energy from one form to another, to manipulate forces, and to accomplish work in the process. In the case of computing machines, energy transformation, force manipulation, and physical work are incidental, for the most part. Computers are designed to transform information structures (symbolic representations), not energy. They manipulate symbols, not forces. And what they do is more nearly analogous to thinking than to the performance of physical work.

Because of these differences, what is known about how to design conventional machines to make them usable in light of the capabilities and limitations of their intended users has limited applicability to the problem of designing computer-based information systems. Until very recently no one ever had occasion to interact with a machine that could correct one's spelling, propose a diagnosis of a medical illness, or search through a legal data base looking for cases relevant to a particular legal issue. To be sure, much of what is known about the design of displays and input devices and the layout of work spaces is relevant to the design of computer-based systems; however, as the capabilities of these systems become more and more sophisticated, the focus of attention for research is shifting from the physical interface between system and user to the cognitive interface.

One way to conceptualize the interface between an information system and its user is as an interface between two information structures, one of which resides within the system and the other in the user's head. The problem of interface design then becomes that of facilitating the interaction between these information structures. This way of viewing the problem prompts the formulation of questions that would be less obviously appropriate to the study of how people interact with traditional types of machines, such as motor vehicles, household appliances, and manufacturing devices.

Although traditional problems such as those of control design, lighting, and workspace layout do not go away, a variety of new research issues emerge. The new issues have to do with languages, person-machine dialogues, mental models, and the like. Of course, as significant amounts of computing power are built into more and more machines of traditional design, the design of the cognitive interface will become more of an issue in those cases as well.

TRENDS AND PROJECTED DEVELOPMENTS

Since computers first appeared only a few decades ago, several trends have been consistent and clear: increasing speed, increasing reliability, decreasing component size and power requirements, and decreasing unit costs (Abelson, 1982; Branscomb, 1982; Gerola and Gomory, 1984; Mayo, 1977). The aggregate effect of these trends has been remarkable indeed. Toong and Gupta (1982) dramatize the way the computer industry has evolved by contrast with the aircraft industry. If the latter, they suggest, "had evolved as spectacularly as the computer industry over the past 25 years, a Boeing 767 would cost $500 today and it would circle the globe in 20 minutes on five gallons of fuel" (p. 87). In parallel with the rapid evolution of the computer industry--in part as effect and in part as cause--the number of uses to which computers, and information technology more generally, have been put has grown explosively, beyond what anyone could have imagined a few decades ago.

Another way to quantify these developments is in terms of the increase in the amount of available computing capacity. Amount of computing capacity is typically quantified in terms of number of active element groups (AEGs), an active element group being a logic gate or the means of storing a bit of information in memory. Early in this century, before the invention of the digital computer, the annual growth in the use of AEG equivalents was about 10 percent. From 1960 to 1972, during the period of transistor-based circuits, consumption of AEGs increased by about 25 percent annually. Since the advent of integrated circuit chips in 1972, consumption has increased by about 100 percent annually. Very-large-scale-integration (VLSI) technology is producing further gains in performance and decreases in unit costs and is therefore likely to increase the rate of consumption further still (Phipps, 1982).

Today the annual use of AEGs in the United States is about 5 trillion, enough to supply everyone in the world with the equivalent of a simple pocket calculator. Projections extrapolated from the rate of growth of use during the 1972-1980 period suggest that by the year 2000 computing capacity is likely to be the equivalent of a powerful minicomputer for every person in the United States. What will be available in terms of computing power for the average person 50 or 100 years from now is anybody's guess, but it seems safe to assume that it will be enormous.

One major consequence of rapidly decreasing unit costs and the resulting proliferation of computing hardware has been an increasing decentralization of information resources. Coupled with recent advances in communication technology--communication satellites, cable television, packet radio--and the emergence of computer networks, the increasingly wide distribution of computing hardware offers the prospects of a national or even global community of interconnected users of common information resources.

There is every reason to believe that the major trends that have characterized the evolution of information technology in the recent past will continue. Several lines of research and development promise to extend further the technology base, including magnetic bubble memories, Josephson junctions, gallium arsenide semiconductors, parallel processor machine architectures, transphasors and optical computers, and a great deal more attention to the development of powerful software tools (Abraham et al., 1983; Case et al., 1982; Chaudhari et al., 1980; Matiso, 1980; Phipps, 1982; Young, 1981). As for market pull, applications making use of computing and communication resources are multiplying daily. There may be a high correlation between productivity gains and the amount of computing resources available to the work force across a wide range of job classifications. Such a correlation represents a powerful economic incentive to increase the role of information technology throughout the economy. It seems certain that uses of this technology will continue to proliferate.

