Using Computers: The Human Factors of Information Systems

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Using Computers

To Doris

Foreword

This book has grown out of a long-standing interest in computers, how they work, what they can do, and what their existence means and will mean for society and for individuals. It may help put it in perspective if I note the events that have been most influential in sparking and sustaining that interest.

My first encounter with a computer was as an experimental psychologist with the Decision Sciences Laboratory of the U.S. Air Force Electronics Systems Division at Hanscom Field, in Bedford, Massachusetts. In the early 1960s the laboratory acquired a Digital Equipment Corporation PDP-1. This was the third or fourth PDP-1 to be installed, the first two or three of these machines having gone to the Massachusetts Institute of Technology, Bolt Beranek and Newman Inc., and possibly one other place. Prominent in my recollection of those days is the excitement that I shared with several colleagues—including Charles Brown, Donald Connolly, Carl Feehrer, Ugo Gagliardi, Ira Goldstein, and John R. Hayes—in using a computer to control experiments on perception, communication, decision making, learning, and related topics when this was a novel thing to do.

One especially keen memory involves a tiny but serendipitous excursion into computer graphics. In order to learn how to use the computer's oscilloscope display, I wrote a little program that would display any polynomial function over a specified range, perform a variety of specified operations on the function—multiply by a constant, add or delete a root, differentiate, integrate, change a coefficient—and immediately show the results. This was not a complicated program. The computer was used simply as a very fast clerk and draftsman. My only purpose in writing it was to get a little experience in working with a new display device. In fact, however, by interacting with this simple program, I believe I acquired an understanding of polynomial functions that was deeper, and certainly more graphic and dynamic, than what I had obtained from solving textbook problems in college math courses. My experience with this program, and with some related ones that permitted exploration of certain statistical constructs, left me with a firm belief in computer technology's potential for use in education and training.

The DSL experience sparked my interest in computer technology; subsequent affiliations with two other organizations have sustained and intensified it. The first was Tufts University and the second Bolt Beranek and Newman Inc. In 1965 Philip Sampson, Chairman of the Psychology Department at Tufts University and my thesis advisor, invited me to teach an introductory course on computers at Tufts. No such course had been offered on the campus before, and there was no established tradition for how one should be organized, so this was an opportunity to design something more or less from scratch. I taught this course for seven years, thoroughly enjoyed doing so, and stopped only when other job responsibilities made it impossible to continue. This experience forced me to look into some aspects of computer technology that I otherwise would not have studied; it also heightened my interest in computer applications and in the question of what implications the existence of this new and radically different type of machine has for the future.

In 1966 I joined the Information Sciences Division of Bolt Beranek and Newman Inc., which was directed by Jerome Elkind and John Swets. I am grateful to both of these people for giving me this opportunity, and to John Senders, a Principal Scientist at BBN at the time, for instigating this move. BBN has been my professional home for over eighteen years now, and it has been a good home indeed; I am indebted to many colleagues—far too numerous to attempt to mention by name—who have made BBN an intellectually exciting and congenial place to be. Many of these people are represented in the reference list at the end of the book.

One would have to be unusually insensitive to live among the computer-related research and development activities at BBN over the last two decades and not be provoked to think about them. The writing of this book has served to remind me of how extensive those activities have been. They have involved many aspects of computer and communication technology, including time-sharing, packet switching, network design and operation, electronic mail, artificial intelligence, and computer-assisted instruction. Of course, I am more likely to be aware of work going on at BBN than of similar work that is being done elsewhere. If I have failed to give commensurate recognition to other groups or individuals, it is owing to a lack of knowledge on my part, and not to any intent to slight.

