THE HUMAN USE OF HUMAN BEINGS

CYBERNETICS AND SOCIETY

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NORBERT WIENER (1894-1964) was educated at Tufts College and Harvard University. where he received his Ph.D. at the age of nineteen, and continued his studies at Cornell, Columbia, Cambridge (England), Göttingen, and Copenhagen. He taught at Harvard and the University of Maine, and in 1919 joined the staff of the Massachusetts Institute of Technology, where he was Professor of Mathematics for forty years. Named Institute Professor Emeritus in 1959, he continued to lecture and write until his death five years later. He was joint recipient of the Bocher Prize of the American Mathematical Society in 1933, and in 1936 was one of the seven American delegates to the International Congress of Mathematicians in Oslo, Norway. Dr. Wiener served as Research Professor of Mathematics at the National Tsing Hua University in Peking, China in 1935-36 while on leave from M.I.T. During World War II he developed improvements in radar and Navy projectiles and devised a method of solving problems of fire control. His published works include *The Fourier Integral and Certain of Its Applications* (1933), *Cybernetics* (1948), *Extrapolation and Interpolation and Smoothing of Stationary Time Series with Engineering Applications* (1949), and the two-volume autobiography, *Ex-Prodigy: My Childhood and Youth* (1953) and *I Am a Mathematician* (1956). Among his last works was a novel, *The Temper* (1959), as well as *Nonlinear Problems in Random Theory* (1958). In 1963 Dr. Wiener received the National Medal of Science, and in 1964 he published his last book, *God and Golem*, which won the National Book Award in 1965.

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To the memory of my father
LEO WIENER
formerly Professor of Slavic languages
at Harvard University
my closest mentor and dearest antagonist

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PREFACE

THE IDEA OF A CONTINGENT UNIVERSE

The beginning of the twentieth century marked more than the end of one hundred-year period and the start of another. There was a real change of point of view even before we made the political transition from the century on the whole dominated by peace, to the half century of war through which we have just been living. This was perhaps first apparent in science, although it is quite possible that whatever has affected science led independently to the marked break which we find between the arts and literature of the nineteenth and those of the twentieth centuries.

Newtonian physics, which had ruled from the end of the seventeenth century to the end of the nineteenth with scarcely an opposing voice, described a universe in which everything happened precisely according to law, a compact, tightly organized universe in which the whole future depends strictly upon the whole past. Such a picture can never be either fully justified or fully rejected experimentally and belongs in large measure to a conception of the world which is supplementary to experiment but in some ways more universal than anything that can be experimentally verified. We can never test by our imperfect experiments whether one set of physical laws or another can be verified down to the last decimal. The Newtonian view, however, was compelled to state and formulate physics as if it were, in fact, subject to such laws. This is now no longer the dominating attitude of physics, and the men who contributed most to its downfall were Bolzmann in Germany and Gibbs in the United States.

These two physicists undertook a radical application of an exciting, new idea. Perhaps the use of statistics in physics which, in large measure, they introduced was not completely new, for Maxwell and others had considered worlds of very large numbers of particles which necessarily had to be treated statistically. But what Bolzmann and Gibbs did was to introduce statistics into physics in a much more thoroughgoing way, so that the statistical approach was valid not merely for systems of enormous complexity, but even for systems as simple as the single particle in a field of force.

Statistics is the science of distribution, and the distribution contemplated by these modern scientists was not concerned with large numbers of similar particles, but with the various positions and velocities from which a physical system might start. In other words, under the Newtonian system the same physical laws apply to a variety of systems starting from a variety of positions and with a variety of momenta. The new statisticians put this point of view in a fresh light. They retained indeed the principle according to which certain systems may be distinguished from others by their total energy, but they rejected the supposition according to which systems with the same total energy may be clearly distinguished indefinitely and described forever by fixed causal laws.

There was, actually, an important statistical reservation implicit in Newton's work, though the eighteenth century, which lived by Newton, ignored it. No physical measurements are ever precise; and what we have to say about a machine or other dynamic system really concerns not what we must expect when the initial positions and momenta are given with perfect accuracy (which never occurs), but what we are to expect when they are given with attainable accuracy. This merely means that we know, not the complete initial conditions, but something about their distribution. The functional part of physics, in other words, cannot escape considering uncertainty and the contingency of events. It was the merit of Gibbs to show for the first time a clean-cut scientific method for taking this contingency into consideration.

The historian of science looks in vain for a single line of development. Gibbs' work, while well cut out, was badly sewed, and it remained for others to complete the job that he began. The intuition on which he based his work was that, in general, a physical system belonging to a class of physical systems, which continues to retain its identity as a class, eventually reproduces in almost all cases the distribution which it shows at any given time over the whole class of systems. In other words, under certain circumstances a system runs through all the distributions of position and momentum which are compatible with its energy, if it keeps running long enough.