In view of these expectations and in light of countless ongoing efforts to exploit aspects of this technology for commercial purposes, we can identify many specific developments that seem likely in the near future (Nickerson, 1982). There will be surprises, of course, and undoubtedly some of the most profound events will be among those that are least expected. Several anticipated developments are especially relevant to the problem of identifying research challenges and opportunities in the area of user/information system interaction:

- Computing resources will become available to nearly anyone who wishes to use them for either vocational or personal purposes.
- Smart devices will appear everywhere: in homes, automobiles, offices, appliances, tools, and toys.
- Computer-mediated information services will proliferate, such as electronic mail, information banks, electronic news services, want ads, and job postings.
- Many tasks currently performed by human beings will become automated, others will be radically modified, and some new jobs will be created.
- Information technology will profoundly affect institutionalized education, both directly, via the use of computer-based instructional techniques in the classroom, and indirectly, as a consequence of the general availability of information resources and information manipulation tools. Demands on educational institutions to prepare students for roles in an increasingly information-oriented society will steadily grow.

BEHAVIORAL AND COGNITIVE ISSUES

Inasmuch as most people will become potential users of information systems in one way or another, some of the behavioral and cognitive science issues that will have to be addressed relate to the capabilities and limitations of human beings as a species. A better understanding of these capabilities and limitations vis-a-vis the acquisition, storage, use, and transmission of information is clearly essential to a better understanding of how to design systems well suited to serve people's information needs. We need to know more, for example, about how people seek information, how they evaluate and filter it, how they organize and manage it, how they store and retrieve it, how they assess what they have and what they need, and how they can adapt to and learn new kinds of information processing.

To be sure, part of the task is to make more effective use of what has already been learned about human decision making, problem solving, and information processing generally. Examples of reported problems that may be pertinent to the design of information systems include: undue commitment to costs already incurred, overconfidence in the extent of one's own knowledge, limited ability to reconstruct why one undertook decisions, confusion when called on to evaluate hypotheses in light of new evidence, underestimation of task completion time, and reversion to solutions that have already failed when problem solving becomes difficult. But results already in the literature need to be supplemented with new studies, because the expanding technology will provide tools and techniques for manipulating and using information in new and qualitatively different ways than we have known before.

Information technology also will foster new modes of interaction among people, which in turn will stimulate the emergence of new social structures. Understanding the effects of these changes will require a better understanding than we now have of various aspects of human communication and interaction. We need to understand better, for example, the extent to which communication patterns in the workplace and elsewhere are determined by fundamental human characteristics as opposed to the capabilities and constraints of communication technology: does people's preference for face-to-face communication via speech (Chapanis, 1975; Gerola and Gomory, 1984) reflect a deep-seated human need or simply the limitations of currently available alternatives? Will computer-based information systems facilitate or inhibit communication? What will determine whether they help or hinder understanding across disciplines and cultures? Interpersonal communication clearly serves purposes other than that of verbal information exchange, although they may not always be recognized explicitly. It will be important to know to what extent these purposes can be met via electronic mail, shared electronic work spaces, electronic bulletin boards, and other new computer-based means of communication.

Another issue that relates to all potential users of information systems is that of the measurement of workload. How to measure mental effort has been a challenging problem for some time and is likely to be for some time to come (Hart, 1983; Nicholson, 1974; Wierwille and Williges, 1978). It is complicated in the case of user/information system interaction by the fact that the range of cognitive activities involved is very broad and not easily described. And, as is true of cognitive workload measurement in many contexts, the user's observable activity often provides little evidence of the kind of information processing that is going on covertly.

While some important behavioral and cognitive issues relate to people in general, others do not. Just as there are many types of information systems, the people who use them have different educational and professional or vocational backgrounds, tapping different system capabilities for different purposes in different contexts (Cuff, 1980; Eason et al., 1975). Definition of some behavioral and cognitive issues could be facilitated by the development of taxonomies that not only classify users in some useful way, but also distinguish among the purposes for which systems are used, the capabilities or tools that are used, and the specific tasks that are performed. Design guidelines that cut across such classifications are in some sense more powerful than those that apply only to a particular type of user using a particular type of tool for a particular type of task; therefore, their formulation is worth much effort. However, general guidelines are often too abstract to be applicable directly to specific cases without first being translated into more situation-specific forms; insightful user-tool-task taxonomies are useful, perhaps essential, in making such principles applicable to specific cases. With regard to the need to recognize different types of users, it is also important to bear in mind that if the population of potential users is to include essentially everyone, some attention must be given to the fact that various levels of ability will be represented, ranging from very high to very low.

Another class of cognitive issues relates to the implications of computers for the further development of our understanding of the complexities of modern life. There can be no doubt that the computational power that these machines have made available has already greatly facilitated scientific progress in many fields and thereby influenced the ways in which we conceptualize various aspects of the world. It is less clear, however, what role computers can be expected to play in other uses of abstract, infinite concepts in mathematics. For example, the study of different order-types in logic or the use of abstract spaces in analysis, such as Banach or Hilbert spaces, the role of automorphism groups in algebra, and various other complex, abstract structures in topology and algebraic geometry are not easily related to computers as we now know them. Yet clearly these advances in our ability to think at higher levels of abstraction are crucial to modern mathematics, and they pose a considerable challenge to computer programming and work in artificial intelligence.

