I

WHAT IS CYBERNETICS?

I HAVE BEEN OCCUPIED for many years with problems of communication engineering. These have led to the design and investigation of various sorts of communication machines, some of which have shown an uncanny ability to simulate human behavior, and thereby to throw light on the possible nature of human behavior. They have even shown the existence of a tremendous possibility of replacing human behavior, in many cases in which the human being is relatively slow and ineffective. We are thus in an immediate need of discussing the powers of these machines as they impinge on the human being, and the consequences of this new and fundamental revolution in technique.

To those of us who are engaged in constructive research and in invention, there is a serious moral risk of aggrandizing what we have accomplished. To the public, there is an equally serious moral risk of supposing that in stating new potentials of fact, we scientists and engineers are thereby justifying and even urging their exploitation at any costs. It will therefore be taken for granted by many that the attitude of an investigator who is aware of the great new possibilities of the machine age, when employed for the purpose of communication and control, will be to urge the prompt exploitation of this new "know-how" for the sake of the machine and for the minimization of the human element in life. This is most emphatically not the purpose of the present book.

The purpose of this book is both to explain the potentialities of the machine in fields which up to now have been taken to be purely human, and to warn against the dangers of a purely selfish exploitation of these possibilities in a world in which to human beings, human things are all-important.

That we shall have to change many details of our mode of life in the face of the new machines is certain; but these machines are secondary in all matters of value that concern us to the proper evaluation of human beings for their own sake and to their employment as human beings, and not as second-rate surrogates for possible machines of the future. The message of this book as well as its title is *the human use of human beings*.

The problem of the definition of man is an odd one. To say that man is a featherless biped is merely to put him in the same class as a plucked chicken, a kangaroo, or a jerboa. This is a rather heterogeneous group, and it can be extended to our heart's content without throwing any further light on the true nature of man. It will not do to say that man is an animal with a soul. Unfortunately, the existence of the soul, whatever it may mean, is not available to the scientific methods of behaviorism; and although the Church assures us that men have souls and dogs do not, an equally authoritative institution known as Buddhism holds a different view.

What does differentiate man from other animals in a way which leaves us not the slightest degree of doubt, is that he is a talking animal. The impulse to communicate with his fellow beings is so strong that not even the double deprivation of blindness and deafness can completely obliterate it. It is not only that with adequate training the blind deaf-mute may become a Laura Bridgman or a Helen Keller, but even more, that without any training whatever, a Helen

Keller will make a desperate attempt to break the almost impregnable barrier which separates her from the rest of the world. There are animals besides man which are social, and live in a continuous relation to their fellow creatures, but there is none in whom this desire for communication, or rather this necessity for communication, is the guiding motive of their whole life. What then is this communication, which is so human and so essential? I shall devote this chapter, and indeed the greater part of this book to the introduction of concepts and theories contributing to the answer to this question.

One of the most interesting aspects of the world is that it can be considered to be made up of *patterns*. A pattern is essentially an arrangement. It is characterized by the order of the elements of which it is made, rather than by the intrinsic nature of these elements. Two patterns are identical if their relational structure can be put into a one-to-one correspondence, so that to each term of the one there corresponds a term of the other; and that to each relation of order between several terms of one, there corresponds a similar relation of order between the corresponding terms of the other. The simplest case of one-to-one correspondence is given by the ordinary process of counting. If I have five pennies in my pocket, and five apples in a basket, I can put my apples in a row, and lay one penny beside each. Each penny will correspond to one apple and one apple only, and each apple will correspond to one penny and one penny only.

However, the notion of one-to-one correspondence is not confined to finite sets, which can be given a number in the sense of elementary arithmetic. For example, the pattern of the sequence of whole numbers from 1 on is identical with that of the sequence of even numbers, since we can assign as a counterpart to each number its double, and since the before-and-after relations of the doubles will be the same as those of the original numbers. Again, a copy of a painting, if it is accurately made, will have the same pattern as the original, while a less perfect copy will have a pattern which is in some sense similar to that of the original.

The pattern of a thing may be spread out in space, as for example, the pattern of a wallpaper; or it may be distributed in time, as the pattern of a musical composition. The pattern of a musical composition again suggests the pattern of a telephone conversation, or the pattern of dots and dashes of a telegram. These two types of pattern are given the special designation of messages, not because their pattern itself differs in any way from the pattern of a musical composition, but because it is used in a somewhat different manner: namely, to convey information from one point to another, and even from one remote point to another.