This last proposition, however, is neither true nor possible in anything but trivial systems. Nevertheless, there is another route leading to the results which Gibbs needed to bolster his hypothesis. The irony of history is that this route was being explored very thoroughly in Paris at exactly the time when Gibbs was working in New Haven; and yet it was not until 1920 that the Paris work met the New Haven work in a fruitful union. I had, I believe, the honor of assisting at the birth of the first child of this union.

Gibbs had to work with theories of measure and probability which were already at least twenty-five years old and were grossly inadequate to his needs. At the same time, however, Borel and Lebesgue in Paris were devising the theory of integration which was to prove apposite to the Gibbsian ideas. Borel was a mathematician who had already made his reputation in the theory of probability and had an excellent physical sense. He did work leading to this theory of measure, but he did not reach the stage in which he could close it into a complete theory. This was done by his pupil Lebesgue, who was a very different sort of person. He had neither the sense of physics nor an interest in it. Nonetheless Lebesgue solved the problem put by Borel, but he regarded the solution of this problem as no more than a tool for Fourier series and other branches of pure mathematics. A quarrel developed between the two men when they both became candidates for admission to the French Academy of Sciences, and only after a great deal of mutual denigration, did they both receive this honor. Borel, however, continued to maintain the importance of Lebesgue's work and his own as a physical tool; but I believe that I myself, in 1920, was the first person to apply the Lebesgue integral to a specific physical problem—that of the Brownian motion.

This occurred long after Gibbs' death, and his work remained for two decades one of those mysteries of science which work even though it seems that they ought not to work. Many men have had intuitions well ahead of their time; and this is not least true in mathematical physics. Gibbs' introduction of probability into physics occurred well before there was an adequate theory of the sort of probability he needed. But for all these gaps it is, I am convinced, Gibbs rather than Einstein or Heisenberg or Planck to whom we must attribute the first great revolution of twentieth century physics.

This revolution has had the effect that physics now no longer claims to deal with what will always happen, but rather with what will happen with an overwhelming probability. At the beginning in Gibbs' own work this contingent attitude was superimposed on a Newtonian base in which the elements whose probability was to be discussed were systems obeying all of the Newtonian laws. Gibbs' theory was essentially new, but the permutations with which it was compatible were the same as those contemplated by Newton. What has happened to physics since is that the rigid Newtonian basis has been discarded or modified, and the Gibbsian contingency now stands in its complete nakedness as the full basis of physics. It is true that the books are not yet quite closed on this issue and that Einstein and, in some of his phases, De Broglie, still contend that a rigid deterministic world is more acceptable than a contingent one; but these great scientists are fighting a rear-guard action against the overwhelming force of a younger generation.

One interesting change that has taken place is that in a probabilistic world we no longer deal with quantities and statements which concern a specific, real universe as a whole but ask instead questions which may find their answers in a large number of similar universes. Thus chance has been admitted, not merely as a mathematical tool for physics, but as part of its warp and weft.

This recognition of an element of incomplete determinism, almost an irrationality in the world, is in a certain way parallel to Freud's admission of a deep irrational component in human conduct and thought. In the present world of political as well as intellectual confusion, there is a natural tendency to class Gibbs, Freud, and the proponents of the modern theory of probability together as representatives of a single tendency; yet I do not wish to press this point. The gap between the Gibbs-Lebesgue way of thinking and Freud's intuitive but somewhat discursive method is too large. Yet in their recognition of a fundamental element of chance in the texture of the universe itself, these men are close to one another and close to the tradition of St. Augustine. For this random element, this organic incompleteness, is one which without too violent a figure of speech we may consider evil; the negative evil which St. Augustine characterizes as incompleteness, rather than the positive malicious evil of the Manichaeans.

This book is devoted to the impact of the Gibbsian point of view on modern life, both through the substantive changes it has made in working science, and through the changes it has made indirectly in our attitude to life in general. Thus the following chapters contain an element of technical description as well as a philosophic component which concerns what we do and how we should react to the new world that confronts us.

I repeat: Gibbs' innovation was to consider not one world, but all the worlds which are possible answers to a limited set of questions concerning our environment. His central notion concerned the extent to which answers that we may give to questions about one set of worlds are probable among a larger set of worlds. Beyond this, Gibbs had a theory that this probability tended naturally to increase as the universe grows older. The measure of this probability is called entropy, and the characteristic tendency of entropy is to increase.

As entropy increases, the universe, and all closed systems in the universe, tend naturally to deteriorate and lose their distinctiveness, to move from the least to the most probable state, from a state of organization and differentiation in which distinctions and forms exist, to a state of chaos and sameness. In Gibbs' universe order is least probable, chaos most probable. But while the universe as a whole, if indeed there is a whole universe, tends to run down, there are local enclaves whose direction seems opposed to that of the universe at large and in which there is a limited and temporary tendency for organization to increase. Life finds its home in some of these enclaves. It is with this point of view at its core that the new science of Cybernetics began its development.[1]

[1] There are those who are skeptical as to the precise identity between entropy and biological disorganization. It will be necessary for me to evaluate these criticisms sooner or later, but for the present I must assume that the differences lie, not in the fundamental nature of these quantities, but in the systems in which they are observed. It is too much to expect a final, clear-cut definition of entropy on which all writers will agree in any less than the closed, isolated system.