RESEARCH INSTRUMENTATION AND METHODS

The equipment required in a laboratory to support research on user/system interaction depends to a large extent on the nature of the research to be performed. Researchers in the area of educational software should probably be alert to the types of personal computer systems that are likely to become widely available to students in the near future and make sure that their laboratories include such machines. Research on multimedia (text, facsimile, voice) message systems requires a facility with sufficient capacity to support the considerable processing needs involved and the high-resolution graphic display terminals that facsimile implies. To investigate distributed processing applied to complex communication and control problems, a constellation of fairly powerful work stations connected by a network is essential.

Apart from these kinds of considerations, the planning of any laboratory facilities to support research on user/information system interaction must be done keeping in mind that state-of-the-art equipment will become obsolete very quickly. Therefore, another planning objective should be preserving the ability to adapt rapidly to change. This dictates caution about decisions that would lock a facility into dependence on the use of equipment the costs of which must be depreciated over long periods of time.

Perhaps a more important implication is the risk that the results of research aimed at developing more useful and usable systems will be obsolete before they can be applied. Given the pace at which equipment becomes obsolete, how can we ensure that research will not be outdated before it is completed?

For research to produce results that are of more than passing interest, it must address issues that are system-independent; it must be aimed at the discovery of general principles that are applicable across a broad range of equipment. Researchers must not limit their thinking to existing instruments but should consider future generations of information systems as well. This does not mean that research should not be done with real systems. Indeed, it is primarily by using real systems that one acquires an understanding of the technology's capabilities and limitations, and perhaps more important, its potential.

Fortunately, research that is done with specific systems need not yield results that are limited in applicability to those systems. The physical properties of a system--except for the interface--are probably of little concern to the vast majority of its users. The important issues from the user's point of view relate to functioning and convenience of use. The user is unlikely to need to know or to care, for example, whether the information that a system contains is being stored in a magnetic bubble memory, on an optical disc, or in a hologram; what those who use a system care about is how accessible the information is and whether the system can produce it in a useful form.

The general question of interest, therefore, is what instrumentation is needed to permit research on the system-independent questions relating to information accessibility and representation that should be addressed experimentally during the next several years. This question cannot be answered effectively until at least some specific research questions have been adequately formulated. This is, perhaps, stating the obvious; however, all too frequently research questions and experimental designs seem to derive from rather than to determine the availability of research facilities. This is not to suggest that it is reasonable to proceed as though one had the luxury of defining research paradigms without regard to the feasibility of instrumentation, but simply to argue that the identification of questions that need answering is a more appropriate point of departure for planning a research effort than is the identification of specific experiments that can be done readily with a particular facility. As a matter of strategy, it is important to frame questions in such a way that their answers can be stated in terms that are relatively independent of the specific hardware/software systems that produced them.

Closely associated with the question of instrumentation is that of methodology generally. To achieve a unified body of knowledge based on experimental research, we need to develop and use more powerful experimental techniques. Much of the experimental research to date has been limited by the tendency to manipulate one or a few factors at a time. This approach can lead to difficulties in piecing findings together, because experiments are rarely performed in the same context. Typically, a researcher studying a particular factor will set up an experiment in such a way as to enhance differences; thus it is difficult to know the relative contribution of different factors even in the same context. Greater use of multivariate experimentation and evaluation might improve this situation.

Information systems can be viewed from the multivariate perspective of research that incorporates simultaneous effects of the many factors affecting user/information system interaction as well as the many ways of measuring user behavior. More complex and efficient multifactor experimental designs could capture the richness of interacting factors in these systems. And composite metrics of user behavior could be developed to specify the underlying dimensions that characterize the ways in which people and information systems interact (Williges and Williges, 1982).

RECOMMENDATIONS FOR RESEARCH

The opportunities and challenges for research on user/information system interaction are numerous. However, it is not clear that any useful purpose would be served by exhaustively listing the possibilities for research, even if it were feasible to do so. The charge to the committee in planning the workshop was to focus on "fundamental experimental research most necessary to improve user/information system interaction." Accordingly, this section identifies questions and issues that can be addressed experimentally and that, in the view of the workshop participants, are especially important to an understanding and improvement of user/information system interaction. We do not claim that our list of research problems includes all of the most important ones; indeed, we suspect that additional important questions will be formulated as a result of research. In this field, as in most others, some of the most useful results of well-conceived research are insights that lead to the formulation of questions that are more meaningful or useful than those with which one began.

Theory Orientation

Before considering specific research questions, we note that a focus on fundamental research suggests an emphasis on theory-oriented research. We see this as a great need--perhaps the great need--of the field. With relatively few exceptions (e.g., Card et al., 1983), research on user/information system interaction has not been theory-oriented. Studies often have involved comparisons among competing products or designs (e.g., command languages, text editors, mail systems) and have yielded results that serve immediate objectives but contribute little to the building of a theory, or theories, that would guide further research and help bring some order to the field. This is not to suggest that there is nothing to be gained from creative experimentation and exploration that is neither theory-based nor theory-motivated, but in general the greater leverage is in theoretically oriented work.

The most fundamental need of the field is a better and deeper understanding of the capabilities and limitations of human beings as seekers, creators, users, and transmitters of information, and of the implications of these capabilities and limitations for the design and use of information systems. While a comprehensive theory of user/information system interaction would probably be an unrealistic goal at the present time, theoretical treatments of certain specific topics could benefit the field substantially. Among these topics are information representation, information seeking, information filtering and evaluation, and information organization and management. We comment briefly on each of these topics in what follows, before moving on to other important research needs.

