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# ON TOOLS

The stories of man and of his machines are inseparably woven together. Machines have enabled man to transform his physical environment. With their aid he has plowed the land and built cities and dug great canals. These transformations of man's habitat have necessarily induced mutations in his societal arrangements. But even more crucially, the machines of man have strongly determined his very understanding of his world and hence of himself. Man is conscious of himself, of the existence of others like himself, and of a world that is, at least to some extent, malleable. Most importantly, man can foresee. In the act of designing implements to harrow the pliant soil, he rehearses their action in his imagination. Moreover, since he is conscious of himself as a social creature and as one who will inevitably die, he is necessarily a teacher. His tools, whatever their primary practical function, are necessarily also pedagogical instruments. They are then part of the stuff out of which man fashions his imaginative reconstruction of the world. It is within the intellectual and social world he himself creates that the individual prehearses and rehearses countless dramatic enactments of how the world might have been and what it might become. That world is the repository of his subjectivity. Therefore it is the stimulator of his consciousness and finally the constructor of the material world itself. It is this self-constructed world that the individual encounters as an apparently external force. But he contains it within himself; what confronts him is his own model of a universe, and, since he is part of it, his model of himself.

Man can create little without first imagining that he can create it. We can imagine the rehearsal of how he would use it that must have gone on in a stone-age man while he laboriously constructed his axe. Did not each of us recapitulate this ancestral experience when as small children we constructed primitive toys of whatever material lay within our reach? But tools and machines do not merely signify man's imaginativeness and its creative reach, and they are certainly not important merely as instruments for the transformation of a malleable earth: they are pregnant symbols in themselves. They symbolize the activities they enable, i.e., their own use. An oar is a tool for rowing, and it represents the skill of rowing in its whole complexity. No one who has not rowed can see an oar as truly an oar. The way someone who has never played one sees the violin is simply not the same, by very far, as the way a violinist sees it. A tool is also a model for its own reproduction and a script for the reenactment of the skill it symbolizes. That is the sense in which it is a pedagogic instrument, a vehicle for instructing men in other times and places in culturally acquired modes of thought and action. The tool as symbol in all these respects thus transcends its role as a practical means toward certain ends: it is a constituent of man's symbolic recreation of his world. It must therefore inevitably enter into the imaginative calculus that constantly constructs his world. In that sense, then, the tool is much more than a mere device: it is an agent for change. It is even more than a fragment of a blueprint of a world determined for man and bequeathed to him by his forebearers—although it is that too.

It is readily understandable that hand-held tools and especially hand-held weapons have direct effects on the imaginations of individuals who use them. When hunters acquired spears, for example, they must have seen themselves in an entirely new relationship to their world. Large animals which had earlier raided their foodstores and even attacked their children and which they feared, now became man's prey. Man's source of food grew, for now men could kill animals at a distance, including many species that had eluded them before. The effectively greater abundance of food must also have enlarged the domain over which they could range, thus increasing the likelihood that they would meet other people. Their experience of the world changed and so too must have their idea of their place in it.

The six-shooter of the nineteenth-century American West was known as the "great equalizer," a name that eloquently testifies to what that piece of hardware did to the self-image of gun-toters who, when denuded of their weapons, felt themselves disadvantaged with respect to their fellow citizens. But devices and machines, perhaps known to (and certainly owned and operated by) only a relatively few members of society, have often influenced the self-image of its individual members and the world-image of the society as a whole quite as profoundly as have widely used hand tools. Ships of all kinds, for example, were instrumental in informing man of the vastness of his domain. They permitted different cultures to meet and to cross-fertilize one another. The seafarer's ships and all his other artifacts, his myths and legends, effectively transmitted his lore from generation to generation. And they informed the unconscious of those who stayed on the land as much as that of those who actually sailed. The printing press transformed the world even for those millions who, say, in Martin Luther's time, remained illiterate and perhaps never actually saw a book. And of the great masses of people all over the world whose lives were directly and dramatically changed by the industrial revolution, how many ever actually operated a steam engine? Nor is modern society immune to huge shocks administered as side effects of the introduction of new machines. The cotton-picking machine was deployed in the cotton fields of the American South beginning about 1955. It quickly destroyed the market for the only thing vast masses of black Southern agricultural workers had to sell: their labor. Thus began the mass migration of the American Black to the cities, particularly to such northern manufacturing centers as Detroit, Chicago, and New York, but also to the large Southern cities, such as Birmingham and Atlanta. Surely this enormous change in the demography of the United States, this internal migration of millions of its citizens, was and remains one of the principal determinants of the course of the American civil-rights movement. And that movement has nontrivially influenced the consciousness of every American at least, if not of almost every living adult anywhere on this earth.

