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THE COMPUTER IN A FINITE WORLD

by JAY DAVID BOLTER*

Human beings are, by tradition, if not by nature, technologists. By using technology, we attempt to shape our physical and social environment to match our needs and desires, and, in changing our environment, we change ourselves. Our perception of the world changes with the growing power that technology provides. When mankind had no real knowledge of medicine and only a primitive form of agriculture, the world was a surprising and dangerous place—filled with wild animals, diseases, and famines. With the coming of the Industrial Revolution, the steam engine and modern chemistry and biology gave us much greater control over nature.

All technologies have some effect upon our views of self and of nature. Information technologies play a particularly important role. While inventions such as writing, the calendar, and the clock may not have been as immediately useful as the moldboard plough or crop rotation, they have greatly altered our world view—our general attitude toward our social and physical worlds.

Consider the invention of the mechanical clock in the late twelfth century.[1] The invention may have evolved from a specific technical need: the monks in the monasteries needed to know when to say their offices. Sleeping through their obligations might have endangered their souls, and water-driven alarm clocks were not reliable. By contrast, mechanical clocks would not freeze during a winter night. Having solved the monks' temporal problem, the clock moved from the monastery into the medieval town in the fourteenth century, as great tower clocks were constructed with moving figures or astronomical indicators.

Eventually, the mechanical clock, a new information processor, invaded all areas of daily life.[2] Employers began to set workers' hours by the bells of the town clock. People began to eat and sleep according to the clock's mechanical rhythms. The more accurate clocks and watches

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1. For a detailed account of the clock from the Middle Ages to the present, see D. LANDES, REVOLUTION IN TIME: CLOCKS AND THE MAKING OF THE MODERN WORLD (1983).

2. *See* L. MUMFORD, TECHNICS AND CIVILIZATION 14 (1934).

of the eighteenth and nineteenth centuries were a necessary prerequisite for the factory system of the Industrial Revolution. The clock sharpened our perception of time. Modern astronomy and physics would certainly be impossible without the clock, but even our everyday notions of time have become more precise and mathematical under its influence. We see the temporal world differently than did an ancient Roman or a Stone Age farmer; we see it divided into abstract temporal units, and we plan our lives accordingly.

The introduction of computers into our offices and homes is causing a similar shift in our world view. Because the computer is a more complex and subtle device than the mechanical clock, its effects are even more wide-ranging. Computers are causing a fundamental change in our relationship to nature. It will require the contributions of academics, planners, and businessmen to help us adjust to this change. We need to account for the economic impact of the machine, its psychological effect on its users, and the political problems of information hoarding and sharing.[3] We are also faced with questions as to how the computer fits into the history of technology and the technological world views of people from ancient times to the present.[4]

There is another approach to the impact of the computer age—the philosophical approach. How the computer may change our basic categories of thought and our attitude toward the world as a place and a time in which human beings think and act are subjects to be considered. This approach leads to conclusions which are of interest to businessmen and engineers as well as philosophers. Businessmen and engineers are as concerned as philosophers about issues of time and space, since they need to finish projects on time, move things efficiently from place to place, create physical structures that will stand up, or create an economic structure that will endure.

Where, then, does the computer fit into the philosopher's ruminations or the engineer's plan? A first impression may be that the computer is a device that annihilates time and space. Computers and related electronic equipment are devices that read, store, and manipulate information at a rate that human beings cannot even perceive. Electronic devices seem to annihilate space as well, for example, when they transfer data quickly to enable us to watch live television pictures from the moon. In these respects, computers belong to an extended family of recent tools and machines designed to break down barriers of time and space; telephones, radios, automobiles, and airplanes are familiar members of this family. These devices create a tiny and homogene-

3. For insights into the psychological effect of the machine on children and adults, see S. TURKLE, THE SECOND SELF (1984).

4. *See* J. BOLTER, TURING'S MAN: WESTERN CULTURE IN THE COMPUTER AGE (1984).

ous physical and intellectual world. We are able to move ourselves to almost any inhabited part of the planet in a matter of hours and move our information anywhere in a fraction of a second. We do live, as Marshall McLuhan said, in a "global village."