The most immediate cause of this book was an opportunity in the spring of 1983 to chair a workshop on user–information system interaction sponsored by the National Research Council's Committee on Human Factors. The main objective of the workshop was to identify problems relating to the use of computer-based information systems that could be the foci of research sponsored by the Information Science and Technology Division of the National Science Foundation. To prepare for that workshop, I wrote a background paper, which turned out to be the beginnings of the book. When the idea of expanding the paper into a book was first entertained, the audience in mind was engineering psychologists, human-factors researchers, and people building computer-based systems for use by individuals not trained in computer technology. As the book evolved, the target audience broadened somewhat. While the main focus of the book still is on the human factors of computers and computer-based systems, I have tried to make it informative to anyone with an interest in such systems, how they are used, and what they mean.

I am grateful to my friend and colleague Richard Pew, who, as Chairman of the NRC Committee on Human Factors, asked me to chair the workshop; to the workshop participants—Sara Bly, Baruch Fischhoff, Henry Fuchs, Edmund Klemmer, Steven Leveen, R. Duncan Luce, Theodore Myer, Allen Newell, Howard Resnikoff, Brian Shackel, Daniel Westra, Robert Williges, and Patricia Wright—whose efforts assured the workshop's success; and to Robert Hennesey and Stanley Deutsch of the NRC staff, who, as Workshop Organizer and Study Director, provided invaluable help in arranging the workshop and getting out its report. I want also to thank Edward Weiss and Hal Bamford of the National Science Foundation for their sponsorship of the workshop, and my management, especially David Walden, President of BBN Laboratories, for their support of my participation in the workshop and the writing of the book. Although none of these people can be held accountable for the book's shortcomings, each of them shares some of the responsibility for the fact that it got written.

Several colleagues have been kind enough to read specific portions of the manuscript at various stages of its preparation and to provide very helpful comments on them. These include Madeleine Bates, John O'Hare, John Makhoul, Walter Reitman, and Natesa Sridharan. I have thoroughly enjoyed my interactions with Harry and Betty Stanton of MIT Press Bradford Books and am pleased to have this volume in their collection. Special thanks go to Joan Santoro and Diane Flahive for typing the manuscript and patiently enduring the many changes and revisions, and to Barbara Smith for helping find some elusive references.

My greatest debt of gratitude, by far, is to my wife, Doris, who has been a constant source of inspiration and support in more ways than I could possibly recount, not only during this project, but over many years. It is to her that, with much love, I dedicate this book.

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1

Introduction

Species other than human beings use implements. A chimpanzee, for example, will employ a twig to extract insects from a porous tree trunk; it will use a leaf as a cup, a stick as a lever, a rock as a nutcracker. The differences between the most impressive examples of tool use by nonhuman species and what humankind has done in this regard, however, are sufficiently great to justify identification of our propensity to build and use tools as a distinctively human trait.

The tools that have been developed over the millennia constitute an impressive assortment indeed: tools for constructing objects from clay, wood, or metal; tools for weaving fabrics; tools for harvesting natural resources, such as timber and coal; tools for mending wounds and reconstructing diseased organs, for investigating worlds that are inaccessible to our unaided senses, for moving ourselves and cargos from place to place, for enabling us to communicate over long distances. Some of our tools, especially those of more complex design, we refer to as machines; but they are tools—things that serve as means to an end—nonetheless.

An often noted effect of the development of ever more versatile and sophisticated tools has been the corresponding decrease in the dependence on human muscle as a source of power. This, in turn, has changed the roles that people play in social units and has helped shape, in ways that are not always apparent, our attitudes toward ourselves. The idea of propelling ocean-going vessels by large crews of galley slaves chained to their oars is morally repugnant today. The temptation to be smug about our enlightened attitudes on such matters should be tempered, however, by a recognition that our moral judgment gets considerable reinforcement from the simple fact that as a means of propelling ships, human muscle is not economically competitive with the alternatives that technology has made available.

The history of the development of tools offers instances of profound alteration in human life—occasions when the development of a tool, by making it possible to do something that could not be done before or to do some familiar thing in a different way, has changed the course of history. The plow, the yoke, the wheel, the loom, the printing press, the steam engine, the airplane—each was the agent of such a transition.