The Acquisition and Use of Information

Information Representation

Computer technology provides an unprecedented opportunity to develop new ways of representing information, including multimedia schemes that would mix different representational forms in whatever ways are most conducive to assimilation and retention of the information to be conveyed. What is needed in order to exploit this potential is a better understanding of how to determine what would constitute effective representational mixes in specific cases.

Implicit in the concept of a theory of information representation is the distinction between information and a particular representation of it. This distinction is easy to make in some cases; for example, the quantity thirteen is represented as 13, XIII, and  in the Hindu-Arabic, Roman, and Mayan number systems, respectively. In other cases, the distinction may be very difficult to make in practice. How does one distinguish, for example, between the information contained in a textbook on organic chemistry and the particular way in which the information is represented in that book? There exist, of course, many textbooks on organic chemistry, all presumably intended to convey more or less the same information, but each representing it in a different way.

Surprisingly little is known about how to determine whether a particular representation of a concept, principle, relationship, or body of knowledge is better or worse than another for purposes of communication or exposition. We lack an appropriate conceptual framework for describing information apart from its representation. Information theory, powerful as it is for many applications, does not help much in this regard because of its insensitivity to meaning. The practical need for a theory of representation is increased as a consequence of the fact that information technology extends the range of representational options considerably. A theory would provide guidance regarding what representations(s) is (are) most appropriate for specific information and situations and regarding how to mix effectively various representational modes such as text, outlines, linked-node diagrams, graphs, pictures, dynamic process models, and speech.

A question in this area with long-term research interest is how the development of new representational modes may affect the thinking of the people who use them. Unquestionably, the concepts and images through which we understand the world are strongly conditioned by the representational schemes we use (e.g., natural language, mathematics, the specialized symbol systems of specific disciplines such as chemistry, physics, and music). If new representational techniques (e.g., dynamic process simulations) become widely used for expository purposes, the effects on basic thought processes may be extremely important. Identification and documentation of these effects should be continuing goals of research.

Information Seeking

How do people decide what information they need in specific contexts? How do they determine where to look for it? By what criteria do they decide to stop looking? How is their information-seeking behavior influenced by effort and other types of costs? In what ways does the ability to assimilate, retain, and use information depend on the process by which it was found?

Information technology is making it possible to store enormous amounts of information in electronic repositories. With the proliferation of computer networks and personal computers, an ever-increasing fraction of the population will have direct and easy access to such repositories. Access to very large information stores, such as the Library of Congress, will be of limited value in the absence of information-seeking aids that will help one find one's way around in them. And the development of effective aids would be facilitated by a better understanding of information-seeking behavior as it occurs in a wide variety of contexts.

Information Filtering and Evaluation

Most people are exposed to, or have direct and easy access to, much more information than they can possibly absorb or use effectively. Not only does one constantly pick and choose among the various information sources that are more or less continuously available--radio and television stations, newspapers, magazines, books, other people; one also attends selectively to any particular source to which one happens to be "tuned in" at any given moment. Moreover, consciously or unconsciously, one evaluates the information to which one is attending and modifies one's view of life and outlook on the world--one's knowledge base--accordingly.

With the proliferation of computer-based information systems and services, the information sources available to people will increase and, presumably, so will the ability to select the kind of information they want to see or hear. We need to know more about selection, filtering, and evaluation processes in order to understand the psychological and social effects of the multiplication of continuously available information sources.

Information Organization and Management

More and more of the tasks that people perform in the workplace and elsewhere involve information manipulation: composing, editing, form filing, scheduling, charting. Information manipulation can be thought of generically as a matter of collecting bits and pieces of information from a variety of sources, including one's head, and organizing them in some conventional form--memo, letter, graph, budget, or report--that is intended to make them useful to someone else or to oneself at a later time. We need a better understanding of the ways in which people interact with information in the performance of such tasks: how they keep it straight in their heads while in the process of organizing (or reorganizing) it externally, the uses they make of external memory aids such as notes, outlines, and diagrams. How do they manage large amounts of information over long periods of time? How do they organize their more-or-less lifelong personal informaion stores: books, correspondence, pictures, financial records, important documents (birth certificates, passports, deeds, insurance policies)?

Such knowledge is critical to the design of computer-based tools that will facilitate the performance of information manipulation tasks.

Comment

The discussion of the several preceding topics is not intended to suggest that there are no data on how people seek, filter, evaluate, organize, and manage information or on how effectively they can deal with different representational forms. There is much in the experimental literature relating to each of these topics. There is a need, however, to put the existing information into a theoretical framework that will facilitate its application to the design of versatile information systems of the type that technology is making feasible. More attention to theory would also have the beneficial effect of revealing major gaps in the knowledge base and would thereby provide needed direction to further research.