A pattern which is conceived to convey information, or something transmissible from individual to individual, is not taken as an isolated phenomenon. To telegraph is to convey a message by the proper use of dots and dashes; and here it is necessary that these dots and dashes be a selection from among a set which contains other possibilities as well. If I am sending the letter *e*, it gains its meaning in part because I have not sent the letter *o*. If my only choice is to send the letter *e*, then the message is merely something that is either there or not there; and it conveys much less information.

In the early days of telephone engineering, the mere sending of a message was so much of a miracle that nobody asked how it should best be sent. The lines were able to take care of all the information forced on them, and the real difficulties were in the design of the terminal apparatus at the sending and receiving ends. Under these conditions, the problems concerning the maximum carrying capacity of telephone lines were not yet of any importance. However, as the art developed, and ways were found to compress several messages into a single line by the use of carriers and other similar means, economy in sending speech over the telephone lines began to develop an economic importance. Let me explain what we mean by "carriers" and by "carrier-telephony."

A mathematical theorem due to Fourier states that every motion within very broad limits can be represented as a sum of the very simplest sort of vibrations which give rise to pure musical notes. A way has been found to take an oscillation on an electric line, and to shift each one of the notes that make it up, by a certain constant pitch. In this manner, we may take a pattern in which several subsidiary patterns would otherwise be placed on top of each other, and separate them so that they are placed side by side in positions, and do not produce a mere confusion. Thus we may run three lines together in the typewriter in such a way that they are superimposed and blurred, or we may write them in their proper sequence, and keep them separate. This process of moving different messages into separate positions of pitch is known as *modulation*.

After modulation, the message may be sent over a line which is already carrying a message, if the displacement in pitch is sufficient. Under proper conditions, the message already transmitted and the new message will not affect one another; and it is possible to recover from the line both the original undisplaced message and the modulated message, in such a way that they go to separate terminal equipment. The modulated message may then be subjected to a process which is the inverse of modulation, and may be reduced to the form which it originally had before it was entrusted to the apparatus. Thus two messages may be sent along the same telephone line. By an extension of this process, many more than two messages may be sent over the same line. This process is known as carrier-telephony, and has vastly extended the usefulness of our telephone lines without any correspondingly great increase in investment.

Since the introduction of carrier methods, telephone lines have been used at a high efficiency of message transmission. Thus the question of how much information can be sent over a line has become significant, and with this, the measurement of information in general. This has been made more acute by the discovery that the very existence of electric currents in a line is the cause of what is called *line noise,* which blurs the messages, and offers an upper limit to their ability to carry information.

The earlier work on the theory of information was vitiated by the fact that it ignored noise-levels and other quantities of a somewhat random nature. It was only when the idea of randomness was fully understood, together with the applications of the related notions of probability, that the question of the carrying capacity of a telegraph or telephone line could even be asked intelligently. When this question was asked, it became clear that the problem of measuring the amount of information was of a piece with the related problem of the measurement of the regularity and irregularity of a pattern. It is quite clear that a haphazard sequence of symbols or a pattern which is purely haphazard can convey no information. Information thus must be in some way the measure of the regularity of a pattern, and in particular of the sort of pattern known as *time series.* By time series, I mean a pattern in which the parts are spread in time. This regularity is to a certain extent an abnormal thing. The irregular is always commoner than the regular. Therefore, whatever definition of information and its measure we shall introduce must be something which grows when the *a priori* probability of a pattern or a time series diminishes. We shall later find the proper numerical measure for the amount of information. This range of ideas was already familiar in the branch of physics known as statistical mechanics, and was associated with the famous second law of thermodynamics, which asserts that a system may lose order and regularity spontaneously, but that it practically never gains it.

A little later in this chapter, I shall give this law its proper statement in terms of the scientific notion of *entropy* which I shall then define. For the present this qualitative formulation of the law will suffice. The notion of information has proved to be subject to a similar law — that is, a message can lose order spontaneously in the act of transmission, but cannot gain it. For example, if one talks into a telephone with a great deal of line noise, and a great deal of loss of energy of the main message, the person at the other end may miss words that have been spoken, and may have to reconstruct them on the basis of the significant information of the context. Again, if a book is translated from one language into another, there does not exist that precise equivalence between the two languages which will permit the translation to have exactly the same meaning as the original. Under these conditions, the translator has only two alternatives: namely, to use phrases which are a little broader and vaguer than those of the original, and which certainly fail to contain its entire emotional context, or to falsify the original by introducing a message which is not precisely there, and which conveys his own meaning rather than that of the author. In either case, some of the author's meaning is lost.