On the other hand, we should remember that computers also have profound temporal and spatial limitations. In spite of their great power, indeed because of their power, computers raise our awareness of their and our limitations. This awareness is also important in shaping the "electronic" world view that the computer fosters in us. What must next be considered, then, is how the computer manipulates space and time.

Space for the computer means storage space—the physical area in which programs and data are stored. This storage space is ultimately composed of electronic devices which represent information as a series of bits. Most programmers and casual users, however, know little about the organization or functioning of computer storage. Because electronic technology is layered, one can use computer software without understanding the operation of its hardware, just as one can drive a car without knowing the details of the internal combustion engine. Programmers and general users can safely view computer storage as an abstract "workspace" where they can locate and retrieve information.

Computer space is used to store highly structured pieces of information. A secretary seated at a word processor enters documents, such as letters, reports, and invoices. An accountant using a spreadsheet program enters a matrix of numbers and equations. A programmer working in a language such as PASCAL creates a variety of different structures with such exotic names as arrays, trees, and heaps. He uses abstract computer space to simulate a portion of space in the real world. He may represent an architect's conception of a building, an engineer's model of a new airplane, or even a living entity such as a colony of bacteria. At every level of sophistication, people use computer space to represent and alter structures of information—structures which have meaning in the world outside the machine.

As for computer time, the computer is the heir to the mechanical clock. Like the clock, the computer runs on electronic pulses that measure time in precise mathematical units. In fact, every general-purpose computer contains one or more electronic clocks that measure and control its operation. The computer is a discrete logic machine. It performs discrete operations upon units of data in a sequence controlled by the pulsing of the electronic clock. As is the case with computer space, casual users, and even trained programmers, need not concern themselves directly with the ticking of the electronic clock; the details of timing are concerns for the engineers who design and build computers. Programmers and casual users, however, do see the results of the computer's discrete management of time. A secretary may observe that a word processor works step-by-step, sometimes very slowly, as it formats a document. A programmer learns, as part of his craft, how to make computer time work for him—how to exploit the machine's step-by-step processing by breaking his problem into subunits, each of which is performed in one or a few separate operations. The programmer and the secretary learn how to husband the computer's time to achieve a desired result.

Programming languages and word processors give users the ability to manipulate electronic time and space to suit their needs. Computer users become architects of time and space, constructing within the computer a microcosm of the outside world. The important point, then, is the contact between space and time in the real world and space and time in the machine. Computer space and time are so malleable that they can be used to simulate almost anything in the outside world. For instance, the Pentagon uses the computer to simulate a war in Europe; computer space becomes the European theatre, and Russian and American tanks clash on this electronic battlefield. Economists create models of the economy by programming variables for consumption, industrial production, and rates of investment and use the computer's clock to measure simulated monthly changes in these variables. Industrial engineers in CAD/CAM (computer-assisted design and manufacture) invoke programs to create three-dimensional images of products ranging from automobiles to plastic milk cartons. Biologists simulate cell growth or the migratory patterns of birds, while astronomers simulate the birth of a star. In a sense, every computer program is a simulation, since every program sets up a correspondence between the computer's space and time and some portion of the environment. Although we seldom think of it, even a word processor is a simulator: the typist simulates a document, which remains in computer space until it has been revised, formatted, and finally printed.

Because computers successfully imitate elements of the real world, users are inclined to view the world in terms compatible to the time and space of the computer; lessons learned on the machine can be applied to other areas. These lessons affect all branches of science as well as business. The introduction of computers and word processors into the white-collar office is an interesting example. Computer space (files, spreadsheets, and electronic networks) is becoming an extension of the physical space of the office. The trend in business systems is to make the computer simulate a real desk to create the illusion of an electronic desktop. On his videoscreen, the user can manipulate such familiar objects as pencils, file folders, calculators, and even a wastebasket. The goal is to make the computer system as "friendly" as possible by explaining it in terms that the executive or secretary already understands.

