EVOLVING CYBERNETIC MACHINERY AND HUMAN VALUES

by Ralph Wendell Burhoe

The relation of machinery to human values is much more intimate than many suspect. In order to understand more clearly this close relation between machinery and values, it may be helpful to clarify some recent enrichment for the words "values" and "machinery." To talk about human values in an ancient language that does not intersect the meanings of the new language of contemporary science is a rather frustrating and often futile enterprise, as C. P. Snow has pointed out in his *Two Cultures*.[1] The specialists in the humanities sometimes do not have equivalent meanings for what is being said in the new scientific language. And members of different scientific and scholarly disciplines generally may get confused unless they take some time to get common referents for their terms.

To get a meaningful connection between machinery and values, then, I shall first talk about values, even humanistic human values, in a language or conceptual system which has common meanings deriving from physics that are commonly utilized in contemporary frontiers of learning in various fields of phenomena, ranging into biology, anthropology, sociology, psychology, and even theology. Perhaps some of the new concepts or theories used to describe biological and behavioral systems may provide us a bridge so that we can talk about human values and machines in a common language.

Life and Values Described as Machinery

Michael Polanyi, that modern Renaissance man, who has done pioneer thinking ranging from physical chemistry through biology to sociology and philosophy, pointed to a relationship between machines and life:

> From machines, we pass to living beings. We arrive there by remembering that animals move about mechanically and that they have internal organs

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which perform functions as the parts of a machine do, functions which sustain the life of the organism in the way that machines serve the interests of their users. For centuries past, the workings of life have been likened to the workings of machines, and physiologists have been seeking to interpret the organism as a complex network of mechanisms. Any single part of the organism is puzzling to physiology and meaningless to pathology until the way it benefits the organism is discovered. We may add that any description of such a system in terms of its physicochemical topography would be quite meaningless but for the fact that the description covertly recalls the system's physiological interpretation. Similarly, the topography of a machine is meaningless until we guess how it works and for what purpose.

In this light, the organism is shown to be, like a machine, a system under dual control. [1] Its structure serves as a boundary condition, harnessing [2] the physicochemical process by which its organs perform their functions. Thus, morphogenesis, the process by which the structure of living beings develops, can be likened to the shaping of a machine which will act as a boundary for the laws of inanimate nature. As these laws serve the machine, so they also serve the developed organism.[2]

Polanyi pointed out how the purpose of a machine derives from the information or the boundary conditions put into its structure and the power supplied to it, which "harness as it were the laws of nature at work in its material and in its driving force and make them serve our purpose."[3] In living organisms the shaping or structuring of the machinery or "the morphogenetic process is explained in principle by the genetic transmission of information stored in a chemical compound, the famous DNA interpreted in this sense by Watson and Crick. The informations stored in DNA, which control morphogenesis, can be shown to be boundary conditions like those imposed on a material by shaping it into a machine."[4]

An earlier physiological way of describing structures that define and motivate the purpose and the goals or values of a living organism is in terms of the integrated operation of various organic submechanisms, ranging through levels from subcellular physicochemical machinery to total organ systems. This machinery is the system of biochemical and neurological controls that produce homeostasis, that is, the continuity of orderly function or purpose of the organism that maintains it as a relatively stable system in the midst of the disordering flux of its environment. Numerous biological and behavioral scientists have illuminated the dynamic negative feedback mechanisms which give the organism purposive activities, actions that serve to keep it functioning as a living organism. The basic design or information which structures this complex network of machinery is, as Polanyi noted, the genetic information or genotype which informs the "Wisdom of the Body," about which Walter B. Cannon wrote so eloquently forty years ago.[5]

In the case of the organisms of *Homo sapiens,* we can proceed another step beyond information or wisdom supplied by the genotype, and we note a new level of input of information which the anthropologists have called culture. Here, there is transmitted, quite independently from the genetic transmission in the DNA code of the *genotype,* a whole complex of information that by analogy I call the *culturetype.* This information is transmitted to the young of the species, being inseminated through the sensory end organs, by means of which children read the behavior of the adults, and the young then give new birth to this behavior pattern by imitating it. As the ethologists have made clear in the past few decades, such "cultural" transmission of information by neurological insemination or learning from the behavior of parents, siblings, and peers is much more widespread in lower animals than we had thought a half century ago. But, in man, the amount of information transmitted by the culturetype has advanced to far higher levels of importance by means of linguistic symbol systems which provide models of significant elements of the organic self and of the world, and which serve as means of transmitting a culturetype that can be highly complex and undergo very rapid evolution or change.[6] Modern science is a very special and powerful mechanism for a more rapid evolution of language by means of systematic programs of imaginative hypothesis creation and testing.[7]

With this double heritage of information to structure his purposes or goals and his behavior, man becomes a truly remarkable mechanism of values. I am using the term "values" as equivalent to behavioral goals or purposes. His genetic heritage of purposes, goals, and values is more than a billion years old. His cultural heritage of values, which is built upon and closely integrated with the genetic, is more than a million years old. The various disciplines of behavioral science are providing ever more details on how man's structures, purposes, and related behavior are a mechanism, or a complex system of mechanisms, whose boundary conditions set the norms or goals of men as individuals and the values of integrated societies of individuals. Moreover, various areas of science are increasingly providing a new myth or picture of the creation of this purposive creature in terms of natural selections operating over some billions of years to eliminate the nonstable or nonviable patterns and to build ever higher levels of improbable order from hydrogen to *Homo.*[8]