What is the compelling urgency of the machine that it can so intrude itself into the very stuff out of which man builds his world?

Many machines are functional additions to the human body, virtually prostheses. Some, like the lever and the steam shovel extend the raw muscular power of their individual operators; some, like the microscope, the telescope, and various measuring instruments, are extensions of man's sensory apparatus. Others extend the physical reach of man. The spear and the radio, for example, permit man to cast his influence over a range exceeding that of his arms and voice, respectively. Man's vehicles make it possible for him to travel faster and farther than his legs alone would carry him, and they allow him to transport great loads over vast distances. It is easy to see how and why such prosthetic machines directly enhance man's sense of power over the material world. And they have an important psychological effect as well: they tell man that he can remake himself. Indeed, they are part of the set of symbols man uses to recreate his past, i.e., to construct his history, and to create his future. They signify that man, the engineer, can transcend limitations imposed on him by the puniness of his body and of his senses. Once man could kill another animal only by crushing or tearing it with his hands; then he acquired the axe, the spear, the arrow, the ball fired from a gun, the explosive shell. Now charges mounted on missiles can destroy mankind itself. That is one measure of how far man has extended and remade himself since he began to make tools.

To construe the influence of prosthetic tools on man's transformation entirely in terms of the power they permitted man to aggregate to himself may invite a view of man's relationship to nature whose principal—indeed, almost sole—component is a raw power struggle. Man, in this view, finally conquered nature simply by mustering sufficient power to overcome natural space and time, to engineer life and death, and finally to destroy the earth altogether. But this idea is mistaken, even if we accept that man's eternal dream has been, not merely the discovery of nature, but its conquest, and that that dream has now been largely realized. For if victory over nature has been achieved in this age, then the nature over which modern man reigns is a very different nature from that in which man lived before the scientific revolution. Indeed, the trick that man turned and that enabled the rise of modern science was nothing less than the transformation of nature and of man's perception of reality.

The paramount change that took place in the mental life of man, beginning during roughly the fourteenth century, was in man's perception of time and consequently of space. Man had long ago noticed (and, we may suppose, thought about) regularities in the world about him. Alexander Marshack has shown that even Upper Paleolithic man (circa 30,000 B.C.) had a notation for lunar cycles that was, in Marshack's words, "already evolved, complex and sophisticated, a tradition that would seem to have been thousands of years old by this point."[1] But from Classical antiquity until relatively recently, the regularity of the universe was searched for and perceived in great thematic harmonies. The idea that nature behaves systematically in the sense we understand it—i.e., that every part and aspect of nature may be isolated as a subsystem governed by laws describable as functions of time—this idea could not have been even understood by people who perceived time, not as a collection of abstract units (i.e., hours, minutes, and seconds), but as a sequence of constantly recurring events.

Times of day were known by events, such as the sun standing above a specific pile of rocks, or, as Homer tells us, by tasks begun or ended, such as the yoking of the oxen (morning) and the unyoking of the oxen (evening). Durations were indicated by reference to common tasks, e.g., the time needed to travel a well-known distance or to boil fixed quantities of water. Seasonal times were known by recurring seasonal events, e.g., the departure of birds.

Until Darwin's theory of evolution began to sink into the stream of commonly held ideas, i.e., to become "common sense," people knew that the world about them—the world of reproducing plants and animals, of rivers that flowed and dried up and flowed again, of seas that pulsed in great tidal rhythms, and of the ever-repeating spectacles in the heavens—had always existed, and that its fundamental law was eternal periodicity. Cosmological time, as well as the time perceived in daily life, was therefore a sort of complex beating, a repeating and echoing of events. Perhaps we can vaguely understand it by contemplating, say, the great fugues of Bach. But a special form of contemplation is required of us: we must not think in the modern manner, i.e., of Bach as a "problem solver," or of each of his *opera* in his *Art of the Fugue* as being his increasingly refined "solution" to a problem he had originally set himself. Instead we must think that Bach had the whole plan in his mind all the time, that he thought of the *Art of the Fugue* as a unified work with no beginning and no end, itself eternal like the cosmos, and like it enormously intricate in its connections, circles within circles within circles. We might then find it possible to think of life as having been not merely punctuated but entirely suffused by this kind of music, both on the grand cosmological-theological scale and on the small day-to-day level. Such time is a revolution of cycles and epicycles within cycles, not the receptacle of a uniformly flowing progression of abstract moments we now "know" it to be. And nature itself consisted, to be sure, of individual phenomena, but individual phenomena that were constantly repeating metamorphoses of themselves, and hence were permanent, eternal. "What is eternal is circular, and what is circular is eternal," Aristotle said, and even Galileo still believed the universe to be eternal and to be governed by recurrence and periodicity.