The comparison may also work in reverse. The executive may begin to think of his old physical desk in terms suggested by his new electronic one. Objects float in an abstract electronic space on his screen. He can search for files, change their names, alter their contents, and replace them—all in a tidy and systematic manner. He begins to think, "if only office space could be as well ordered and as responsive as the space inside the machine!" If the electronic desktop provides him with a new view of his office, then electronic communication makes it possible to extend this computerized view beyond his immediate environment. Teleconferencing pulls distant locations into the user's own computer space. Computer networks make the world not only a smaller space but also an electronic one. The user seated at his terminal communicates with people across the nation in the same fashion as he communicates with those in the next room. They have all become part of his computer space, or rather, he and they jointly inhabit an electronic space for communicating, calculating, and writing.

To laymen, computers seem infinitely fast and powerful. Magazines and newspapers regularly report new and startlingly achievements in speed and storage capacity. We read of machines that complete in a few seconds problems that would require human mathematicians hundreds of years to solve or of a storage device that can store the Encyclopaedia Britannica five times over on a disk no larger than a long-playing record. The computer can indeed achieve such wonders, but it is also true that engineers and scientists are constantly pushing the fastest and largest machines beyond their limits. Some mathematical problems involving differential equations or linear algebra are simply too complex for any contemporary machine. Other problems must be radically simplified in order to run in a reasonable amount of time. Meteorologists who use computers to forecast the weather are always looking for faster machines and better methods, since the limitations of the computer are a prime reason why their forecasts are valid only for a period of about twenty-four hours. In the world of computer mathematics, the goal is to find methods that are quick and accurate—methods that make skillful use of the limited power of the machine. The art of solving mathematical problems by computer is called "numerical analysis," and many good mathematicians now devote their whole careers to the husbanding of scarce resources of electronic time and space.

These limitations do not only affect mathematics. Scarcity threatens every application of computers. One example is the problem of chess. Computers are now quite good at this game, although they play in a mechanical fashion, entirely different than the play of humans. In looking at a chess problem, a human expert considers only a few moves before making his own. He knows how to focus on his own best moves and the best replies of his opponent. Computers do not have this sense of discrimination. Instead, they must play out dozens or hundreds of possible moves in order to find the best one. When properly programmed, a large computer can consider millions of moves in a very short time and come up with a very good move of its own. Why can it not, therefore, play perfect chess? Why not program the machine to take somewhat longer and consider every possible move and its repercussions? The reason is the sheer number of computations that this would require. It has been estimated that there are 10^{120} possible moves in the game of chess. That is a one followed by 120 zeroes—a number that is larger than that of all of the atoms in the universe. To play perfect chess, a very fast computer would require millions of years for each move.[5]

The problem is that the computer is a finite machine that must always follow a discrete, step-by-step method. Complex problems with many interacting variables tend to explode under such a method, generating a tremendous number of possible outcomes. Some problems, such as those of mathematical analysis, involve infinity itself, and whenever the computer comes up against the infinite, it is stymied. Even the largest supercomputer has only so much time and space to devote to a solution. Its capacity is simply dwarfed by the requirements of many mathematical and logical problems. True, computer technology is always improving. One estimate is that machine speed is increasing one hundredfold every ten years. These increases will make the solution of specific problems feasible. For example, weather forecasting should improve. No mere improvement in the speed of the digital computer, however, could ever conquer the chess problem or make the exacting work of the numerical analyst unnecessary.

Furthermore, the finite nature of computer time and space affects all users, not merely scientists or sophisticated programmers. Computer resources are costly. Unlike natural resources, the cost of computing power is falling, but the perceived need for the power is rising simultaneously. The typist at a word processor learns the value of computer resources when he discovers that his document exceeds the capacity of the computer's memory. Memory, or storage space, is an important element in the performance and the price of any computer. Advertisements for personal computers proudly proclaim the number of "K," or kilobytes of memory, that they provide. A few years ago, 64K seemed to be an enormous amount. Now, 128K is too small for many of the most popular programs; yet, 128K is more than 1500 times as much storage as the ENIAC (the first electronic calculator in 1946) possessed. As for time, each new generation of microchips promises

5. D. LEVY, 1975 US COMPUTER CHESS CHAMPIONSHIP 2 (1976).

faster performance. Still, the demands of the users always seem to equal or exceed the current generation of machines. At the very least, the speed you want costs more than you can comfortably afford.