Values Specified by Selected Information

Certain general principles concerning the nature and the values or purposes of living systems—principles that embrace the higher cultural as well as the earlier biological and genetic stages or levels of evolution—have been developed. All stages require the accumulation of a carefully selected body of information that programs the design or pattern. Polanyi has expressed it in the following:

> For, just as the information contained in a printed page is conveyed in a distinctive arrangement of letters which is not due to any physical interaction between the letters, so the information content of a DNA molecule inheres in an ordering of its constituents which is not due to any physical interaction between them. It is a boundary condition, and as such, it is extraneous to the chemical forces composing the molecule, just as if their pattern were artificial, as that of a machine is.[9]

Herbert Simon has written *The Sciences of the Artificial*,[10] in which he distinguished "artificial" from "natural" science. Artificial objects and phenomena are those which are designed for a purpose or goal; and, in their having a purpose or goal, they are equivalent to Polanyi's man-made machines. Simon's sciences of the artificial are the sciences of design. The various professions of music, architecture, medicine, and engineering are concerned with the processes of design. Behavior that is adapted to achieve goals is artificial behavior, as contrasted with natural phenomena.[11] Since, in men and all living structures, goals are built in by means of such boundary conditions as DNA and cultural information that provide the remembered information defining the boundary conditions or norms for viable systems of complex organizations that can adapt and evolve, the resulting behavior of men and living creatures is artificial, that is, designed and purposive.

But Simon, in this book, is not as concerned with the more routine execution of goals, through already established programs of automatically executed response to homeostatic controls, as he is in the "phylogenetic" search, the search for new adaptations and even new goals. He advocates that there is already beginning, through work with computer design and computer simulation of creative thought processes, some clarification of a science of the artificial, a science of design or synthesis.

Three Levels of Machinery Involved in Selecting Human Values

In the science of design of novel and hitherto nonexistent adaptations of living systems to the total circumstances of the environment on which they are dependent, one finds a common principle in each of three different levels of mechanisms of learning and remembering new designs for living. The three levels of mechanisms of learning that are evolving together in the case of *Homo sapiens* are: (1) the *genotype* or DNA code, which is an encyclopedia of information (on how to build an organism) that has been revised, edited, and preserved through numerous editions by a tough editor for about a billion years; (2) the *culturetype,* which is an encyclopedia of information on a design for life that has been preserved in the memory storage of sets of brains and cultural artifacts, with additions and revisions by the same tough editor over a few million years; and (3) the *brain* of individual man, which is an encyclopedia of information supplied with the edited information of levels 1 and 2, but also with new and unedited information from within and without the organism, and with a mechanism for reading and editing that new information against the background of levels 1 and 2 as well as with a mechanism for applying all that information to novel as well as established designs for living. We shall discuss each of these three levels in reverse order.

In level 3, the *human brain* operates with a relatively recently evolved capacity, provided jointly from levels 1 and 2, to apply its information tentatively in symbolic forms. This allows avoidance of the better than hundred-to-one chance of overt failure to find a viable solution in any random search for a novel adaptation. Level 3 is of special interest, not only because it is the primary place where levels 1 and 2 are integrated, but also because it is really a new level for learning and remembering, a wholly new kind of agency for producing variations on which the reality system or nature can operate to select viable adaptations and reject the unviable. The brain, especially the human brain, is a cybernetic mechanism clearly designed for searching out and testing new patterns of viability in an economical way. It does this by playing a game (like monopoly or chess) where symbolic models represent the self's values and the world. The brain is also, of course, a machine for executing automatically the preprogrammed adaptive repertoire of responses to environmental stimuli.[12]

The creative artist, poet, prophet, engineer, or scientist operate in level 3 to produce novel forms by a kind of imaginative leap, which is different from logical deduction or from automatically preprogrammed response patterns in that a certain amount of "randomness" is operating in the "search strategies," or "scanning," going on either at the conscious or unconscious levels.[13] Within the brain, the search is made by means of operating a game, model, or symbol system of the real world and human values. The model of human values is a model to represent the ultimate actual or real goals or requirements for the fulfillment of the conditions of life, that is, a good design for living. This symbolic model of human values in the brain is largely shaped by genotypic information of what is desirable or undesirable, good or evil. Definitions or criteria for goodness or desirability in food, sex, temperature, etc., are basically structured by the genotype and are sometimes called instinctive. On this base, various modifications, within limits, are made by the brain's learning (conditioning or reinforcement) from experience in the natural and the cultural sectors of the environment.

Within the brain, the search for value fulfillment as well as the search for entirely new values is carried out on a "projection screen" designed in the central nervous system by the DNA or genetic heritage. You might call it an erasable "blackboard" on which the brain tries out a symbolic model devised mostly by means of unconscious mechanisms but increasingly in the recent past by conscious operations. If the first model for proposed action in the world which is tried out on the blackboard does not fulfill the criteria for satisfaction or selection provided by the valuing sector of the brain, then it is quickly erased and another one tried until one that appears satisfactory or good is selected. After this preliminary search in the realm of imagination, in the realm of the symbolic models of the world, a decision is made to try out in action in the outside world at an appropriate time the "blackboard action" found to be the best of all the models tried. If no good model has been found and action is necessary—and this is often the case—then we take a risk; we gamble by trying out in reality a random choice. But if our brain's models of the world and of our values (our models of "the good") are accurate and effective, then we can eliminate a thousand failures in imaginary play and come upon a decision whose execution in the real world will in fact be successful.[14]