Darwin's understanding of time was radically different. He saw nature itself as a process in time and the individual phenomena of nature as irreversible metamorphoses. But he was far from being the originator of the idea of progress that is now so much with us. Indeed, he would not have been able to think his thoughts at all, if something very nearly like our current ideas of time had not already been an integral part of the common sense of his era.

How man's perception of time changed from that of the ancients to ours illuminates the role played by another kind of machine (one that is not prosthetic) in man's transformation from a creature of and living in nature to nature's master.

The clock is not a prosthetic machine; its product is not an extension of man's muscles or senses, but hours, minutes, and seconds, and today even micro-, nano-, and pico-seconds. Lewis Mumford calls the clock, not the steam engine, "the key machine of the modern industrial age."[2] In the brilliant opening chapter of his *Technics and Civilization,* he describes, among other things, how during the Middle Ages the ordered life of the monasteries affected life in the communities adjacent to them.

> "The monastery was the seat of a regular life. . . . the habit of order itself and the earnest regulation of time-sequences had become almost second nature in the monastery. . . . the monasteries—at one time there were 40,000 under the Benedictine rule—helped to give human enterprise the regular collective beat and rhythm of the machine; for the clock is not merely a means of keeping track of the hours, but of synchronizing the actions of men. . . . by the thirteenth century there are definite records of mechanical clocks, and by 1370 a well-designed 'modern' clock had been built by Heinrich von Wyck at Paris. Meanwhile, bell towers had come into existence, and the new clocks, if they did not have, till the fourteenth century, a dial and a hand that translated the movement of time into a movement through space, at all events struck the hours. The clouds that could paralyze the sundial . . . were no longer obstacles to time-keeping: summer or winter, day or night, one was aware of the measured clank of the clock. The instrument presently spread outside the monastery; and the regular striking of the bells brought a new regularity into the life of the workman and the merchant. The bells of the clock tower almost defined urban existence. Time-keeping passed into time-serving and time-accounting and time-rationing. As this took place, Eternity ceased gradually to serve as the measure and focus of human actions."[3]

Mumford goes on to make the crucial observation that the clock "disassociated time from human events and helped create the belief in an independent world of mathematically measurable sequences: the special world of science."[4] The importance of that effect of the clock on man's perception of the world can hardly be exaggerated. Our current view of time is so deeply ingrained in us, so much "second nature" to us, that we are virtually incapable any longer of identifying the role it plays in our thinking. Alexander Marshack remarks:

> "The concept of the time-factored process in the hard sciences is today almost tautological, since all processes, simple or complex, sequential or interrelated, finite or infinite, develop or continue and have measurable or estimable rates, velocities, durations, periodicities, and so on. However, the sciences which study these processes are themselves 'time-factored,' since the processes of cognition and recognition, of planning, research, analysis, comparison, and interpretation are also sequential, interrelated, developmental and cumulative."[5]

Indeed, the two fundamental equations of physics that every high-school student knows are $F = ma$ and $E = mc^2$. The $a$ in the first stands for acceleration, i.e., a change of velocity with time, and the $c$ in the second stands for the velocity of light, i.e., the displacement of light with time.

I mention the clock here not merely because it was a crucial determinant of man's thinking—there were, after all, many other inventions that helped initiate the new scientific rationalism; for example, lines of longitude and latitude on the globe—but to show that prosthetic machines alone do not account for man's gain of power over nature. The clock is clearly not a prosthetic machine; it extends neither man's muscle power nor his senses. It is an autonomous machine.

Many machines are automatic in the sense that, once they are turned on, they may run by themselves for long periods of time. But most automatic machines have to be set to their task and subsequently steered or regulated by sensors or by human drivers. An autonomous machine is one that, once started, runs by itself on the basis of an internalized model of some aspect of the real world. Clocks are fundamentally models of the planetary system. They are the first autonomous machines built by man, and until the advent of the computer they remained the only truly important ones.

Where the clock was used to reckon time, man's regulation of his daily life was no longer based exclusively on, say, the sun's position over certain rocks or the crowing of a cock, but was now based on the state of an autonomously behaving model of a phenomenon of nature. The various states of this model were given names and thus reified. And the whole collection of them superimposed itself on the existing world and changed it, just as much as a cataclysmic rearrangement of its geography or climate might have changed it. Man now had to develop new senses for finding his way about the world. The clock had created literally a new reality; and that is what I meant when I said earlier that the trick man turned that prepared the scene for the rise of modern science was nothing less than the transformation of nature and of his perception of reality. It is important to realize that this newly created reality was and remains an impoverished version of the older one, for it rests on a rejection of those direct experiences that formed the basis for, and indeed constituted, the old reality. The feeling of hunger was rejected as a stimulus for eating; instead, one ate when an abstract model had achieved a certain state, i.e., when the hands of a clock pointed to certain marks on the clock's face (the anthropomorphism here is highly significant too), and similarly for signals for sleep and rising, and so on.