I

CYBERNETICS IN HISTORY

Since the end of World War II, I have been working on the many ramifications of the theory of messages. Besides the electrical engineering theory of the transmission of messages, there is a larger field which includes not only the study of language but the study of messages as a means of controlling machinery and society, the development of computing machines and other such automata, certain reflections upon psychology and the nervous system, and a tentative new theory of scientific method. This larger theory of messages is a probabilistic theory, an intrinsic part of the movement that owes its origin to Willard Gibbs and which I have described in the introduction.

Until recently, there was no existing word for this complex of ideas, and in order to embrace the whole field by a single term, I felt constrained to invent one. Hence "Cybernetics," which I derived from the Greek word *kubernētēs*, or "steersman," the same Greek word from which we eventually derive our word "governor." Incidentally, I found later that the word had already been used by Ampere with reference to political science, and had been introduced in another context by a Polish scientist, both uses dating from the earlier part of the nineteenth century.

I wrote a more or less technical book entitled *Cybernetics* which was published in 1948. In response to a certain demand for me to make its ideas acceptable to the lay public, I published the first edition of *The Human Use of Human Beings* in 1950. Since then the subject has grown from a few ideas shared by Drs. Claude Shannon, Warren Weaver, and myself, into an established region of research. Therefore, I take this opportunity occasioned by the reprinting of my book to bring it up to date, and to remove certain defects and inconsequentialities in its original structure.

In giving the definition of Cybernetics in the original book, I classed communication and control together. Why did I do this? When I communicate with another person, I impart a message to him, and when he communicates back with me he returns a related message which contains information primarily accessible to him and not to me. When I control the actions of another person, I communicate a message to him, and although this message is in the imperative mood, the technique of communication does not differ from that of a message of fact. Furthermore, if my control is to be effective I must take cognizance of any messages from him which may indicate that the order is understood and has been obeyed.

It is the thesis of this book that society can only be understood through a study of the messages and the communication facilities which belong to it; and that in the future development of these messages and communication facilities, messages between man and machines, between machines and man, and between machine and machine, are destined to play an ever-increasing part.

When I give an order to a machine, the situation is not essentially different from that which arises when I give an order to a person. In other words, as far as my consciousness goes I am aware of the order that has gone out and of the signal of compliance that has come back. To me, personally, the fact that the signal in its intermediate stages has gone through a machine rather than through a person is irrelevant and does not in any case greatly change my relation to the signal. Thus the theory of control in engineering, whether human or animal or mechanical, is a chapter in the theory of messages.

Naturally there are detailed differences in messages and in problems of control, not only between a living organism and a machine, but within each narrower class of beings. It is the purpose of Cybernetics to develop a language and techniques that will enable us indeed to attack the problem of control and communication in general, but also to find the proper repertory of ideas and techniques to classify their particular manifestations under certain concepts.

The commands through which we exercise our control over our environment are a kind of information which we impart to it. Like any form of information, these commands are subject to disorganization in transit. They generally come through in less coherent fashion and certainly not more coherently than they were sent. In control and communication we are always fighting nature's tendency to degrade the organized and to destroy the meaningful; the tendency, as Gibbs has shown us, for entropy to increase.

Much of this book concerns the limits of communication within and among individuals. Man is immersed in a world which he perceives through his sense organs. Information that he receives is co-ordinated through his brain and nervous system until, after the proper process of storage, collation, and selection, it emerges through effector organs, generally his muscles. These in turn act on the external world, and also react on the central nervous system through receptor organs such as the end organs of kinaesthesia; and the information received by the kinaesthetic organs is combined with his already accumulated store of information to influence future action.

Information is a name for the content of what is exchanged with the outer world as we adjust to it, and make our adjustment felt upon it. The process of receiving and of using information is the process of our adjusting to the contingencies of the outer environment, and of our living effectively within that environment. The needs and the complexity of modern life make greater demands on this process of information than ever before, and our press, our museums, our scientific laboratories, our universities, our libraries and textbooks, are obliged to meet the needs of this process or fail in their purpose. To live effectively is to live with adequate information. Thus, communication and control belong to the essence of man's inner life, even as they belong to his life in society.

The place of the study of communication in the history of science is neither trivial, fortuitous, nor new. Even before Newton such problems were current in physics, especially in the work of Fermat, Huygens, and Leibnitz, each of whom shared an interest in physics whose focus was not mechanics but optics, the communication of visual images.