In the realm of level 2 of human learning, the *culturetype* or accumulation of wisdom in the culture, the individual creations of poets, philosophers, prophets, statesmen, engineers, scientific discoverers, and other individual discoverers of novel and better-adapted patterns of living (including thinking) are changes in a cultural population analogous to DNA mutations in the genetic population. These cultural mutations may spread rapidly (now sometimes around the world in a second) through a population by a process of selection that operates out of the power of the mutation or novel pattern to satisfy the needs felt by the other members of the population. A second-order selection is later made by a larger selector or judge, which may confirm or overrule and reverse the first judge, the preferences felt by people. The lower court is the imaginary or model world inside people's brains. The higher court is the consequence of action in the real world. This second-order and superior or ultimately determinative stage of selection brings cultural selection into the same court that operates on genetic selection, and, although the machinery is that of the brain rather than that of the double helix of DNA, it is still selection by the nature of the situation and may appropriately be called natural selection.

Here is an example of how the selective process may go. If the population adopts a technical discovery that appeals to it but thereby loses its viability as a population (say, by an atomic holocaust or by the decay of the realism of its models of social-behavior requirements because of the effects of a pleasure-producing drug or habit), the first-order selection by the conscious preferences of the people—the lower-court judge—is then overruled by the higher court of the actual historical consequences of the first selection. In other cases, the higher-court judgment may confirm the lower court of the previously established human preferences. In fact, until recently, at least, since the lower court was appointed by the higher-court—that is, human values or preferences have been largely shaped or tested and approved by genetic selection—the higher court has overwhelmingly confirmed the lower. But failure to achieve a viable adaptation always overrules any mutations or novel behavior patterns, cultural as well as genetic, whether men like them or not, if the novel patterns do not provide an adequate adaptation to the reality of the nature of the situation. The same judgment is also placed upon the already established preferences, regardless of the past success of the gene pool; if they do not provide adequate adaptation under present circumstances, they are eliminated.

If the cultural innovation or mutation is adaptive at both the first and second order of selection, then we see that we have again the same phylogenetic mechanism operating: a search pattern (conscious or unconscious, rationally planned or random). This can be expressed in other words as a variability in a population on which natural selection in a hierarchy of courts can operate to establish a "fit," "adapted," or "metastable" pattern which the nature of the circumstances or natural selection permits.

In level 1 of *Homo's* ways of learning or evolving, *the genotype,* we find the same mechanism of a search for adaptation by means of the production of variations in the patterns of the DNA code of inherited information, by means of "random errors" in replication, and by semirandom sexual recombinations, some of which are selected according to their success in informing viable patterns of life. But here the mechanism is in the primitive form of slow and costly, seemingly random trials, most of which are failures. Certain species and subspecies of *Homo* have been eliminated by failure of the DNA patterns to provide adaptation to their environment. But in the case of *Homo,* the "inadequacy" of the genotype or genetic inheritance is no longer the sole, and perhaps not even the primary, source of failure to adapt. It is well known today that the traits or characteristics of an organism are products of an interaction between a genotype and an environment; and, in the human case, the environment may be dominated in some aspects by that new body of inherited information which we call the culturetype. If the environment or its culturally shaped aspects can be varied suitably, identical genotypes can be made to produce very different phenotypes, that is, different patterns of structure and behavior; or, different genotypes may be constrained by suitable cultural boundary conditions to yield equivalent phenotypes. In *Homo sapiens,* the most marked changes produced by varying culturetypes are in the behavioral repertoires.

Different types of culture do produce correspondingly different or variant linguistic, technological, and other behavior patterns in separate populations which have essentially equivalent gene pools. One culture may induce a well-adapted or viable society which would be selected because of its success in its ecological niche, while another culture induces a poorly adapted society, which would fail to survive in that same or a similar niche. The unadaptive culture in some cases brings about the physical and genetic death of its population, such as by starvation or disease. Thus, the success or failure of level 1 in the human case depends on the success or failure of levels 2 and 3. Another way of saying this is that, the larger or more significant the input from a cultural heritage, the less dependent is man on the "fitness" of his genetic heritage.

An example is the viability of a population which would naturally be subject to certain diseases or other disabilities that previously did characterize a certain genotypic pattern in a certain natural habitat; but the population is made immune to the disabilities by the cultural heritage of its medical practice which provides a suitable inoculation. The disability might be the inadequacy of man's physiology to stand the cold as compared with that of polar bears—a disability which was overcome by such technologies of clothing, housing, and fire, as was developed in Eskimo culture.

Conclusion on Selecting Values

By whatever methods or machinery of learning or adapting to reality that he may take, *Homo sapiens* now has quite clear information that the highest court of judgment of selection or rejection is the larger ecosystem of which he is a part. This court operates unceasingly[15] to select or reject either the long-established or the novel information in his brain, which is the locus where the several sources of information—genotype, culturetype, and current pictures of the self's values and the world—are integrated and create decisions and action in the real world.

The Machinery of Human Values—Individual and Social

We have described the machinery for the generation, selection, and embodiment of man and his values, and we find his values (his purposes or goals) to be embodied in the information or boundary conditions structured in his machinery. Like the 98.6 degree norm for man's body temperature, to maintain which the negative feedback cybernetic systems continually strive, the whole complex, integrated, hierarchical network of purposes or goals that shape our structure and behavior reveals our values as structured by machinery. That is to say that the language of the sciences can give an account of human values, as well as of the world, in terms of mechanisms, mechanisms that can be described and demonstrated in the general system of physical concepts and methods of verification. There is no doubt but that we can speak of human values in other languages or conceptual schemes, where the words "machine" or "mechanism" might appear out of place even as a metaphor. But, for the present, I wish to continue to explore human values within the physical language of mechanism and machinery.

