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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 vis-

ible 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 coun-

try [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)
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> 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.

About This Book

Computers and the types of information systems that computers make possible represent new challenges to those who wish to find ways to ensure that the machines we build are well suited to human use. Much of what has been learned about the design of person-machine interfaces over the past few decades is applicable in the case of computer-based systems. The existence of these systems raises some issues that have not been faced before, however. Never before have we dealt with machines that could talk, correct one's spelling, or diagnose a disease. Computer-based tools can do many of the cognitively demanding tasks that we used to consider achievable only by capabilities unique to human beings. They hold the promise, as many observers have pointed out, of extending our intellectual resources much as the Industrial Revolution extended our physical capabilities.

How are we to ensure that the computer-based tools developed over the next few decades will indeed be well matched to their users? How are we to minimize the human casualties of the further development of this technology? There were many casualties of the Industrial Revolution; can we manage the Information Revolution so that it does not have equally undesirable effects on some people? What can we do to increase the chances that the development and exploitation of this technology will contribute to the common good, to equity, to peace, to individual freedom and opportunity, to human dignity, and to the quality of life in general? These are the kinds of questions that have motivated this book.

My purposes are to provide an overview of where information technology is and where it appears to be headed, to review some of the human-factors research that has been done on computer-based systems to date, and to identify some of the issues and questions that are especially worthy of further research. The first few chapters following this introduction describe the development of information technology in the recent past, the uses of this technology in several fields, and some of the ways in which the technology is expected to develop in the foreseeable future. Subsequent chapters focus on the study of person-computer interaction, with special attention to the interface, both physical and cognitive. Consideration is then given to a variety of software tools and communication and

information services that have been developed. Implications of information technology for employment, and especially for work that has traditionally been done in an office setting, are discussed. Various approaches to the design of interactive systems and some proposed guidelines are reviewed. Several user-related issues are then discussed. Some, but not much, attention is given to the activity of programming. Emphasis is placed on artificial intelligence and the current high level of interest in the development of expert systems. In the final chapters of the book an effort is made to identify some opportunities and challenges for research, and to speculate a bit on the potential that information technology holds for enhancing the quality of human life.