Fermat furthered the study of optics with his principle of minimization which says that over any sufficiently short part of its course, light follows the path which it takes the least time to traverse. Huygens developed the primitive form of what is now known as "Huygens' Principle" by saying that light spreads from a source by forming around that source something like a small sphere consisting of secondary sources which in turn propagate light just as the primary sources do. Leibnitz, in the meantime, saw the whole world as a collection of beings called "monads" whose activity consisted in the perception of one another on the basis of a pre-established harmony laid down by God, and it is fairly clear that he thought of this interaction largely in optical terms. Apart from this perception, the monads had no "windows," so that in his view all mechanical interaction really becomes nothing more than a subtle consequence of optical interaction.

A preoccupation with optics and with message, which is apparent in this part of Leibnitz's philosophy, runs through its whole texture. It plays a large part in two of his most original ideas: that of the *Characteristica Universalis*, or universal scientific language, and that of the *Calculus Ratiocinator*, or calculus of logic. This Calculus Ratiocinator, imperfect as it was, was the direct ancestor of modern mathematical logic.

Leibnitz, dominated by ideas of communication, is, in more than one way, the intellectual ancestor of the ideas of this book, for he was also interested in machine computation and in automata. My views in this book are very far from being Leibnitzian, but the problems with which I am concerned are most certainly Leibnitzian. Leibnitz's computing machines were only an offshoot of his interest in a computing language, a reasoning calculus which again was in his mind, merely an extention of his idea of a complete artificial language. Thus, even in his computing machine, Leibnitz's preoccupations were mostly linguistic and communicational.

Toward the middle of the last century, the work of Clerk Maxwell and of his precursor, Faraday, had attracted the attention of physicists once more to optics, the science of light, which was now regarded as a form of electricity that could be reduced to the mechanics of a curious, rigid, but invisible medium known as the ether, which, at the time, was supposed to permeate the atmosphere, interstellar space and all transparent materials. Clerk Maxwell's work on optics consisted in the mathematical development of ideas which had been previously expressed in a cogent but non-mathematical form by Faraday. The study of ether raised certain questions whose answers were obscure, as, for example, that of the motion of matter through the ether. The famous experiment of Michelson and Morley, in the nineties, was undertaken to resolve this problem, and it gave the entirely unexpected answer that there simply was no way to determine the motion of matter through the ether.

The first satisfactory solution to the problems aroused by this experiment was that of Lorentz, who pointed out that if the forces holding matter together were conceived as being themselves electrical or optical in nature, we should expect a negative result from the Michelson-Morley experiment. However, Einstein in 1905 translated these ideas of Lorentz into a form in which the unobservability of absolute motion was rather a postulate of physics than the result of any particular structure of matter. For our purposes, the important thing is that in Einstein's work, light and matter are on an equal basis, as they had been in the writings before Newton; without the Newtonian subordination of everything else to matter and mechanics.

In explaining his views, Einstein makes abundant use of the observer who may be at rest or may be moving. In his theory of relativity it is impossible to introduce the observer without also introducing the idea of message, and without, in fact, returning the emphasis of physics to a quasi-Leibnitzian state, whose tendency is once again optical. Einstein's theory of relativity and Gibbs' statistical mechanics are in sharp contrast, in that Einstein, like Newton, is still talking primarily in terms of an absolutely rigid dynamics not introducing the idea of probability. Gibbs' work, on the other hand, is probabilistic from the very start, yet both directions of work represent a shift in the point of view of physics in which the world as it actually exists is replaced in some sense or other by the world as it happens to be observed, and the old naive realism of physics gives way to something on which Bishop Berkeley might have smiled with pleasure.

At this point it is appropriate for us to review certain notions pertaining to entropy which have already been presented in the introduction. As we have said, the idea of entropy represents several of the most important departures of Gibbsian mechanics from Newtonian mechanics. In Gibbs' view we have a physical quantity which belongs not to the outside world as such, but to certain sets of possible outside worlds, and therefore to the answer to certain specific questions which we can ask concerning the outside world. Physics now becomes not the discussion of an outside universe which may be regarded as the total answer to all the questions concerning it, but an account of the answers to much more limited questions. In fact, we are now no longer concerned with the study of all possible outgoing and incoming messages which we may send and receive, but with the theory of much more specific outgoing and incoming messages; and it involves a measurement of the no-longer infinite amount of information that they yield us.

Messages are themselves a form of pattern and organization. Indeed, it is possible to treat sets of messages as having an entropy like sets of states of the external world. Just as entropy is a measure of disorganization, the information carried by a set of messages is a measure of organization. In fact, it is possible to interpret the information carried by a message as essentially the negative of its entropy, and the negative logarithm of its probability. That is, the more probable the message, the less information it gives. Cliches, for example, are less illuminating than great poems.