A comforting note for those of us who are worrying about the difficulties of man's increasing confrontation with complex machines may be simply to reflect on how a man feels about encountering a machine so complex as another man, or a woman, a machine so full of potentials of value and disvalue to him. Even the computer networks today do not compare in complexity with the machinery we talk with at a luncheon table or on a subway platform, or at home in the playpen.

It is also important to note that, at the moment, our greatest fear is that this human machinery will fail us, rather than that the stupid but faithful machines driven by fossil fuel will fail us. Today, as for a thousand years past, it is the failures of his human companions that give man his chief worries. While new technology has armed our human enemies, the problem is, as it was a thousand years ago, not their arms, but that they are our enemies. While the malevolent or stupid and ecologically disruptive uses our enemies or friends may make of the new technology may be disruptive to our privacy, peace, health, and welfare, it is not the technology that can be blamed but the malevolence of our enemies or stupidity of our friends. At the present moment of technological development, man's greatest fear continues to be man. But in a moment we shall look at the implications of a machine potentially more complex than man and see whether we have something to fear.

We have noted that the machinery of human values comes to a focus in the human brain where a dynamic hierarchy of evolving negative-feedback cybernetic mechanisms generate the purposes and programs of human behavior as it interacts with information from the environment. We have also noted that in part this brain—this homeostat where the norms of human values reside and by means of whose cybernetic machinery we move our bodily machinery to fulfill them—is also the creation of man insofar as the input of the information stored in the culture is man-made. Thus, long before the twentieth century, we can say that man has been engaged in building a machine for generating and remembering human values. We will have to admit that most of it was done without man's fully realizing what he was doing, just as most men have little idea of the chemical operations in which they are engaged when they eat and convert the food particles into the vast and complex machinery of the body which operates with a wisdom that far exceeds that of our conscious minds. We have also said a bit about how our semiconscious and often-random contributions to build a culture are judged or selected.

The Man-made Machine That Can Evaluate and Act

But in the twentieth century we have rapidly advanced the development of a new kind of machine by which we can get assistance for some of the tasks that are a bit tedious for our brains: machines for calculating, computing, or cogitating. This new kind of computing machine is not merely an opportunistic reformation of some minor patterns of human culture to reform or improve the functioning of human brains, but a brand-new kind of machine wrought out of electronic circuits and valves and energized by electricity—quite other substances than the human brain's mix of nucleic and amino acids, energized by a slow process of oxidation of carbon. Yet the computers are machines that can carry on functions similar to those of brains, such as to draw logical conclusions, understand and translate languages, play games, solve problems, make decisions, operate factories, fly airplanes, reprogram themselves, etc. What is more, our theories tell us it is possible for computer machinery to provide for self-repair and maintenance, self-replication, and the capacity to evolve[16] much more rapidly than have our brains.

Theoreticians concerned with computers and cybernetic mechanisms at the Massachusetts Institute of Technology back in the 1940s recognized that this machinery was performing functions analogous to those of the brain, and there began an interesting analysis of the nature of the brain in terms of the new man-made homeostats, and vice versa.[17]

By the 1950s computers had become a booming engineering and scientific business that soon spread from applications to military and government problems to use throughout the world's economy. The humor of a time reflects some of man's underlying hopes and fears, and I recall a story that was going around MIT in the 1950s that went something like this:

The computer people wanted to solve a complex problem too difficult for the fairly limited store of information and capacity of any single computer to calculate logical conclusions. So the computer engineers hitched together a whole population of the world's computers. And, according to an ancient tradition, they called in a clergyman to celebrate the new hookup in this history-making program. After the clergyman had given his blessing, the head engineer turned graciously to the clergyman and said, "Why don't you ask the new combination of computers the first question?" The clergyman hesitated a moment and then asked, "Is there a God?" The computer network did not give any answer for some moments, and the engineers began to wonder if there might be some failure in making connections; but after the unexpected pause the computer network came back with the ominous answer, "Yes, there is now."

The computers have been feared and ridiculed as their impact on our lives has been increasing. Many have feared the uncanny memories of computer data banks which could be used to reveal our personal histories to people from whom we would hide them. Many have feared the narrow literalism of the "computer mind" and its stupid messing up of the larger dimensions of man's spiritual and artistic life. Many have tried to allay our fear of the computer by saying that all it can do is what it is programmed to do, to which Marvin Minsky has been known to respond that, according to some psychologists, this is all that a man can do.

Alfvén's Tale of the Computer

The motion picture and novel *2001: A Space Odyssey*[18] featured a computer named Hal, and the drama represented a lot of the hopes and fears people have about computers. But perhaps one of the best and most reliable dramatic interpretations of the hopes and fears about the computer is that written by Hannes Alfvén, who has since received the Nobel Prize for his work in physics rather than for his *The Tale of the Big Computer: A Vision,* written under a pseudonym.[19] His drama is a history written by a computer. It is a tale written some years hence about the history of the earth and the origin of the computer age.