User/Information System Exchange

An important generic problem relating to user/information system interaction is that of finding ways to increase the rate at which information can be transmitted from user to system and vice versa, or what is referred to as the input-output bandwidth. The need is most obvious in the case of the user-to-system side of the interface. Typing is a very slow means of conveying information, even for skilled typists. Pointing techniques can be considerably faster in some cases, but these are relatively passive from the user's point of view; that is to say, the user's ability to communicate is limited by the options the system explicitly presents at any given time.

There is a great deal of interest in the use of speech as a means of increasing input bandwidth, and it seems likely that the technology of speech processing and understanding will make this an increasingly viable option (Levinson and Liberman, 1981; Waltz, 1982). There are many questions associated with the use of speech, for example, problems resulting from its transient and sequential nature, that must be addressed. Some of these may not be clearly articulated until there exist some systems with nontrivial capability for speech input.

Closely related to the question of speech as an input medium is that of natural language. (Speech and natural language are sometimes used as synonyms, but it is possible to have speech input--e.g., single isolated words--that is more constrained than natural language, and possible also to have natural language input in a form other than speech--e.g., typed). Numerous efforts are currently being made to develop interfaces using natural language. None of these efforts has yet yielded a language with the richness and complexity of human language, but there are systems that have considerable flexibility in limited domains of discourse.

We can expect continuing efforts to develop systems with more extensive natural language capabilities, but it will be some time before the full flexibility of humans as natural language users is emulated in software. In the meantime, it is clear that the ease with which and the rate at which information can be conveyed from a user to an information system will depend greatly on the characteristics of the command language that is used. Research is needed to identify ways--short of developing full natural language capability--to increase both the naturalness and the power of the languages in use. One way to decrease somewhat the mismatch between the precision required by the computer and the fuzzy but intelligent ways of human beings is to give the computer the inferential capability to permit it to figure out what users want when they have expressed themselves imprecisely. Some steps have been taken in this direction with the development of the DWIM ("Do what I mean") feature of Interlisp (Teitelman, 1972; Teitelman and Masinter, 1981), but the capability is still very limited. Much remains to be done in this area.

Other means of increasing the input bandwidth include the monitoring of physiological signals of various types in order to circumvent the need for overt motor responses by sensing a user's intent more directly. Possibilities along these lines must be considered relatively futuristic and speculative at this point, but they should not be overlooked.

The desirability of finding ways to increase the rate of information transmittal from a system to its user may be somewhat less obvious, in view of the fact that it is already quite easy to provide users with information at a much greater rate than they can assimilate it. The point is not to present more information per unit time, but to find ways to encode information so as to increase the rate at which it can be assimilated. Unfortunately, more attention is being given to the development of larger display surfaces, higher-resolution displays, multiple displays, and various display partitioning or overlay techniques, such as tiling or windowing, than to the question of how information should be represented in order to maximize its assimilation. Experiments are being performed with as many as 15-20 windows of information being presented simultaneously. Control displays consisting of several monitors, each with different information, are in use routinely.

Insufficient attention is being given, however, to the question of how to exploit display technology in such a way as to take maximum advantage of users' perceptual and cognitive capabilities while making allowance for their limitations. The possibility of greater use of dynamic coding dimensions (e.g., blinking, scintillating, enlargement, brightening, reverse coloring) should be extensively explored, as should the use of motion to convey information about time-varying data and relationships.

Except for the interest in synthesized speech, which is fairly intense, relatively little attention has been given to the possible exploitation of sound as an output medium. To be sure, some systems use audio cues as warning signals or to indicate the need for particular actions, but more general use of sound remains a relatively unexplored means of increasing the bandwidth of the computer-user interface.

The issue of interface design is complicated by the strong possibility that the ideal interface will differ for different users. There is a need, therefore, for the development of interfaces that can be adapted by users to their individual preferences and styles or that will adapt automatically in response to user performance. The idea of developing kits of interface-building tools for customizing interfaces--including languages--to specific user populations or even to individual users is one that merits exploration.

User Training and Support

Development of Users' Skills and Knowledge

Inasmuch as users may have to deal with many different kinds of information systems in daily life, it should be useful to teach people general skills and to provide them with the opportunity to develop knowledge in the use of such systems. Some of these skills could be akin to those taught in library science class--for example, where to look for particular information. Others might include more generic abilities, such as how to evaluate hypotheses, how to access one's own knowledge, how to organize information for retrieval, how to evaluate the usefulness of information for decision making, and how to monitor one's own performance. Such skills might be taught in dedicated classes or as part of the instruction in the use of specific systems. Useful research could focus on desirable repertoires of skills for different types of users and the best methods for teaching them, including especially the possibility of approaches that might be incorporated in public school curricula.

User Aids and On-Line Assistance

As the diversity of users of interactive systems continues to increase, the sophistication of on-line assistance becomes more important. The use of on-line assistance both for aiding experienced users and for providing training for beginners needs to be supported by research. On-line assistance protocols that vary in content and type of presentation should be developed to match the needs of various user groups. Of particular concern is the assistance required by the so-called foreign expert, a person who has some familiarity with computer-based systems in general but needs help in switching to a new system or task application.