I have already referred to Leibnitz's interest in automata, an interest incidentally shared by his contemporary, Pascal, who made real contributions to the development of what we now know as the desk addingmachine. Leibnitz saw in the concordance of the time given by clocks set at the same time, the model for the pre-established harmony of his monads. For the technique embodied in the automata of his time was that of the clockmaker. Let us consider the activity of the little figures which dance on the top of a music box. They move in accordance with a pattern, but it is a pattern which is set in advance, and in which the past activity of the figures has practically nothing to do with the pattern of their future activity. The probability that they will diverge from this pattern is nil. There is a message, indeed; but it goes from the machinery of the music box to the figures, and stops there. The figures themselves have no trace of communication with the outer world, except this one-way stage of communication with the pre-established mechanism of the music box. They are blind, deaf, and dumb, and cannot vary their activity in the least from the conventionalized pattern.

Contrast with them the behavior of man, or indeed of any moderately intelligent animal such as a kitten. I call to the kitten and it looks up. I have sent it a message which it has received by its sensory organs, and which it registers in action. The kitten is hungry and lets out a pitiful wail. This time it is the sender of a message. The kitten bats at a swinging spool. The spool swings to its left, and the kitten catches it with its left paw. This time messages of a very complicated nature are both sent and received within the kitten's own nervous system through certain nerve end-bodies in its joints, muscles, and tendons; and by means of nervous messages sent by these organs, the animal is aware of the actual position and tensions of its tissues. It is only through these organs that anything like a manual skill is possible.

I have contrasted the prearranged behavior of the little figures on the music box on the one hand, and the contingent behavior of human beings and animals on the other. But we must not suppose that the music box is typical of all machine behavior.

The older machines, and in particular the older attempts to produce automata, did in fact function on a closed clockwork basis. But modern automatic machines such as the controlled missile, the proximity fuse, the automatic door opener, the control apparatus for a chemical factory, and the rest of the modern armory of automatic machines which perform military or industrial functions, possess sense organs; that is, receptors for messages coming from the outside. These may be as simple as photoelectric cells which change electrically when a light falls on them, and which can tell light from dark, or as complicated as a television set. They may measure a tension by the change it produces in the conductivity of a wire exposed to it, or they may measure temperature by means of a thermocouple, which is an instrument consisting of two distinct metals in contact with one another through which a current flows when one of the points of contact is heated. Every instrument in the repertory of the scientific-instrument maker is a possible sense organ, and may be made to record its reading remotely through the intervention of appropriate electrical apparatus. Thus the machine which is conditioned by its relation to the external world, and by the things happening in the external world, is with us and has been with us for some time.

The machine which acts on the external world by means of messages is also familiar. The automatic photoelectric door opener is known to every person who has passed through the Pennsylvania Station in New York, and is used in many other buildings as well. When a message consisting of the interception of a beam of light is sent to the apparatus, this message actuates the door, and opens it so that the passenger may go through.

The steps between the actuation of a machine of this type by sense organs and its performance of a task may be as simple as in the case of the electric door; or it may be in fact of any desired degree of complexity within the limits of our engineering techniques. A complex action is one in which the data introduced, which we call the *input*, to obtain an effect on the outer world, which we call the *output*, may involve a large number of combinations. These are combinations, both of the data put in at the moment and of the records taken from the past stored data which we call the *memory*. These are recorded in the machine. The most complicated machines yet made which transform input data into output data are the high-speed electrical computing machines, of which I shall speak later in more detail. The determination of the mode of conduct of these machines is given through a special sort of input, which frequently consists of punched cards or tapes or of magnetized wires, and which determines the way in which the machine is going to act in one operation, as distinct from the way in which it might have acted in another. Because of the frequent use of punched or magnetic tape in the control, the data which are fed in, and which indicate the mode of operation of one of these machines for combining information, are called the *taping.*

I have said that man and the animal have a kinaesthetic sense, by which they keep a record of the position and tensions of their muscles. For any machine subject to a varied external environment to act effectively it is necessary that information concerning the results of its own action be furnished to it as part of the information on which it must continue to act. For example, if we are running an elevator, it is not enough to open the outside door because the orders we have given should make the elevator be at that door at the time we open it. It is important that the release for opening the door be dependent on the fact that the elevator is actually at the door; otherwise something might have detained it, and the passenger might step into the empty shaft. This control of a machine on the basis of its *actual* performance rather than its *expected* performance is known as *feedback*, and involves sensory members which are actuated by motor members and perform the function of *tell-tales* or *monitors*—that is, of elements which indicate a performance. It is the function of these mechanisms to control the mechanical tendency toward disorganization; in other words, to produce a temporary and local reversal of the normal direction of entropy.

I have just mentioned the elevator as an example of feedback. There are other cases where the importance of feedback is even more apparent. For example, a gun-pointer takes information from his instruments of observation, and conveys it to the gun, so that the latter will point in such a direction that the missile will pass through the moving target at a certain time. Now, the gun itself must be used under all conditions of weather. In some of these the grease is warm, and the gun swings easily and rapidly. Under other conditions the grease is frozen or mixed with sand, and the gun is slow to answer the orders given to it. If these orders are reinforced by an extra push given when the gun fails to respond easily to the orders and lags behind them, then the error of the gun-pointer will be decreased. To obtain a performance as uniform as possible, it is customary to put into the gun a control feedback element which reads the lag of the gun behind the position it should have according to the orders given it, and which uses this difference to give the gun an extra push.