In this respect, the computer may not seem different from other technologies. After all, a fast automobile costs more than a slow one, and a good microwave oven costs more than a conventional oven. There is, however, a difference. Programming a computer is not like using an oven to bake a loaf of bread. A computer cannot itself do anything as practical as baking bread, but it can simulate a whole bakery—it can represent the raw materials with data structures and analyze the costs of manufacturing. Although the computer cannot make lunch, it can help us think about how we process food. The computer is an abstract machine that can imitate the action of any other machine as well as many facets of nature. Using a computer is an exercise in a special electronic way of thinking. For each computer user, the finite and manipulable qualities of computer space and time become suggestive in a way that other technologies seldom become. If computing is the art of managing resources, then computing can aid our approaches to many problems in our social, economic, and physical environment.

Computers can, of course, be used in a wasteful fashion, but the nature of the machine tends to discourage waste. The secretary learns how to constrain a document in order to fit it into the available space. The businessman devises ways to limit his spreadsheet to a manageable size. The programmer discovers how to structure his data for efficient operation. Stephen Levy has recently written a book on hackers—young men who turn their talents for programming and engineering into a permanent love affair with the computer.[6] In the sixties, these compulsive programmers worked on the relatively large and expensive machines at centers such as MIT. In the seventies, they moved to California to take part in the microcomputer revolution. Levy found that hackers from both coasts, and from very different intellectual backgrounds, share a peculiar aesthetic sense in their work. They are not satisfied simply to make their programs work. Rather, the programs have to be efficient, clean, quick, and clever in ways that no outsider would likely appreciate. Hackers spend hours at their machines trying to streamline their programs—to accomplish in three instructions what had previously required five. Their aesthetic sense, if not their fanaticism, permeates the computer world. The finite beauty of the computer touches any sensitive user.

It is no accident that even in the business world, computers are often called on to maximize efficiency. One company computerizes its inventory to eliminate waste and save money; another installs a com-

6. S. LEVY, HACKERS: HEROES OF THE COMPUTER REVOLUTION (1984).

puter to manage the energy needs of its headquarters. The simulated world of the computer is an ideal space for the experimentation of possible outcomes in the real world, since the refinements can be tested on the machine and then introduced into the real version. For example, computers can be used to model the concentration of pollution in a city. Various changes can be made in the model—the building of a factory, the altering of traffic patterns, the installing and removing of pollution devices. Because computer space and time are manipulable, planners can simulate the building and tearing down of their factories in a matter of minutes at no cost.

The whole ecological movement and the idea of a steady-state economy are not simply the result of the invention of the digital computer. Rather, the computer as a finite machine reinforces political and social trends that have been occurring in the past few decades. Since the eighteenth century, Europe and America have undergone a remarkable economic and demographic expansion—an expansion made possible by the progressive exploitation of natural resources. Until recently, it seemed that these resources of fossil fuels, water, metals, and timber were endless. We developed an ethic of infinite progress, and if World War I destroyed the notion of infinite human perfectability, few doubted that our economic world could at least continue to expand indefinitely. Now we are approaching the ultimate spatial, if not temporal, limits to our technological society. We are suffering the consequences of overpopulation and exploitation of the natural world. New forms of engineering are becoming necessary. The emphasis must now be on efficient use of resources rather than continued expansion. Perhaps a new social ethic will be needed as well—one that encourages the husbanding of our intellectual and moral resources, even as we conserve water and energy. Will we be able to overcome the inertia of old ideas and define a new relationship with our environment based on the realization that all valuable resources are finite? If we do, the digital computer, the finite information processor, will be an important tool in the process of redefinition.