Sometimes one cannot attribute radical change to the development of a single tool, but rather to a set of closely related developments that have had great impact over a short period of time. The point is illustrated by the history of farming in this country over the past 200 years. Whereas in the middle of the nineteenth century roughly 70 percent of the total U.S. labor force was devoted to farming, today about 3 percent grows enough food to feed the entire country, and to produce embarrassing surpluses as well. The shift from a dependence on human labor to the widespread use of machines took place gradually over several decades but got a big push with the development of such devices as Eli Whitney's cotton gin in 1793 and Cyrus McCormick's reaper in 1831.

While there can be little doubt that the tools that have been fashioned over the millennia have, on balance, produced enormous benefits for humankind, the story is not without its dark chapters. Many of the most ingenious of those tools have been implements of war, and the motivation for their development has been to provide the means to inflict death and destruction on some "other" subset of humanity. And many of the tools that were developed for more productive purposes have been employed by their owners to exploit their users. Even tools that are almost universally considered desirable and beneficial possessions can represent a threat of one sort or another: the automobile, perceived by many in our society as not only desirable but essential, is a case in point. While it provides us with unprecedented mobility as individuals, it is also directly responsible for about 50,000 highway deaths per year in the United States alone, besides being a major contributor to air pollution and the threatened depletion of fossil fuels. The automobile is convenient to use as an example of an important and valued tool that has some negative aspects, simply because it is so visible and the problems associated with it are so familiar; but one could illustrate the point with any number of other examples.

The question of how to design tools so as to ensure their usefulness to, and usability by, their intended users is one that toolmakers have addressed instinctively, if not explicitly, from the beginning of the toolmaking enterprise. A visit to a museum of hand tools suffices to impress one with the richness of human imagination and the sensitivity of toolmakers to the exquisitely subtle differences in the demands of superficially similar tasks.

Until fairly recently the problem of assuring a good match between tools and their users was left entirely to tool designers, who typically were also users of the tools they designed. But the tools that were developed became increasingly complex; and as the rate of increase in complexity accelerated during the middle of the twentieth century, the need arose for a new discipline devoted to the study of the interaction of people with tools, and particularly with those of sufficient complexity to be called machines. Many of the machines being developed were not designed by single individuals who fully understood their use and were themselves experienced users. The ways in which these machines coupled, or "interfaced," with their users became more complicated and the demands on the users were less well understood. Engineering psychology, human-factors engineering, or ergonomics, as the discipline is variously called, has been studying person-machine interaction and participating in the design of machines, especially of interfaces, for roughly four decades now. It has found much to do, and the impact the discipline has had on machine design has been substantial.

A New Tool

At about the middle of this century a new type of machine appeared, one that was different in some fundamental ways from other machines we had become familiar with and had learned passably well how to design and use. 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, however, energy transformation, force manipulation, and physical work are incidental, for the most part. Computers are designed to transform information structures, not energy. They manipulate symbols, not forces. And what they do is more nearly analogous to thinking than to the performance of physical work.

The motivation for inventing new tools is usually a desire to increase the efficiency with which familiar work is done. Sometimes, however, new machines have proved to have uses far beyond those imagined by their developers. The designers of electronic digital computing machines in the early 1940s were primarily interested in computing projectile trajectories and breaking communication codes (Goldstine 1972; McCorduck 1984): World War II was then at its peak. It is doubful if the early developers of these machines, or anyone else for that matter, had any notion of their potential range of applicability or how ubiquitous they would shortly become.

I have quoted a story told by Lord Vivian Bowden before, to make this point, and cannot resist doing so again. In 1950 Bowden was given the task of determining whether it would be possible for a commercial firm to manufacture computing machines and sell them at a profit. The company in question was Ferranti, which had just completed the first digital computer to be built by a commercial firm in England.