This rejection of direct experience was to become one of the principal characteristics of modern science. It was imprinted on western European culture not only by the clock but also by the many prosthetic sensing instruments, especially those that reported on the phenomena they were set to monitor by means of pointers whose positions were ultimately translated into numbers. Gradually at first, then ever more rapidly and, it is fair to say, ever more compulsively, experiences of reality had to be representable as numbers in order to appear legitimate in the eyes of the common wisdom. Today enormously intricate manipulations of often huge sets of numbers are thought capable of producing new aspects of reality. These are validated by comparing the newly derived numbers with pointer readings on still more instruments that mediate between man and nature, and which, of course, produce still more numbers.

"The scientific man has above all things to strive at self-elimination in his judgments," wrote Karl Pearson in 1892.[6] Of the many scientists I know, only a very few would disagree with that statement. Yet it must be acknowledged that it urges man to strive to become a disembodied intelligence, to himself become an instrument, a machine. So far has man's initially so innocent liaison with prostheses and pointer readings brought him. And upon a culture so fashioned burst the computer.

"Every thinker," John Dewey wrote, "puts some portion of an apparently stable world in peril and no one can predict what will emerge in its place." So too does everyone who invents a new tool or, what amounts to the same thing, finds a new use for an old one. The long historical perspective which aids our understanding of Classical antiquity, of the Middle Ages, and of the beginnings of the Modern Age also helps us to formulate plausible hypotheses to account for the new realities which emerged in those times to replace older ones imperiled by the introduction of new tools. But as we approach the task of understanding the warp and woof of the stories that tell, on the one hand, of the changing consciousness of modern man, and, on the other, of the development of contemporary tools and particularly of the computer, our perspective necessarily flattens out. We have little choice but to project the lessons yielded by our understanding of the past, our plausible hypotheses, onto the present and the future. And the difficulty of that task is vastly increased by the fact that modern tools impact on society far more critically in a much shorter time than earlier ones did.

The impulse the clock contributed toward the allienation of man from nature required centuries to penetrate and decisively affect mankind as a whole. And even then, it had to synergistically combine with many other emerging factors to exercise its influence. The steam engine arrived when, in the common-sense view, time and space were already quantified. An eternal nature governed by immutable laws of periodicity implied a mandate, one made explicit in holy books and exercised by institutional vicars of the eternal order. That quasi-constitutional, hence constrained, authority had long since been displaced by, for example, the relatively unconstrained authority of money, i.e., of value quantified, and especially the value of a man's labor quantified. These and many other circumstances combined to make it possible for the steam engine to eventually transform society radically. Later tools, e.g., the telephone, the automobile, radio, impinged on a culture already enthralled by what economists call the pig principle: if something is good, more is better. The hunger for more communication capacity and more speed, often stimulated by the new devices themselves, as well by new marketing techniques associated with them, enabled their rapid spread throughout society and society's increasingly rapid transformation under their influence.

When the first telegraph line connecting Texas with New York was laid, doubts were expressed as to whether the people in those places would have anything to say to one another. But by the time the digital computer emerged from university laboratories and entered the American business, military, and industrial establishments, there were no doubts about its potential utility. To the contrary, American managers and technicians agreed that the computer had come along just in time to avert catastrophic crises: were it not for the timely introduction of computers, it was argued, not enough people could have been found to staff the banks, the ever increasingly complex communication and logistic problems of American armed forces spread all over the world could not have been met, and trading on the stock and commodity exchanges could not have been maintained. The American corporation was faced with a "command and control" problem similar to that confronting its military counterpart. And like the Pentagon, it too was increasingly diversified and internationalized. Unprecedentedly large and complex computational tasks awaited American society at the end of the Second World War, and the computer, almost miraculously it would seem, arrived just in time to handle them.