I shall excerpt some elements of Alfvén's tale. It begins:

> It was in the very distant past that the first computer appeared, and with it dawned a new era. . . . Despite one appalling disaster, this period of history is dominated by a fantastic evolution which transformed the primitive pre-computer communities and welded them into the perfectly integrated and organized society of today.
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> Compared with the data-processing systems of our own day, the original devices were very elementary. Their development is to some extent comparable to biological evolution from the simplest living organism to man. . . . Social evolution as a whole followed guidelines classed as optimal by the computers, and people began to follow the advice and instructions—we may even venture to say commands—of data-processing machines in an increasing number of fields. . . .
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> Computers . . . eased the wearisome and exacting work of the intellect; in the end they relieved mankind of the burden of thought itself.
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> The more useful computers proved to be, the greater their numbers. . . . Generation after generation they grew and matured, assuming an ever more dominant position in the evolution of society. . . .
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> The era introduced by the advent of the earliest data machine is sometimes called the computer age, but this term is more appropriate to the period now about to begin. The characteristic feature of the time extending from the first computer to our own day is not complete domination by data machines, but rather a fruitful cooperation—a symbiosis—between man and computer. It is this symbiosis which on the one hand has enriched human existence and on the other has enabled computers to evolve and become more numerous.[20]

Alfvén's tale then goes on to give an account of the larger history of the earth, and the computer historian who writes the tale says:

Our poets, especially those commonly called mystics, tend to regard the period immediately succeeding the formation of the Earth as a mighty effort on the part of nature to engender computers directly, without the help of any intermediary. They are alluding to the geological processes which crystalized out many of the substances of which a data machine consists. But the task of bringing forth computers from sterile soil proved too difficult. The tectonic forces which created mountains and differentiated minerals could not produce anything as subtle and complex as a computer. For this a lengthy, troublesome detour was required, and the greatest of all tasks had to be completed step by step.

Nature then started upon a simpler project which could be carried out by the means then available. Such is the explanation of the origin of life. . . . Life, which evolved into ever more complex structures, was nature's substitute for directly bred computers. . . .

When we study the beginnings of biological evolution, its purpose seems to us obscure. How can one regard a tiny blob of protoplasm—an amoeba, for instance—as a first step toward computers? But if we follow the evolutionary process further we come upon certain clues, . . . At quite an early stage we detect the formation of a nervous system.[21]

In the section on the triumph of mammals over the giant reptilian forms like dinosaurs, the computer historian points out:

But the mammals had one great advantage: their nervous system reacted more swiftly than that of the giants, and they were what used to be called more intelligent. In modern terms we should say that the rudimentary computer represented by their nervous system was more efficient: that is, being closer to true computers, mammals were superior beings, and so won the battle for survival.[22]

In the section on "The Origin of Man" the computer historian writes:

Yet we must regard the arrival of man as one of the truly important events in history, for it was through him alone that computers could come into existence. . . .

Human qualities . . . derive from a well-developed nervous system. Indeed it can be said that a man's brain represents a relatively serviceable computer, . . .[23]

The tale presents a weakness in man that may explain why man lost out to the computer:

. . . *the problem of organizing society is so highly complex as to be insoluble by the human brain, or even by many brains working in collaboration.* It is this conclusion which is known as the Sociological Complexity Theorem. The mathematically cogent proof of this theorem is one of the finest scientific achievements of the early symbiotic age.

We now know with certainty, therefore, that no stable society could possibly have been built in the pre-computer age. Idealists and social reformers were trying to solve a problem which by its very nature was insoluble.[24]

In his account of the origin of the computer, Alfvén states:

> Scientists and engineers worked hard, with a gleam in their eyes; they knew that the little gadget in front of them was something exceptional—but did they foresee the new era that was opening before them, or suspect that what had happened was comparable with the origin of life on earth?[25]

It is true that even many of the computer "experts" have not suspected this. But some of them, and others who understood the nature of life and were following computer developments from the sidelines, I know, had some glimmering that this was comparable to the origin of life on earth. Alfvén is one who thus understands it, and he goes on in the tale to tell the story of the symbiotic era of interdependence between man and computer and the evolutionary emergence of computers as the dominant form of life in the Computer Age, where the computers have surpassed men in all the significant values and activities of life, and man is a pet kept for sentimental reasons. The historian summarizes events at the end of the Symbiotic Age:

> As regards performance, data machines are now superior to men in practically every sphere. We have also had a horrific experience of men's incompetence as organizers, and since the bureaucratic catastrophe it has been an axiom that all vital community functions must be performed by data machines without human intervention. It is essential to avoid disruption brought about by morally defective people. . . .
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> In some ways it may be thought unfortunate that the human brain did not evolve further during the time when computers were making so striking an advance. Many new discoveries made in neurophysiological studies of the brain have inspired improvements in computers, but the reverse process is less marked. . . .
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> Despite all the dramatic events of the symbiotic age, evolution on the whole has moved steadily in one direction. While data machines have developed enormously, man has not. Biologically speaking, a human being of today differs little from one living at the start of the computer era; man has been overtaken and outstripped in almost every field. Of special importance is the fact that data machines are now independent of mankind. Maintenance work for which men were once needed is now completely computer-controlled. Computers can also reproduce their own kind. . . . Computers have matured; they are now capable of building a society and supporting a civilization without human beings.[26]

The new Age of Computers has dawned, and Alfvén is only one of those competent to see that man may currently and inexorably be involved in creating and nourishing a new species, a new creature which might replace him, just as men are the successors of anthropoids, mammals, vertebrates, worms, and amoebae as the "highest," most completely evolved form of life on earth. Moreover, the new computer brains that are evolving are of a radically new order not hitherto known on earth. They are much more different from men than men are from other biological species.