An interesting application of the concept of amount of information is to the elaborate telegraph messages which are offered at Christmas or birthdays or other special occasions. The message may cover a whole page of text, but what is sent is just a code symbol such as *B7*, meaning the seventh coded message to be sent on birthdays. Such special messages are only possible because the sentiments expressed are merely conventional and repetitive. The moment the sender shows any originality in the sentiments he desires to convey, the reduced rates are no longer available. The meaning of the cheap-rate message is disproportionately small compared with the length of the message. We again see that the message is a transmitted pattern, which acquires its meaning by being a selection from a large number of possible patterns. The amount of meaning can be measured. It turns out that the less probable a message is, the more meaning it carries, which is entirely reasonable from the standpoint of our common sense.[1]

We ordinarily think of a message as sent from human being to human being. This need not be the case at all. If, being lazy, instead of getting out of bed in the morning, I press a button which turns on the heat, closes the window, and starts an electric heating unit under the coffeepot, I am sending messages to all these pieces of apparatus. If on the other hand, the electric egg boiler starts a whistle going after a certain number of minutes, it is sending me a message. If the thermostat records that the room is too warm, and turns off the oil burner, the message may be said to be a method of control of the oil burner. Control, in other words, is nothing but the sending of messages which effectively change the behavior of the recipient.

It is this study of messages, and in particular of the effective messages of control, which constitutes the science of

[1] See appendix to this chapter.

Cybernetics,[2] which I christened in an earlier book. Its name signifies the art of pilot or steersman. Let it be noted that the word "governor" in a machine is simply the latinized Greek word for steersman.

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 machine and man, and between machine and machine, are destined to play an ever-increasing part.

To indicate the rôle of the message in man, let us compare human activity with activity of a very different sort; namely, the activity of the little figures which dance on the top of a music box. These figures dance 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. 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 not a trace of any communication with the outer world, except this one-way stage of communication with 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 the left, and the kitten

[2] *Cybernetics, or Control and Communication in the Animal and the Machine;* 1949, The Technology Press of M. I. T., Cambridge; John Wiley & Sons, New York; and Hermann et Cie, Paris.

catches it with its left paw. This time messages of a very complicated nature are both sent and received. The kitten is informed of the motion of its own paw by organs called proprioceptors or kinaesthetic organs. These organs are certain nerve end-bodies to be found in its joints, in its muscles, and in its 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 skill is possible, not to mention the extreme dexterity of the kitten.

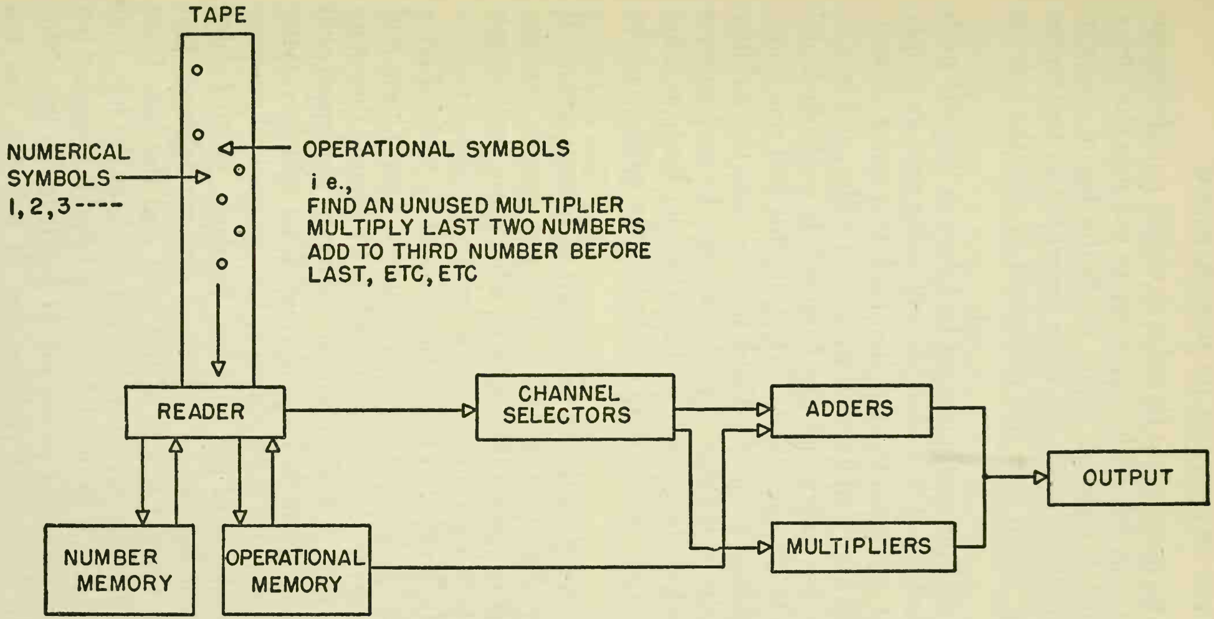
I have contrasted the behavior of the little figures on the music box on the one hand, and the human and animal behavior on the other. It might be supposed that the music box was an example typical of all machine behavior, in contrast to the behavior of living organisms. This is not so. The older machines, and in particular the older attempts to produce automata, did in fact work on a closed clockwork basis. On the other hand, the machines of the present day possess sense organs; that is, receptors for messages coming from the outside. These may be as simple as photo-electric cells which change electrically when a light falls on them, and which can tell light from dark. They may be 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. 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 photo-electric 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 the message constituted by 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. A complex action is one in which the combination of 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 illustrate the situation by means of the following conventionalized diagram.