Developers and experienced users of an information system often can see guaranteed, error-free ways to extract particular pieces of information from the system because they know what information it contains and understand how it is organized. Novice users typically cannot be assured of success on any specific retrieval effort because they lack accurate and complete models of the systems they use. Each usage (and even each sequential step in each usage) involves something of a gamble. In some cases this state of uncertainty may persist indefinitely, perhaps because the design is too complex to be grasped, because the designer's perspective is too foreign to the user, or because there is no coherent logic to be grasped (as might happen with an omnibus data base with information supplied independently from several sources). In such cases the user needs help to make good gambles. That help could come in the form of training for coping with uncertainty or in the form of a system that facilitates decision making (e.g., leaving an audit trail so that users can see where they went wrong, showing the vagueness of each menu offering, listing all alternatives explicitly, and creating realistic expectations of success).

The possibility of storing large amounts of nontextual data (e.g., video images) in computer-accessible repositories raises the need for the development of new types of on-line aids. The growing use of video discs for image storage represents a significant technological advance whose impact is just beginning to be realized. There are information systems that allow users to roam through a data base of images, even editing when desired. Given that large data bases of visual information are a reality, there is a need for methods to facilitate selective access to them. Consider, for example, the problem of searching a very large wordless data base of visual patterns, such as trademark logos, faces, or Landsat photographs, to determine whether a particular pattern is included in the set. How does one organize such a data base so as to preclude the necessity of an exhaustive search every time there is occasion to look for a specific item? More generally, what kinds of procedures might be developed to facilitate the search for nontextual information? The ability to look for specific items by moving around inside a visual data base could be a useful one, but probably only if the data base is organized so that users can tell at any given time whether they are getting closer to or farther from the target.

Group Problem Solving and Decision Making

A research problem of considerable practical significance as well as theoretical interest relates to the use of information technology to facilitate multi-person problem solving and decision making. How might this technology be used to help extract from a group (committee, task force, management team) the knowledge and wisdom of its individual members relevant to some problem or decision at hand and to use it to derive a solution or decision that is optimal relative to the aggregate intellectual resources of the group? The question is applicable both to groups that meet physically and to those that convene electronically via teleconferencing facilities; the answer, however, may not be the same in both cases.

This question is especially important in view of the many complex problems of modern society. The procedures that are currently used to cope with such problems necessarily involve division of labor and responsibility. Evidence that these procedures work well and produce high quality results is not compelling.

We also need to develop procedures and criteria for evaluating systems that are intended to enhance problem solving or decision making or to augment intellectual performance in some other way. What we want to be able to determine is whether the use of such systems really does improve performance in the desired ways: Does it lead to better solutions and decisions? This requires, of course, the ability to assess the relative quality of solutions and decisions--which is a research problem in itself. It requires also the ability to distinguish degrees of appropriateness of system use. If evaluation of a system's capabilities is the goal, one must be able to segregate effects that are due to inappropriate or inept use of a system from those that derive from system characteristics.

Cognitive Effects of Programming

There has been much speculation that experience in programming and using computers may have substantive effects on the way people think (Abelson and diSessa, 1981; Feurzeig et al., 1981; Papert, 1972, 1980). Experience in programming is believed by some to promote an analytic and modular approach to problem solving, what might be characterized as a commitment to "procedural reasoning." The evidence that experienced programmers approach nonprogramming problems differently than others do is not yet compelling. Even if it were, there would remain a question as to cause and effect. If it could be shown that programmers as a group tend to think differently than do nonprogrammers, the question would remain as to whether programmers come to think differently because of their programming experience or whether they are attracted to programming because of a predisposition to think in ways that are conducive to that activity.

While the question of the effects of programming experience on thinking is unresolved, there is little doubt of its importance. Programming is among the most rapidly growing professions and avocations in the world, which means that a sizable and growing fraction of the population has some amount of programming experience. It would be of more than passing interest to know whether this experience has provided these people with skills and attitudes that have implications beyond the programming context.

In addition, an increasing fraction of primary and secondary school children are obtaining programming experience outside school. Not all children have this experience, however, and it would be useful to know to what extent such experience provides the children who have it with intellectual tools that will be useful in their academic experience. This question takes on added significance in light of the fact that computers in homes (about 10 million) currently outnumber those in schools (about 325,000) by roughly 30 to 1 (Holden, 1984a). (Given that the country has 80 million households and less than 200,000 school buildings, it is not surprising that vendors are tailoring their products to the home market.) An interesting aspect of the distribution of computers in homes is the fact that 60 percent of the buyers of computers costing more than $500 for home use have incomes over $40,000 (Holden, 1984b).

Information Technology and Jobs

Although we do not know in any detail what the impact of information technology will be on jobs, we can be reasonably certain that it will be profound. Some tasks that are now performed by humans will be taken over entirely by machines, other tasks will be radically altered, and new types of jobs will be created. Whether the total demand for human labor, manual and cognitive, will decrease significantly is a question that continues to generate much debate. Without presuming to know the answer, we believe the possibility of greatly reduced job opportunities is one that should not be ignored.