In fact, huge managerial, technological, and scientific problems had been solved without the aid of electronic computers in the decades preceding the Second World War and especially during the war itself. A dominant fraction of the industrial plant of the United States was coordinated to provide the tools of war—foodstuffs, clothing, etc.—and to supply the required transport to vast armies spread all over the globe. The Manhattan Project produced the atomic bomb without using electronic computers; yet the scientific and engineering problems solved under its auspices required probably more computations than had been needed for all astronomical calculations performed up to that time. The magnitude of its managerial task surely rivaled that of the Apollo Project of the sixties. Most people today probably believe that the Apollo Project could not have been managed without computers. The history of the Manhattan Project seems to contradict that belief. There are corresponding beliefs about the need for computers in the management of large corporations and of the military, about the indispensability of computers in modern scientific computations, and, indeed, about the impossibility of pursuing modern science and modern commerce at all without the aid of computers.*

The belief in the indispensability of the computer is not entirely mistaken. The computer becomes an indispensable component of any structure once it is so thoroughly integrated with the structure, so enmeshed in various vital substructures, that it can no longer be factored out without fatally impairing the whole structure. That is virtually a tautology. The utility of this tautology is that it can reawaken us to the possibility that some human actions, e.g., the introduction of computers into some complex human activities, may constitute an irreversible commitment. It is not true that the American banking system or the stock and commodity markets or the great manufacturing enterprises would have collapsed had the computer not come along "just in time." It is true that the specific way in which these systems actually developed in the past two decades, and are still developing, would have been impossible without the computer. It is true that, were all computers to suddenly disappear, much of the modern industrialized and militarized world would be thrown into great confusion and possibly utter chaos. The computer was not a prerequisite to the survival of modern society in the postwar period and beyond; its enthusiastic, uncritical embrace by the most "progressive" elements of American government, business, and industry quickly made it a resource essential to society's sur-

* I am sure that, had computers attained their present sophistication by 1940, technicians participating in the Manhattan Project would have sworn that it too would have been impossible without computers. And we would have had similarly fervent testimony from the designers of Second World War aircraft, and from the managers of logistics of that war. If Germany had had computers from the outset of Hitler's dictatorship, common sense would today hold that only with the aid of computers could the Nazis have controlled the German people and implemented the systematic transportation of millions of people to death camps and their subsequent murder. But the Second World War was fought, and the millions did die, when there were still no computers.

vival *in the form* that the computer itself had been instrumental in shaping.

In 1947 J. W. Forrester wrote a memorandum to the U.S. Navy "On the Use of Electronic Digital Computers as Automatic Combat Information Centers." Commenting on subsequent developments in 1961, he wrote,

> "one could probably not have found [in 1947] five military officers who would have acknowledged the possibility of a machine's being able to analyze the available information sources, the proper assignment of weapons, the generation of command instructions, and the coordination of adjacent areas of military operations. . . . During the following decade the speed of military operations increased until it became clear that, regardless of the assumed advantages of human judgment decisions, the internal communication speed of the human organization simply was not able to cope with the pace of modern air warfare. This inability to act provided the incentive."[7]

The decade of which Forrester speaks was filled with such incentives, with discoveries that existing human organizations were approaching certain limits to their ability to cope with the ever faster pace of modern life. The image Forrester invokes is of small teams of men hurrying to keep up with events but falling ever further behind because things are happening too fast and there is too much to do. They have reached the limit of the team's "internal speed." Perhaps this same imagery may serve as a provocative characterization also for teams of bank clerks frantically sorting and posting checks in the middle of the night, attacking ever larger mountains of checks that must, according to law, be cleared by a fixed deadline. Perhaps all, or at least many, of the limits of other kinds that were being approached during that decade may usefully be so characterized. After all, it is ultimately the "internal speed" of some human organization that will prove the limiting factor when, say, an automobile firm attempts to run a production line capable of producing an astronomical variety of cars at a high and constant rate, or when, say, some central government agency takes the responsibility for guarding millions of welfare clients against the temptation to cheat by closely monitoring both their welfare payments and whatever other income they may, possibly illicitly, receive.

The "inability to act" which, as Forrester points out, "provided the incentive" to augment or replace the low-internal-speed human organizations with computers, might in some other historical situation have been an incentive for modifying the task to be accomplished, perhaps doing away with it altogether, or for restructuring the human organizations whose inherent limitations were, after all, seen as the root of the trouble. It may be that the incentive provided by the military's inability to cope with the increasing complexity of air warfare in the 1950's could have been translated into a concern, not for mustering techniques to enable the military to keep up with their traditional missions, but for inventing new human organizations with new missions, missions relevant to more fundamental questions about how peoples of diverse interests are to live with one another. But the computer was used to build, in the words of one air force colonel, "a servomechanism spread out over an area comparable to the whole American continent," that is, the SAGE air-defense system. Of course, once "we" had such a system, we had to assume "they" had one too. We therefore had to apply our technology to designing offensive weapons and strategies that could overpower "our" defenses, i.e., "their" presumed defenses. We then had to assume that "they" had similar weapons and strategies and therefore . . ., and so on to today's MIRVs and MARVs and ABMs.