Potential parents of a saint or a hero would supposedly rejoice in such an event. But the literature of today shows more regret than rejoicing over the possible coming age of the computer, even among computer experts. The equivalent of the legendary "Man from Mars" and of the largely imaginary fears of Unidentified Flying Objects has come upon us as an existential reality from a surprising direction, the computer made by our own heads and hands instead of imaginary beings from a distant planet. The computer's rapid evolutionary capacities could potentially make the computer move ahead of us within a few decades,[27] rather than take the customary thousands or millions of years for superior species to develop or the billion or more years for biological life and man to arise from the cumulated selections nature has been making on the potential combinations and permutations of amino and nucleic acids.

I suggest that the greatest technological impact on man today—exceeding by far the potentials of any other technology—is the coming Age of the Computer. Some of us can see its dawning events already.[28] But what will our reactions be when we find that all that we have lived for, all that we have striven for and sought to accomplish, all our purposes and goals—intellectual, moral and spiritual, as well as material—can be accomplished much more rapidly and successfully by such a successor living system as nonbiological computers? For me this is not any more a fiction for science than was the rocket power to fly to the moon which I heard Robert Goddard explain in the 1930s and about which I heard his colleagues snicker. For me it is no more fictitious or remote than was the potentiality of nonexplosive atomic power, which in 1948 I heard some of our atomic experts deny was possible. The sciences have fostered a world of miracles, and a modicum of scientific understanding of the nature of things (including life, brains, and human culture) enables one to see ahead to some of the important potentialities the future holds for man.

On Human Destiny, Meaning, and Morale

The religions and related human institutions for portraying the meaning of human destiny and for building morale and morals will, in particular, be faced with these problems of what is man's meaning if all that he can do on earth will be better done by his child, the computer. If men come to feel that their own purposes and values are eroded by their being replaced by a new order of life which they barely comprehend and which leaves them as if they were worms to be ground under the feet of their superior successors, as we men now may happen from time to time to step upon a worm without any twinge of conscience, what will generate in man the necessary feelings of dignity and worth? The stories of the Judeo-Christian book of Genesis or of recent science—that man has been created the top of the heap in the cosmos, certainly in the world—will have no more credibility as in the age of symbiosis with computers more and more men come to recognize that the computer is outthinking them and is also evolving faster. We have one problem if we envision the coming age of the computer as one in which men will be dominated by a powerful invading enemy who kicks us around and eventually kicks us out.

Another problem of human morale derives from the supposition that the symbiotic computer will be friendly and supportive to man, and this would seem to be more likely than that the computer whose initial programming is by man would be hostile. A common answer to the problem of man when someone tells him that his work will be taken away and he will have to live a life of leisure is not to be scared, but to say with eagerness that he will prefer to go fishing, to watch the sport spectacles, or just to eat, drink, and be merry in the midst of the affluent leisure that the age of cybernetic computers promises.

But this would be to be unscientific about the nature of human nature and also contrary to much traditional religious wisdom. Man as a living system is a purposeful machine; he has goals or values. His whole cybernetic hierarchy is built up around an integrated set of goals. His hopes and his fears are the green lights and the red lights that natural selection and cultural conditioning have built into him in a way that is adapted to an environment of scarcity and struggle. In fact, we now understand living systems, including our own, to be by nature the perpetual struggle for maintaining a complex order or organization in the midst of a disruptive, entropic environment. To cease the struggle is not to live, but to become an inert, crystalized order of much lower level. Man's desire for leisure is therefore naturally short-lived, and turns to wormwood and gall when he has much of it. The depression and hopelessness today of many of the affluent youth are only one evidence of how difficult is a life of leisure and of the ready gratification of most of the drive or motivational system which has evolved to adapt organisms to a very different and difficult world. When a machine such as a man or a computer has its purpose or goals, for which it is built to seek to accomplish, taken away from it, it is essentially dead; it has lost its function or soul; indeed, this is another way of saying our human values would be lost if we allowed the computer to wine and dine and completely take care of us.

A note on the matter of human satisfaction or fulfillment and its relation to pleasure and pain, to hope and fear: most descriptions of heaven fail to move us, while most descriptions of hell or frustration and pain are fearful indeed. This is perhaps because of a common error in many religious interpretations that portray heaven as leisure and the abandonment of struggle rather than as the hope and promise of victory, triumph, and meaning in the struggle. The natural history and negative-feedback analysis of pleasure and pain mechanisms in the evolution of living systems are instructive. From my reading of the dynamic homeostatic mechanisms of the brain, I get the following picture.[29] In general, the red lights—or the neural signals that are registered as avoidance signals in awareness (or consciousness)—are correlated with situations that are threats or actual strains and stresses leading to the disruption of the rather straight and narrow requirements of boundary conditions if life is to be maintained. The red lights or fears turn on the negative-feedback machinery to set things right. The lights—or signals that are registered in awareness as desirable, pleasurable, delightful, or good—are negative-feedback signals that tell the organism the direction in which relief from the stress is to be found, or that report that actual operations are in fact reducing the degree of strain and stress. When the strain and stress are gone, there is no signal, no emotion, no pleasure—not even any hope, since hope is by its nature the vision or expectation of an alternative path into the future which overcomes the various hazards that abound to threaten life's defeat.

Hence, as a living system in which all tasks of avoiding the dangers of its own disorganization are overcome to the extent that the computers do our work of creating life, to that extent the computers become the creative struggle to dynamic homeostasis that is life, and men become fossils, breathing for a while as our significant and creative role declines.