> I went to see Professor Douglas Hartree, who had built the first differential analyzers in England and had more experience in using these very specialized computers than anyone else. He told me that, in his opinion, all the calculations that would ever be needed in this country could be done on the three digital computers which were then being built—one in Cambridge, one in Teddington, and one in Manchester. No one else, he said, would ever need machines of their own, or would be able to afford to buy them. He added that the machines were exceedingly difficult to use, and could not be trusted to anyone who was not a professional mathematician, and he advised Ferranti to get out of the business and abandon the idea of selling any more of them. (Bowden 1970, 43)

Professor Hartree's view appears to have been shared by other people who thought about such things. Diebold points out that "shortly after the computer was invented, a statement was given wide circulation that all the computation in the country [United States] could be accomplished on a dozen—and later fifty—large-scale machines" (1969, 48). But if no one could foresee, when computers first appeared on the scene, how profoundly they would come to influence life, it took less than two decades for the scope of their potential impact to become clear. It is easy to find observations similar to the following two, made in the late 1960s:

> The computer gives signs of becoming the contemporary counterpart of the steam engine that brought on the industrial revolution. The computer is an information machine. Information is a commodity no less intangible than energy; if anything, it is more pervasive in human affairs. The command of information made possible by the computer should also make it possible to reverse the trends toward mass-produced uniformity started by the industrial revolution. Taking advantage of this opportunity may present the most urgent engineering, social and political questions of the next generation. (McCarthy 1966, 65)

> Today we are dealing with machines that can change society much more rapidly and profoundly than the machines that accompanied the industrial revolution of the late eighteenth and nineteenth centuries because they deal with the stuff of which society is made—information and its communication. (Diebold 1969, 4)

Computer technology has affected our lives in countless ways since these observations were made. The implications of the further development of this technology are impossible to foresee in detail with any certainty. However, many observers of the "computer revolution," as what we are currently witnessing is sometimes called, believe that its eventual effects will be at least as great as, and perhaps much greater than, those of the Industrial Revolution (Abelson 1982; Evans 1979; Toffler 1980). Some sociologists and futurists have asserted that the United States and other developed countries are in a state of transition, passing from an industrial society to a postindustrial society; they characterize the postindustrial society as an information society (Bell 1976, 1979; Evans 1979; Naisbitt 1984) and see the computer as the primary agent of this change.

In short, the computer is a new machine, a new tool, of enormous potential. It is perhaps the most awesome tool that has yet been developed. In three or four decades it has already transformed many aspects of life on this planet, and we are only beginning to learn how to exploit its capabilities. Like any powerful tool, it can be put to both effective and ineffective use and applied to both good and evil purposes. It is imperative that we learn to use it well and for humane ends.

Information Systems

It is possible to define "information system" in such a way as to include DNA molecules and quasars. While such a definition could be useful in some contexts, it is too broad for the purposes of this book. Here we will think of an information system as any system whose main function is to "process" information for human use: to acquire it, organize it, move it from place to place, store it, and make it accessible to users. Our attention will be focused on information systems that make use of computer and communication technology in some significant way. Examples of the types of information systems that are of interest include electronic mail systems, word-processing systems, military command and control systems, computer-based information services or utilities, and personal computers that individuals use for their own purposes.

Many of the rapid societal changes we are experiencing stem directly from technological developments in methods for processing and disseminating information. In focusing on the plethora of recent developments that justify referring to ours as the information age, it is easy to overlook the fact that earlier advances in information technology—broadly defined—have also profoundly affected our lives. One of these, of course, was the invention of writing, which seems to have happened only about six or seven millennia ago. Another, which occurred a scant 500 years ago, was the development of printing technology—the invention of the printing press and the discovery of how to make relatively inexpensive paper. The invention of writing made it possible to accumulate knowledge, to store it, and to pass it on so that successive generations could build effectively on what had been inherited and learned. Printing technology democratized knowledge by making it accessible not just to a select few but to the masses; in doing so, it greatly accelerated the rate at which humanity's knowledge base grew. Much of the content of this book relates more or less directly to the possibility that information technology is poised for another quantum jump, equally far reaching in its effects. In the final chapter we return explicitly to this idea.