It may be that the people's cultivated and finally addictive hunger for private automobiles could have been satiated by giving them a choice among, say, a hundred vehicles that actually differ substantially from one another, instead of a choice among the astronomical number of basically identical "models" that differ only trivially from one another. Indeed, perhaps the private automobile could have been downgraded as a means of personal transportation in favor of mass transit in, and passenger rail between, the cities. But the computer was used to automate the flow of parts to automobile production lines so that people could choose from among millions of trivial options on their new cars.

It may be that social services such as welfare could have been administered by humans exercising human judgment if the dispensing of such services were organized around decentralized, indigenous population groupings, such as neighborhoods and natural regions. But the computer was used to automate the administration of social services and to centralize it along established political lines. If the computer had not facilitated the perpetuation and "improvement" of existing welfare distribution systems—hence of their philosophical rationales—perhaps someone might have thought of eliminating much of the need for welfare by, for example, introducing negative income tax. The very erection of an enormously large and complex computer based welfare administration apparatus, however, created an interest in its maintenance and therefore in the perpetuation of the welfare system itself. And such interests soon become substantial barriers to innovation even if good reasons to innovate later accumulate. In other words, many of the problems of growth and complexity that pressed insistently and irresistibly for response during the postwar decades could have served as incentives for social and political innovation. An enormous acceleration of social invention, had it begun then, would now seem to us as natural a consequence of man's predicament in that time as does the flood of technological invention and innovation that was actually stimulated.

Yes, the computer did arrive "just in time." But in time for what? In time to save—and save very nearly intact, indeed, to entrench and stabilize—social and political structures that otherwise might have been either radically renovated or allowed to totter under the demands that were sure to be made on them. The computer, then, was used to conserve America's social and political institutions. It buttressed them and immunized them, at least temporarily, against enormous pressures for change. Its influence has been substantially the same in other societies that have allowed the computer to make substantial inroads upon their institutions: Japan and Germany immediately come to mind.

The invention of the computer put a portion of an apparently stable world in peril, as it is the function of almost every one of man's creative acts to do. And, true to Dewey's dictum, no one could have predicted what would emerge in its place. But of the many paths to social innovation it opened to man, the most fateful was to make it possible for him to eschew all deliberate thought of substantive change. That was the option man chose to exercise. The arrival of the Computer Revolution and the founding of the Computer Age have been announced many times. But if the triumph of a revolution is to be measured in terms of the profundity of the social revisions it entrained, then there has been no computer revolution. And however the present age is to be characterized, the computer is not eponymic of it.

To say that the computer was initially used mainly to do things pretty much as they had always been done, except to do them more rapidly or, by some criteria, more efficiently, is not to distinguish it from other tools. Only rarely, if indeed ever, are a tool and an altogether original job it is to do, invented together. Tools as symbols, however, invite their imaginative displacements into other than their original contexts. In their new frames of reference, that is, as new symbols in an already established imaginative calculus, they may themselves be transformed, and may even transform the originally prescriptive calculus. These transformations may, in turn, create entirely new problems which then engender the invention of hitherto literally unimaginable tools. In 1804, a hundred years after the first stationary steam engines of Newcomen and Savery had found common use in England to, for example, pump water out of mines, Trevithik put a steam engine on a carriage and the carriage on the tracks of a horse-tramway in Wales. This ripping out of context of the stationary steam engine and its displacement into an entirely new context transformed the engine into a locomotive, and began the transformation of the horse-tramway into the modern railroad. And incidentally, since it soon became necessary to guard against collisions of trains traveling on the same track, a whole new signaling technology was stimulated. New problems had been created and, in response to them, new tools invented.

It is noteworthy that Thomas Savery, the builder of the first steam engine that was applied practically in industry (circa 1700), was also the first to use the term "horsepower" in approximately its modern sense. Perhaps the term arose only because there were so many horses when the steam engine replaced them, not only in its first incarnation as a stationary power source, but also in its reincarnation as a locomotive. Still, the term "horsepower," so very pointed in its suggestiveness, might well have provoked Trevithik's imagination to probe in the direction it finally moved, to make the creative leap that combined the steam engine and the horse-tramway in a single unified frame of reference. Invention involves the imaginative projection of symbols from one existing, and generally well-developed, frame of reference to another. It is to be expected that some potent symbols will survive the passage nearly intact, and will exert their influence on even the new framework.