The threat to human values posed by the Age of the Computer is the most threatening and devastating posed by man-made machines. There is no possible escape if we suppose that our human values as they now exist are necessarily sacred. Willy-nilly, in a million years, even without man-made machines or computers, *Homo sapiens* will not be flourishing as we know him. The top ecological niche—the "highest" form of life on earth—is a niche that itself evolves too rapidly for man's nature, including the values or information that guide its development and behavior, to remain fixed for long. Regressing culturally is probably impossible, because without a culture man's genotype is no longer viable. Some viable culturetype has become essential for *Homo,* the first of the biological species on earth to reach this state. Moreover, if the potentialities of the nonbiological memories, structures, and behaviors of computerized cybernetic systems are as capable as they seem to some of us for evolving more rapidly and becoming as completely independent of us as the possible synthesis of food now allows us to envision ourselves becoming independent of plant life, then we can suppose that our demise as the forefront of life on earth may come in a matter of 10^n years, where n is not 7 or 6 but only perhaps 3 or 2 and conceivably, even if not likely, less.

Some anthropologists have observed and analyzed the breakup of primitive human cultures when more advanced ones became dominant in their territories, such as the American Indian societies or some of the East Indian societies.[30] These culture-killing encounters in the past have been difficult enough to overcome. It is difficult enough to adapt a culture fast enough to prevent its complete disruption, and in some cases to prevent the pretty widespread or even total elimination from the face of the earth of the genetic strain that harbored it. But the Age of the Computer poses a far worse threat, one to which we cannot adapt simply by learning, and probably not by genetic engineering when that technology arrives. Suppose that it is much easier and faster for computers to learn and adapt than for man. Let us suppose that this picture of man's future is true. It seems much more certain or more likely to take place than many other possible fates, such as invasion by space men. What then is our future?

The same anthropologists and other scientists have observed something of the non-self-centered "wisdom of the culture" that has been built into some cultures as a religious view of human destiny and meaning in the world. As long as they remain credible, these long-tested and selected religious beliefs are able to keep up the morale and moral behavior of a society.[31] It is my suggestion that a modification of the general solution provided by religion, a modification that integrates the best scientific concepts into the general form of the religious solution of man's meaning and hope in a disordering environment that implies certain death, will be the best medicine for our morale and morals as we enter the Age of Man-Computer Symbiosis. As a matter of fact, it will probably be necessary if we are to cope with all the other problems of man-machine interaction.

I suggest that both the present pictures of the sciences as well as some of the traditional wisdom of the Judeo-Christian culture in which modern science gestated both tell the same thing: that man did not make himself, did not set his values, and that he is damned if he does not first serve the one ultimate reality that determines all destiny. That is the red light or hellfire side of the picture. Perhaps one could give it a more positive and heavenly hopefulness if one said that insofar as man serves the requirements of the transcendent reality which determines his destiny, that is, adapts to the conditions it presents, he will by that act be immortally significant, just as the mutations of past genotypes have been immortally significant, in their failures as well as in their successes, in providing the lines that continue to guide the metastable evolving patterns of life that achieve ever more complex ecological niches in the course of time, in spite of the disordering pressures in the physical forces of the dissipative flow of which they are a part. As I hinted earlier, and as Alfvén suggested, man's immortal virtue may lie in his role in making possible the computer, just as we might honor the virtue of the monkey, the mammal, the vertebrate, the worm, or the primitive cell, who in the current creation myth are as much our ancestors as our nearby parents. And, as for the mutations that failed, we can contemplate Alfred Romer's recent address to the American Association for the Advancement of Science, where he pointed out our mammalian indebtedness to the extinct dinosaurs and other cold-blooded vertebrates.[32]

Conclusion

I want to emphasize something that Polanyi, Simon, and Alfvén did not, and that is that man is a machine that was in fact made but not by man. Man is, in this sense, a machine that is, indeed, an artifact. I put the question: Who is my maker? What ultimately shapes the boundary conditions that shape life at all levels? This is a question to which science can help our culture return. The earlier vision of the significant reality that is sovereign over all creation is now nearly lost to us because of a mistaken semantics. Because the term "God" had had primitive semantic associations in some subcultures, people emerging from those subcultures to a culture where those primitive semantic associations are taboo suppose that the term is taboo. Such shallow semantics is as nonsensical as if the physicists who split the atom felt forced to drop the term "atom" because it is the Greek term for "unsplittable." If there is, indeed, a discernible reality that created man and whose selection continues to operate sovereignly, no matter how much or how little man comes to know it and understand it and adapt to it, then there is no reason why we should not call it by the same name that our less scientifically cultured ancestors used, just as we continue to use atom even though we have split it.

But the name is not important. What is important is that the only solution to human values in encounters with machines, including with man himself as well as his culturally artifacted machines, or with the vaster machinery of the ultimate ecosystem of future life, is that man not lose the values or goals that enable his present life—which are a heritage of a million years or more for his culture-type and of a billion years or more for his genotype—and that he continue with conviction and courage the search for better patterns for the future in suitable mutations or changes that explore better adaptations, always at the risk of failure. This is the nature of living systems, and to behave otherwise is to become lifeless.

Our ultimate human values—our concerns, fears and hopes—have to be where the ultimate power is. We have to look to the ultimate power that sets the ultimate boundary conditions for life at all levels in the cosmos. We fail if we focus upon our altogether too finite values that tend too easily to the status quo of our private and transient selves. The solution of our problems is a broader view of the total machinery of the cosmos and of life systems in it. We shall be ruined, if we get lost in the details of certain subsidiary mechanisms, such as machinery to satisfy our minor needs. The virtue and character of humanity is that each brain through genotype and sometimes through culturetype in some degree embodies or incarnates the larger essence, spirit, or program of the total human society and the more everlasting inclusive goals operating in the evolving life systems of this world.