Perhaps even more important than the ability to predict the effects of information technology on job opportunities is a far better understanding than we now have of work and leisure. What needs, besides providing income, does work meet? What alternative ways are there for meeting those needs? What determines the degree of satisfaction that people derive from leisure time? These questions are perhaps outside the scope of the workshop's mandate, but they are viewed as extremely important questions that will take on new significance as a consequence of the various effects of information technology on jobs and job opportunities and hence on the roles of work and leisure in society and the lives of individuals.

An issue pertaining to information technology and jobs that does fall within the scope of the workshop's charge is that of job satisfaction. The introduction of increasingly versatile information systems in work-places, especially offices, will change--is already changing--the requirements of many jobs drastically. The ability to predict the effect of these changes on the degree to which people find their jobs to be satisfying will require not only a better ability to predict what the changes in job requirements will be, but also a better understanding of what the determinants of job satisfaction in information handling situations are.

Attitudes and Accommodation

Attitudes and Affect

Results of empirical studies and reports in the press and other media agree that computers and computer-based systems evoke strong affective responses from people. General attitudes toward computers tend to be highly polarized: people seem more likely to respond strongly, either positively or negatively, than to be indifferent to them (Zoltan and Chapanis, 1982). Computers are often positively associated with efficiency and productivity, versatility, spectacular technological accomplishments (such as space exploration), and innovation. Negative attitudes link computers with privacy invasion, loss of jobs to automation, impersonalization (as epitomized by the "personalized" computer-generated sales solicitation letter), and technocratic elitism.

Often there is a tendency among novices to develop negative attitudes as a consequence of their first efforts to use an information system. One approach that has been suggested for ameliorating this problem is to involve potential users in the design process. The assumption is that such involvement would increase designers' awareness of the capabilities and limitations of intended users and also permit users to influence the development of systems, thus ensuring a better correspondence between a user's capabilities and the system's demands.

Given the ubiquity of computer-based systems and their growing importance in more and more aspects of life, general attitudes toward them are of some consequence. A better understanding of how these attitudes are formed would be helpful toward the promotion of attitudes that are based on an accurate, if limited, understanding of what computers are and what they can and cannot do.

One particular affective phenomenon that has attracted considerable attention is the motivational power of certain types of computer-based systems--in particular video games. Some video games have proven to be so captivating to players, young and old alike, as to cause fairly widespread concern about the time and intellectual energy being spent on this activity. We do not know what it is about these games that is so compelling. Research yielding some insights into this phenomenon could be used constructively to design systems with significant educational potential that are equally motivating.

Accommodations to Rapid Change

One of the most significant characteristics of our age is the rapidity of change resulting from technological developments. There is nothing to lead us to expect the rate of change to decrease in the near future. On the contrary, it seems likely to accelerate. How individuals and societal groups are affected by rapid change is not well understood, and it seems reasonably clear that our accommodation to change, both as individuals and as groups, is often less graceful than we would like it to be. Nowhere is change likely to be more rapid than in the information technology on which this report is focused. A better ability to predict behavioral or attitudinal effects of specific types of changes would have great practical value.

One potentially useful distinction in this regard is between systems that do familiar things, but very much faster than was previously possible, and systems that do new things, perhaps not even thought of previously. Accounting systems are examples of the former. Decision analysis and forecasting systems are examples of the latter. Systems that facilitate group decision making fall somewhere in between; the function is old, but the new setting may make performance qualitatively different. Potential users may reject or accept a system just because it is new. If they reject the new system, they may lose a potentially useful aid; if they accept the new system, they may add an aid but lose control of their operation. New systems have unanticipated effects not only on work patterns within On organization, but also on users' perceptions of their world. There is probably a limit to how much innovation people can absorb without losing their intuitive feel for what a system is doing; we need a better understanding of the determinants of that limit and how to deal with it in specific contexts.

Interacting With Intelligent Systems

Among the most significant changes that are likely to occur during the next few decades will be those resulting from the development and proliferation of systems and devices that have significant intellectual capabilities (Brown, 1983; Manual and Evanczuk, 1983; Rauch-Hindin, 1983). Much effort is currently being devoted to the development of "expert systems" of various sorts and to the application of artificial intelligence to a variety of problem domains. (Expert systems are systems that have the ability to perform tasks typically requiring human expertise.) The vast majority of expert systems that have been built are experimental and are not ready for operational implementation. It seems highly likely, however, that within relatively few years such systems will be in daily use in a variety of contexts. Very little is known about how people will relate to these systems. What will determine the ease or difficulty with which people will accommodate to machines that share some of their cognitive abilities? How will they react to systems that may be intellectually superior to them in certain respects?

The goal that appears to underlie much of the work on intelligent systems is to give them capabilities that are as humanlike as possible. It is widely assumed, for example, that the preferred medium for interaction with a computer-based information system would be unconstrained natural language. In fact, there is little evidence that this assumption is valid. Inasmuch as systems with this capability do not yet exist, arguments on the question are of necessity largely speculative. The question is immensely important, however, inasmuch as it relates to a fundamental aspect of information systems of the future and the ways in which people will interact with them. To address this question adequately will require dealing with some fundamental questions about human communication, and what communication between people should or should not have in common with communication between people and machines.