Computers had horses of another color to replace. Before the first modern electronic digital computers became available for what we now call business data processing—that is, before the acquisition of UNIVAC I by the U.S. Bureau of the Census in 1951—many American businesses operated large so-called "tab rooms." These rooms housed machines that could punch the same kind of cards (now commonly, if often mistakenly, called IBM cards) that are still in use today, sort these cards according to arbitrary criteria, and "tabulate" decks of such cards, i.e., list the information they contained in long printed tables. Tab rooms produced mountains of management reports for American government and industry, using acres of huge clanking mechanical monsters. These machines could perform only one operation on a deck of cards at a time. They could, for example, sort the deck on a specific sorting key. If the sorted deck had to be further sorted according to yet another criterion, the new criterion had to be manually set into the machine and the deck fed through the machine once more. Tab rooms were the horse-tramways of business data processing, tab machines the horses.

In principle, even the earliest commercially available electronic computers, the UNIVAC I's, made entirely new and much more efficient data-processing techniques possible, just as, in principle, the earliest steam engines could already have been mounted on carriages and the carriages on tracks. Indeed, during and just after the Second World War, the arts of operations research and systems analysis, on which the sophisticated use of computers in business was ultimately grounded, were developed to very nearly their full maturity. Still, business used the early computers to simply "automate" its tab rooms, i.e., to perform exactly the earlier operations, only now automatically and, presumably, more efficiently. The crucial transition, from the business computer as a mere substitute for work-horse tab machines to its present status as a versatile information engine, began when the power of the computer was projected onto the framework already established by operations research and systems analysis.

It must be added here that although the railroad in England became important in its own right—it employed many workers, for example—it also enormously increased the importance of many other forms of transportation. Similarly, the synergistic combination of computers and systems analysis played a crucial role in the creation and growth of the computer industry. It also breathed a new vitality into systems analysis as such. During the first decade of the computer's serious invasion of business, when managers often decided their businesses needed computers even though they had only the flimsiest bases for such decisions, they also often undertook fairly penetrating systems analyses of their operations in order to determine what their new computers were to do. In a great many cases such studies revealed opportunities to improve operations, sometimes radically, without introducing computers at all. Nor were computers used in the studies themselves. Often, of course, computers were installed anyway for reasons of, say, fashion or prestige.

A side effect of this oft-repeated experience was to firmly establish systems analysis, and to a lesser extent operations research, as a methodology for making business decisions. As the prestige of systems analysis was fortified by its successes and as, simultaneously, the computer grew in power, the problems tackled by systems analysts became more and more complex, and the computer appeared an ever more suitable instrument to handle great complexity. Normally systems analysis appears, to the casual observer at least, to have been swallowed up by the computer. This appearance is misleading but not without significance. Systems analysis has survived and prospered as a discipline in its own right. The computer has put muscles on its techniques. It has so greatly strengthened them as to make them qualitatively different from their early manual counterparts. The latter, consequently, have largely disappeared. And the computer can no longer be factored out of the former.

The interaction of the computer with systems analysis is instructive from another point of view as well. It is important to understand very clearly that strengthening a particular technique—putting muscles on it—contributes nothing to its validity. For example, there are computer programs that carry out with great precision all the calculations required to cast the horoscope of an individual whose time and place of birth are known. Because the computer does all the tedious symbol manipulations, they can be done much more quickly and in much more detail than is normally possible for a human astrologer. But such an improvement in the technique of horoscope casting is irrelevant to the validity of astrological forecasting. If astrology is nonsense, then computerized astrology is just as surely nonsense. Now, sometimes certain simple techniques are invalid for the domains to which they are applied merely because of their very simplicity, whereas much more complicated techniques of the *same* kind are valid in those domains. That is not true for astrology, but may well be true of, say, numerical weather forecasting. For the latter, the number of data that must be taken into account, and the amount of computation that must be done on them in order to produce an accurate weather forecast, may well be so large that no team of humans, however large, could complete the computations in any reasonable time whatever. And any simplification of the technique sufficient to reduce the computational task to proportions manageable by humans would invalidate the technique itself. In such cases the computer may contribute to making a hitherto impractical technique practical. But what has to be remembered is that the validity of a technique is a question that involves the technique and its subject matter. If a bad idea is to be converted into a good one, the *source* of its weakness must be discovered and repaired. A person falling into a manhole is rarely helped by making it possible for him to fall faster or more efficiently.