It is true that precautions must be taken so that the push is not too hard, for if it is, the gun will swing past its proper position, and will have to be pulled back in a series of oscillations, which may well become wider and wider, and lead to a disastrous instability. If the feedback system is itself controlled—if, in other words, its own entropic tendencies are checked by still other controlling mechanisms—and kept within limits sufficiently stringent, this will not occur, and the existence of the feedback will increase the stability of performance of the gun. In other words, the performance will become less dependent on the frictional load; or what is the same thing, on the drag created by the stiffness of the grease.

Something very similar to this occurs in human action. If I pick up my cigar, I do not will to move any specific muscles. Indeed in many cases, I do not know what those muscles are. What I do is to turn into action a certain feedback mechanism; namely, a reflex in which the amount by which I have yet failed to pick up the cigar is turned into a new and increased order to the lagging muscles, whichever they may be. In this way, a fairly uniform voluntary command will enable the same task to be performed from widely varying initial positions, and irrespective of the decrease of contraction due to fatigue of the muscles. Similarly, when I drive a car, I do not follow out a series of commands dependent simply on a mental image of the road and the task I am doing. If I find the car swerving too much to the right, that causes me to pull it to the left. This depends on the actual performance of the car, and not simply on the road; and it allows me to drive with nearly equal efficiency a light Austin or a heavy truck, without having formed separate habits for the driving of the two. I shall have more to say about this in the chapter in this book on special machines, where we shall discuss the service that can be done to neuropathology by the study of machines with defects in performance similar to those occurring in the human mechanism.

It is my thesis that the physical functioning of the living individual and the operation of some of the newer communication machines are precisely parallel in their analogous attempts to control entropy through feedback. Both of them have sensory receptors as one stage in their cycle of operation: that is, in both of them there exists a special apparatus for collecting information from the outer world at low energy levels, and for making it available in the operation of the individual or of the machine. In both cases these external messages are not taken *neat*, but through the internal transforming powers of the apparatus, whether it be alive or dead. The information is then turned into a new form available for the further stages of performance. In both the animal and the machine this performance is made to be effective on the outer world. In both of them, their *performed*. action on the outer world, and not merely their *intended* action, is reported back to the central regulatory apparatus. This complex of behavior is ignored by the average man, and in particular does not play the role that it should in our habitual analysis of society; for just as individual physical responses may be seen from this point of view, so may the organic responses of society itself. I do not mean that the sociologist is unaware of the existence and complex nature of communications in society, but until recently he has tended to overlook the extent to which they are the cement which binds its fabric together.

We have seen in this chapter the fundamental unity of a complex of ideas which until recently had not been sufficiently associated with one another, namely, the contingent view of physics that Gibbs introduced as a modification of the traditional, Newtonian conventions, the Augustinian attitude toward order and conduct which is demanded by this view, and the theory of the message among men, machines, and in society as a sequence of events in time which, though it itself has a certain contingency, strives to hold back nature's tendency toward disorder by adjusting its parts to various purposive ends.

II

PROGRESS AND ENTROPY

As we have said, nature's statistical tendency to disorder, the tendency for entropy to increase in isolated systems, is expressed by the second law of thermodynamics. We, as human beings, are not isolated systems. We take in food, which generates energy, from the outside, and are, as a result, parts of that larger world which contains those sources of our vitality. But even more important is the fact that we take in information through our sense organs, and we act on information received.

Now the physicist is already familiar with the significance of this statement as far as it concerns our relations with the environment. A brilliant expression of the role of information in this respect is provided by Clerk Maxwell, in the form of the so-called "Maxwell demon," which we may describe as follows.

Suppose that we have a container of gas, whose temperature is everywhere the same. Some molecules of this gas will be moving faster than others. Now let us suppose that there is a little door in the container that lets the gas into a tube which runs to a heat engine, and that the exhaust of this heat engine is connected by another tube back to the gas chamber, through another door. At each door there is a little being with the power of watching the on-coming molecules and of opening or closing the doors in accordance with their velocity.

The demon at the first door opens it only for high-speed molecules and closes it in the face of low-speed molecules coming from the container. The role of the demon at the second door is exactly the opposite: he opens the door only for low-speed molecules coming from the container and closes it in the face of high-speed molecules. The result is that the temperature goes up at one end and down at the other thus creating a perpetual motion of "the second kind": that is, a perpetual motion which does not violate the first law of thermodynamics, which tells us that the amount of energy within a given system is constant, but does violate the second law of thermodynamics, which tells us that energy spontaneously runs down hill in temperature. In other words, the Maxwell demon seems to overcome the tendency of entropy to increase.