SUMMARY OF RECOMMENDATIONS

Information technology is advancing so rapidly that any report describing the state of the art may be obsolete by the time it is published. Consequently, the Workshop on Experimental Research Needs for User/Information System Interaction focused on research requirements of a general nature that are relatively independent of specific information systems. The recommendations in this report require a long-term commitment to basic research that will be fruitful for future systems as well as for those in use or on the drawing boards today.

Changes in design goals for information systems are warranted by changes in the relative costs of computing and human resources. Earlier designs were aimed at optimizing hardware use with relatively little consideration of the impact on the user. With the reduction in processing costs that has resulted from technological advances, the emphasis has changed to make more efficient use of people's time. Thus, the interaction between users and information systems must be a major focus of research aimed at improving total system performance. In particular, our knowledge of the capabilities and limitations of humans as processors and users of information must grow considerably if we are to derive the full benefits of the engineering advances in information technology.

Information technology has broader implications than its economic value in the workplace. This technology will permeate the social and economic fabric of day-to-day living in many ways, some already foreseen and predicted and others beyond current imaginings. Although the time when computer-based information systems will be found in every home may not be just around the corner, it cannot be very far away. To make these systems truly useful to, and usable by, people at all levels of sophistication, the abilities, needs, and preferences of potential users must be understood much better than they are at present. Only to the extent that systems match abilities, meet real needs, and satisfy preferences are they likely to be accepted by users and contribute positively to their productivity and the quality of their lives.

Some of the most consequential human factors issues relating to information technology have to do less with the question of system usability than with the need to understand the implications of this technology for various aspects of the way people relate to jobs, how they communicate and interact with each other, and how they perceive themselves. These issues pose special challenges to research because, in many cases, the territory to be explored is new, and effective research will require new concepts and new approaches.

With these thoughts in mind the workshop participants identified specific research needs:

Theory Orientation

There is a paucity of theory-based research on user/information system interaction. To provide a basis for cumulating the results of research and making them broadly applicable to the design and use of these systems, more attention must be paid to the development of a theoretical foundation.

The Acquisition and Use of Information

Information representation--The distinction between information and its representation must be understood better in order to improve methods of representation and their effects on information assimilation and transfer.

Information seeking--A more thorough understanding is needed of the methods people use to find information, especially as advancing technology permits storage and ready retrieval of large amounts of information.

Information filtering and evaluation--The information people use is a small fraction of the information available to them from many sources. Research on effective means of browsing through, filtering, and evaluating information increases in importance as the amount of available information grows exponentially.

Information organization and management--As more and more jobs involve the manipulation of information, and increasing amounts of information become accessible for people to use for their own purposes, there is a growing need both for a better understanding of how people organize and manage information spontaneously and for the development of techniques that will help them do so more effectively.

Input-Output Bandwidth

Methods for increasing the rate of information exchange between people and information systems are needed to overcome current bandwidth limitations. Techniques such as typing require augmentation or replacement by more rapid input/output methods. Research is required to improve information transmission by the use of speech, natural language, physiological signals, and sound.

User Training and Support

Development of users' skills--Better ways must be developed to teach people skills required for effective use of information systems.

On-line assistance--Studies are needed to determine the types of on-line assistance that will best help novices or new users of particular systems to work productively with those systems.

Group problem solving and decision making--Computer-based information systems permit rapid and flexible interaction among persons who are geographically separated; ways in which information systems might enhance the ability of groups to solve problems and make decisions should be investigated.

Cognitive Effects of Programming

More conclusive evidence of the effects of computer programming on cognitive skills is needed. If effects do occur, they could have important implications for education and training.

Information Technology and Jobs

The effect of information technology on jobs and job skills is not fully understood at this time. New concepts of work and leisure may have to evolve.

Attitudes and Accommodation

Attitudes and affect--Many people have strong positive or negative attitudes toward computers. These attitudes influence their approach to the use and proliferation of information systems in many aspects of daily living, and their causes should be studied.

Accommodation to rapid change--Technology, especially information technology, is advancing so rapidly that we cannot anticipate in detail the economic, social, and psychological changes that will occur as a consequence even in the relatively near future. It becomes important, therefore, to understand what kinds of effects rapid change can have, somewhat independently of the character of the change.

Interaction with intelligent systems--The acquisition by information systems of increasingly sophisticated capabilities of a cognitive type raises many questions regarding the roles and functions of people in the workplace and the relationships between people and these systems. This territory is so unexplored that we hardly know how to approach it, but it could well be the single most important challenge to research relating to the interaction between users and information systems.

CONCLUSION

We noted in the introduction to this report that research on user/information system interaction may involve some false starts and some trial-and-error exploration, because the territory is new and not well marked. We noted too that the real challenge is probably that of identifying the kinds of questions that we should be asking. We have indicated what we think some of those questions are. The list we have produced is neither exhaustive nor final in any sense, but is rather a set of reasonable points of departure for research. We fully expect that one of the major outcomes of the research we have suggested will be a better understanding of the questions we should be asking, and the ability to articulate those questions more precisely than we have done here. In the process of learning how to frame better questions, we should learn something also about how to make better use of information technology, to facilitate the further development of its enormous potential, and to help ensure its application to human and humane goals.

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