It may seem odd, even paradoxical, that the enhancement of a technique may expose its weaknesses and limitations, but it should not surprise us. The capacity of the human mind for sloppy thinking and for rationalizing, for explaining away the consequences of its sloppy thinking, is very large. If a particular technique requires an enormous amount of computation and if only a limited computational effort can be devoted to it, then a failure of the technique can easily be explained away on the ground that, because of computational limitations, it was never really tested. The technique itself is immunized against critical examination by such evasions. Indeed, it may well be fortified, for the belief that an otherwise faultless and probably enormously powerful technique is cramped by some single limitation tends to lead the devotee to put effort into removing that limitation. When this limitation seems to him to be entirely computational, and when a computer is offered to help remove it, he may well launch a program of intensive, time-consuming "research" aimed simply at "computerizing" his technique. Such programs usually generate subproblems of a strictly computational nature that tend, by virtue of their very magnitude, to increasingly dominate the task and, unless great care is taken to avoid it, to eventually become the center of attention. As ever more investment is made in attacking these initially ancillary subproblems, and as progress is made in cracking them, an illusion tends to grow that real work is being done on the main problem. The poverty of the technique, if it is indeed impotent to deal with its presumed subject matter, is thus hidden behind a mountain of effort, much of which may well be successful in its own terms. But these are terms in a constructed context that has no substantive overlap with, or even relationship to, the context determined by the problem to which the original technique is to be applied. The collection of subproblems together with the lore, jargon, and subtechniques which crystalized around them, becomes reified. The larger this collection is, and the more human energy has been invested in its creation, the more real it seems. And the harder the subproblems were to solve and the more technical success was gained in solving them, the more is the original technique fortified.

I have discussed the role that tools play in man's imaginative reconstruction of his world and in the sharpening of his techniques. However, tools play another related role as well: they constitute a kind of language for the society that employs them, a language of social action. Later on I will say more about language. Let it suffice for now to characterize language somewhat incompletely as consisting of a vocabulary—the words of the language—and a set of rules that determine how individual vocabulary items may be concatenated to form meaningful sentences. I leave to one side for the moment the innumerable mysteries that surround the concept of meaning. I restrict myself to its narrowest conception, namely, that of the action which a particular "sentence" in the language of tools initiates and accomplishes.

Ordinary language gains its expressive power in part from the fact that each of its words has a restricted domain of meaning. It would be impossible to say anything in a language that consisted entirely of pronouns, for example. A tool too gains its power from the fact that it permits certain actions and not others. For example, a hammer has to be rigid. It can therefore not be used as a rope. There can be no such things as general-purpose tools, just as there can be no general-purpose words. We know that the use of specific words in vastly general ways, for example, such words as "like" and "y'know," impoverishes rather than enriches current American English.

Perhaps it is as difficult to invent truly new tools as it is to invent truly new words. But the twentieth century has witnessed the invention of at least a modest number of tools that do actually extend the range of action of which the society is capable. The automobile and the highway, radio and television, and modern drugs and surgical procedures immediately come to mind. These things have enabled society to articulate patterns of action that were never before possible. What is less often said, however, is that the society's newly created ways to act often eliminate the very possibility of acting in older ways. An analogous thing happens in ordinary language. For example, now that the word "inoperative" has been used by high government officials as a euphemism for the word "lie," it can no longer be used to communicate its earlier meaning. Terms like "free" (as in "the free world"), "final solution," "defense," and "aggression" have been so thoroughly debased by corrupt usage that they have become essentially useless for ordinary discourse. Similarly, a highway permits people to travel between the geographical centers it connects, but, because of the side effects that it and other factors synergistically engender, it imprisons poor people in inner cities as effectively as if the cities were walled in. The mass-communication media are sometimes said to have reduced the earth to a global village and to have enabled national and even global town meetings. But, in contrast to the traditional New England town meeting which was—and remains so in my home town—an exercise in *participatory* politics, the mass media permit essentially no talking back. Like highways and automobiles, they enable the society to articulate entirely new forms of social action, but at the same time they irreversibly disable formerly available modes of social behavior.

The computer is, in a sense, a tool of this kind. It helped pry open the door to outer space, and it saved certain societal institutions that were threatened with collapse under the weight of a rapidly growing population. But its impact has also closed certain doors that were once open . . . whether irreversibly or not, we cannot say with certainty. There is a myth that computers are today making important decisions of the kind that were earlier made by people. Perhaps there are isolated examples of that here and there in our society. But the widely believed picture of managers typing questions of the form "What shall we do now?" into their computers and then waiting for their computers to "decide" is largely wrong. What is happening instead is that people have turned the processing of information on which decisions must be based over to enormously complex computer systems. They have, with few exceptions, reserved for themselves the right to make decisions based on the outcome of such computing processes. People are thus able to maintain the illusion, and it is often just that, that they are after all the decisionmakers. But, as we shall argue, a computing system that permits the asking of only certain kinds of questions, that accepts only certain kinds of "data," and that cannot even in principle be understood by those who rely on it, such a computing system has effectively closed many doors that were open before it was installed.

In order to understand how the computer attained so very much power, both as an actor and as a force on the human imagination, we must first discuss where the power of the computer comes from and how the computer does what it does. That is what we shall turn our attention to in the next two chapters.