Perhaps I can illustrate this idea still further by considering a crowd milling around in a subway at two turnstiles, one of which will only let people out if they are observed to be running at a certain speed, and the other of which will only let people out if they are moving slowly. The fortuitous movement of the people in the subway will show itself as a stream of fast-moving people coming from the first turnstile, whereas the second turnstile will only let through slow-moving people. If these two turnstiles are connected by a passageway with a treadmill in it, the fast-moving people will have a greater tendency to turn the treadmill in one direction than the slow people to turn it in the other, and we shall gather a source of useful energy in the fortuitous milling around of the crowd.

Here there emerges a very interesting distinction between the physics of our grandfathers and that of the present day. In nineteenth century physics, it seemed to cost nothing to get information. The result is that there is nothing in Maxwell's physics to prevent one of his demons from furnishing its own power source. Modern physics, however, recognizes that the demon can only gain the information with which it opens or closes the door from something like a sense organ which for these purposes is an eye. The light that strikes the demon's eye is not an energy-less supplement of mechanical motion, but shares in the main properties of mechanical motion itself. Light cannot be received by any instrument unless it hits it, and cannot indicate the position of any particle unless it hits the particle as well. This means, then, that even from a purely mechanical point of view we cannot consider the gas chamber as containing mere gas, but rather gas and light which may or may not be in equilibrium. If the gas and the light are in equilibrium, it can be shown as a consequence of present physical doctrine that the Maxwell demon will be as blind as if there were no light at all. We shall have a cloud of light coming from every direction, giving no indication of the position and momenta of the gas particles. Therefore the Maxwell demon will work only in a system that is not in equilibrium. In such a system, however, it will turn out that the constant collision between light and gas particles tends to bring the light and particles to an equilibrium. Thus while the demon may temporarily reverse the usual direction of entropy, ultimately it too will wear down.

The Maxwell demon can work indefinitely only if additional light comes from outside the system and does not correspond in temperature to the mechanical temperature of the particles themselves. This is a situation which should be perfectly familiar to us, because we see the universe around us reflecting light from the sun, which is very far from being in equilibrium with mechanical systems on the earth. Strictly speaking, we are confronting particles whose temperature is 50 or 60° F. with a light which comes from a sun at many thousands of degrees.

In a system which is not in equilibrium, or in part of such a system, entropy need not increase. It may, in fact, decrease locally. Perhaps this non-equilibrium of the world about us is merely a stage in a downhill course which will ultimately lead to equilibrium. Sooner or later we shall die, and it is highly probable that the whole universe around us will die the heat death, in which the world shall be reduced to one vast temperature equilibrium in which nothing really new ever happens. There will be nothing left but a drab uniformity out of which we can expect only minor and insignificant local fluctuations.

But we are not yet spectators at the last stages of the world's death. In fact these last stages can have no spectators. Therefore, in the world with which we are immediately concerned there are stages which, though they occupy an insignificant fraction of eternity, are of great significance for our purposes, for in them entropy does not increase and organization and its correlative, information, are being built up.

What I have said about these enclaves of increasing organization is not confined merely to organization as exhibited by living beings. Machines also contribute to a local and temporary building up of information, notwithstanding their crude and imperfect organization compared with that of ourselves.

Here I want to interject the semantic point that such words as life, purpose, and soul are grossly inadequate to precise scientific thinking. These terms have gained their significance through our recognition of the unity of a certain group of phenomena, and do not in fact furnish us with any adequate basis to characterize this unity. Whenever we find a new phenomenon which partakes to some degree of the nature of those which we have already termed "living phenomena," but does not conform to all the associated aspects which define the term "life," we are faced with the problem whether to enlarge the word "life" so as to include them, or to define it in a more restrictive way so as to exclude them. We have encountered this problem in the past in considering viruses, which show some of the tendencies of life—to persist, to multiply, and to organize— but do not express these tendencies in a fully-developed form. Now that certain analogies of behavior universe, and is thus playing a game against the arch enemy, disorganization. Is this devil Manichaean or Augustinian? Is it a contrary force opposed to order or is it the very absence of order itself? The difference between these two sorts of demons will make itself apparent in the tactics to be used against them. The Manichaean devil is an opponent,

[1] W. Ross Ashby, *Design for a Brain*, Wiley, New York, 1952, and W. Grey Walter, *The Living Brain,* Norton, New York, 1953.

like any other opponent, who is determined on victory and will use any trick of craftiness or dissimulation to obtain this victory. In particular, he will keep his policy of confusion secret, and if we show any signs of beginning to discover his policy, he will change it in order to keep us in the dark. On the other hand, the Augustinian devil, which is not a power in itself, but the measure of our own weakness, may require our full resources to uncover, but when we have uncovered it, we have in a certain sense exorcised it, and it will not alter its policy on a matter already decided with the mere intention of confounding us further. The Manichaean devil is playing a game of poker against us and will resort readily to bluffing; which, as von Neumann explains in his *Theory of Games*, is intended not merely to enable us to win on a bluff, but to prevent the other side from winning on the basis of a certainty that we will not bluff.