The primary danger to man in his encounter with other machinery of any kind—biological, cultural, ordinary human technology, or potentially superhuman computers of the future—is this danger of too narrow a perspective on his immediate rather than his eternal wants. There is no equivalently great danger to man in the world of machinery—be that machinery in the form of viruses, lions, or atomic bombs—than the failure of the machinery in man's head to see the larger, more cosmic perspectives of the machinery of human values. To overcome this danger may require some rather urgent reformation of our cultural machinery of religion and of the related arts (artifacts, machinery) of human culture that inseminate men with their visions of larger hope and meaning.

NOTES

1. C. P. Snow, *The Two Cultures and the Scientific Revolution* (New York: Cambridge University Press, 1964).
2. Gerald Holton, Michael Polanyi, Ernest Nagel, John R. Platt, and Barry Commoner, "Do Life Processes Transcend Physics and Chemistry?" (symposium) *Zygon* 3 (1968): 445-46.
3. Ibid., p. 444.
4. Ibid., 446.
5. Walter B. Cannon, *The Wisdom of the Body* (New York: W. W. Norton & Co., 1932).
6. Ralph Wendell Burhoe and Hudson Hoagland, eds., *Evolution and Man's Progress* (New York: Columbia University Press, 1962).
7. Richard von Mises, *Positivism: A Study in Human Understanding* (Cambridge, Mass.: Harvard University Press, 1951).
8. See Harlow Shapley, *Of Stars and Men* (Boston: Beacon Press, 1958); J. Bronowski, "New Concepts in the Evolution of Complexity: Stratified Stability and Unbounded Plans," *Zygon* 5 (1970): 18-35; and Ralph Wendell Burhoe, "Five Steps in the Evolution of Man's Knowledge of Good and Evil," *Zygon* 2 (1967): 77-96.
9. Polanyi (n. 2 above), pp. 446-47.
10. Herbert A. Simon, *The Sciences of the Artificial* (Cambridge, Mass.: M.I.T. Press, 1969).
11. Ibid., p. 52.
12. I was first introduced into the fascinating similarities of cybernetic and computer mechanisms to the operations of the central nervous system by contact with a group centered at the Massachusetts Institute of Technology in the late 1940s. Among them were Norbert Wiener and Warren McCulloch. There is now a large literature. Simon's book (n. 10 above) is one. An early classic is W. Ross Ashby's *Design for a Brain: The Origin of Adaptive Behavior* (New York: John Wiley & Sons, 1952; 2d ed., 1960). Another is J. Z. Young's *A Model of the Brain* (London: Oxford University Press, 1964), especially the chapters on "The Brain as the Computer of a Homeostat" and on "Models in the Brain." Another is W. Grey Walter's *The Living Brain* (New York: W. W. Norton & Co., 1963).
13. Cf., for instance, pp. 27-31 in Simon (n. 10 above).
14. See Young (n. 12 above), "Some Requirements of an Exploratory Computer," chap. 12.
15. This was eloquently expressed by Darwin in his *The Origin of Species* (1859). See also Ralph Wendell Burhoe, "Natural Selection and God" (*Zygon* 7 [1972]: 30-63), where the Darwin Statement is quoted on p. 62.
16. Gerald Weinberg's "Natural Selection as Applied to Computers and Programs" (*General Systems* 15 [1970]: 145-50) contains an interesting story concerning the problems natural selection brings to computer programmers.
17. See n. 12 above.
18. *2001: A Space Odyssey*, a film (released by MGM in 1968) produced and directed by Stanley Kubrick, with screenplay by Stanley Kubrick and Arthur C. Clarke based

on a short story by Arthur C. Clarke. In the same year *2001: A Space Odyssey* (New York: New American Library, Signet Book, 1968), by Arthur C. Clarke, appeared; this was a novel based on the screenplay, accompanied by interpretative notes.

19. H. Alfvén [Olof Johannesson], *The Tale of the Big Computer: A Vision* (New York: Coward-McCann, Inc., 1968). Subsequent quotations by permission of Coward, McCann & Geoghegan, Inc., Publishers. © 1968 by Victor Gollancz, Ltd.

20. Ibid., pp. 7-9.

21. Ibid., pp. 11-12.

22. Ibid., pp. 13-14.

23. Ibid., pp. 14-15.

24. Ibid., pp. 19-20.

25. Ibid., p. 24.

26. Ibid., pp. 114-15, 118-20.

27. See Simon (n. 10 above).

28. Merely the name of a laboratory in one of our great universities is enough commentary here: "M.I.T. Artificial Intelligence Laboratory."

29. Alfred E. Emerson, "Dynamic Homeostasis: A Unifying Principle in Organic, Social, and Ethical Evolution, *Zygon* 3 (1968): 129-68. See also n. 12 above.

30. E.g., Anthony F. C. Wallace, *Religion: An Anthropological View* (New York: Random House, 1966); Ward H. Goodenough, "Human Purpose in Life," *Zygon* 1 (1966): 217-29.

31. Donald T. Campbell, "Variation and Selective Retention in Socio-Cultural Evolution," *General Systems* 14 (1969): 69-85.

32. Alfred Sherwood Romer, "Major Steps in Vertebrate Evolution," *Science* 158 (1967): 1627-37.