Compared to this Manichaean being of refined malice, the Augustinian devil is stupid. He plays a difficult game, but he may be defeated by our intelligence as thoroughly as by a sprinkle of holy water.

As to the nature of the devil, we have an aphorism of Einstein's which is more than an aphorism, and is really a statement concerning the foundations of scientific method. "The Lord is subtle, but he isn't simply mean." Here the word "Lord" is used to describe those forces in nature which include what we have attributed to his very humble servant, the Devil, and Einstein means to say that these forces do not bluff. Perhaps this devil is not far in meaning from Mephistopheles. When Faust asked Mephistopheles what he was, Mephistopheles replied, "A part of that force which always seeks evil and always does good." In other words, the devil is not unlimited in his ability to deceive, and the scientist who looks for a positive force determined to confuse us in the universe which he is investigating is wasting his time. Nature offers resistance to decoding, but it does not show ingenuity in finding new and undecipherable methods for jamming our communication with the outer world.

This distinction between the passive resistance of nature and the active resistance of an opponent suggests a distinction between the research scientist and the warrior or the game player. The research physicist has all the time in the world to carry out his experiments, and he need not fear that nature will in time discover his tricks and method and change her policy. Therefore, his work is governed by his best moments, whereas a chess player cannot make one mistake without finding an alert adversary ready to take advantage of it and to defeat him. Thus the chess player is governed more by his worst moments than by his best moments. I may be prejudiced about this claim: for I have found it possible myself to do effective work in science, while my chess has been continually vitiated by my carelessness at critical instants.

The scientist is thus disposed to regard his opponent as an honorable enemy. This attitude is necessary for his effectiveness as a scientist, but tends to make him the dupe of unprincipled people in war and in politics. It also has the effect of making it hard for the general public to understand him, for the general public is much more concerned with personal antagonists than with nature as an antagonist.

We are immersed in a life in which the world as a whole obeys the second law of thermodynamics: confusion increases and order decreases. Yet, as we have seen, the second law of thermodynamics, while it may be a valid statement about the whole of a closed system, is definitely not valid concerning a non-isolated part of it. There are local and temporary islands of decreasing entropy in a world in which the entropy as a whole tends to increase, and the existence of these islands enables some of us to assert the existence of progress. What can we say about the general direction of the battle between progress and increasing entropy in the world immediately about us?

The Enlightenment, as we all know, fostered the idea of progress, even though there were among the men of the eighteenth century some who felt that this progress was subject to a law of diminishing returns, and that the Golden Age of society would not differ very much from what they saw about them. The crack in the fabric of the Enlightenment, marked by the French Revolution, was accompanied by doubts of progress elsewhere. Malthus, for example, sees the culture of his age about to sink into the slough of an uncontrolled increase in population, swallowing up all the gains so far made by humanity.

The line of intellectual descent from Malthus to Darwin is clear. Darwin's great innovation in the theory of evolution was that he conceived of it not as a Lamarckian spontaneous ascent from higher to higher and from better to better, but as a phenomenon in which living beings showed (a) a spontaneous tendency to develop in many directions, and (b) a tendency to follow the pattern of their ancestors. The combination of these two effects was to prune an overlush developing nature and to deprive it of those organisms which were ill-adapted to their environment, by a process of "natural selection." The result of this pruning was to leave a residual pattern of forms of life more or less well adapted to their environment. This residual pattern, according to Darwin, assumes the appearance of universal purposiveness.

The concept of a residual pattern has come to the fore again in the work of Dr. W. Ross Ashby. He uses it to explain the concept of machines that learn. He points out that a machine of rather random and haphazard structure will have certain near-equilibrium positions, and certain positions far from equilibrium, and that the near-equilibrium patterns will by their very nature last for a long time, while the others will appear only temporarily. The result is that in Ashby's machine, as in Darwin's nature, we have the appearance of a purposefulness in a system which is not purposefully constructed simply because purposelessness is in its very nature transitory. Of course, in the long run, the great trivial purpose of maximum entropy will appear to be the most enduring of all. But in the intermediate stages an organism or a society of organisms will tend to dally longer in those modes of activity in which the different parts work together, according to a more or less meaningful pattern.

I believe that Ashby's brilliant idea of the unpurposeful random mechanism which seeks for its own purpose through a process of learning is not only one of the great philosophical contributions of the present day, but will lead to highly useful technical developments in the task of automatization. Not only can we build purpose into machines, but in an overwhelming majority of cases a machine designed to avoid certain pitfalls of breakdown will look for purposes which it can fulfill.

Darwin's influence on the idea of progress was not confined to the biological world, even in the nineteenth century. All philosophers and all sociologists draw their scientific ideas from the sources available at their time. Thus it is not surprising to find that Marx and his contemporary socialists accepted a Darwinian

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