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, in order 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.

I have just mentioned the elevator as an example of feedback. There are other cases where feedback is even more essential. 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 some 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-



A TYPICAL TAPING SYSTEM

pointer will be decreased. In order 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 is controlled 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 left, that causes me to turn it to the right; and if I find it 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 operation of the living individual and the operation of some of the newer communication machines are precisely parallel. 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 rôle that it should in our habitual analysis of society.

This is true whether we consider human beings alone, or in conjunction with types of automata which participate in a two-way relation with the world about them. In this, our view of society differs from the ideal of society which is held by many Fascists, Strong Men in Business, and Government. Similar men of ambition for power are not entirely unknown in scientific and educational institutions. Such people prefer an organization in which all orders come from above, and none return. The human beings under them have been reduced to the level of effectors for a supposedly higher nervous organism. I wish to devote this book to a protest against this inhuman use of human beings; for in my mind, any use of a human being in which less is demanded of him and less is attributed to him than his full status is a degradation and a waste. It is a degradation to a human being to chain him to an oar and use him as a source of power; but it is an almost equal degradation to assign him a purely repetitive task in a factory, which demands less than a millionth of his brain capacity. It is simpler to organize a factory or galley which uses individual human beings for a trivial fraction of their worth than it is to provide a world in which they can grow to their full stature. Those who suffer from a power complex find the mechanization of man a simple way to realize their ambitions. I say, that this easy path to power is in fact not only a rejection of everything that I consider to be of moral worth in the human race, but also a rejection of our now very tenuous opportunities for a considerable period of human survival.

The rest of this book is devoted to the development of this theme. In every chapter, we are studying either those respects in which the machine duplicates man, or those aspects of man which appear clearer in view of our study of the machine, or both. We begin with the two notions of *entropy* and of *progress:* notions which are completely necessary for the understanding of the orientation of man in the world, and notions which have been sadly misunderstood. We discuss the communicative behavior of man, as contrasted with that of the ant; and thereby are given a clearer idea of the function of learning in human society. Three more chapters are devoted to the problem of language, both in man and in the machine; and to those aspects of man in which human individuality resembles something essentially linguistic. We have a few words to say about law, and many to say about those widely misunderstood notions, secrecy and intellectual property. In the ninth chapter, we define and criticize the rôles of those two priests of communication in the modern world: the literary intellectual and the scientist. The tenth and eleventh chapters are devoted to the machine, and to the great changes it has made and may be expected to make in the life of the human being of the present generation. Finally, we devote one chapter to the study of certain specific influences, in appearance very different from one another, and in nature very similar, which furnish the chief stumbling blocks to a proper understanding of what communication should mean to us, and to a proper development of communication itself.

APPENDIX

An adequate measure of the amount of meaning should add the amount of meaning of completely independent messages. Now, there is another way of combining quantities related to information, in which we do not add these quantities. If we have two events, each of which occurs with a certain probability, and if there is no connection whatever between them, the joint event of their both occurring will have a probability which is the product of the probabilities of the separate events. For example, if we throw two dice, and there is a probability of one-sixth that each of them independently will show an ace, then the probability of throwing two aces is one-thirty-sixth. If we have two packs of cards, the probability of drawing a king in each pack will be one-thirteenth, and the probability of drawing a king separately from the other pack will be one-thirteenth, so that the probability of drawing a king separately from each pack will be a one-hundred-and-sixty-ninth, which is one-thirteenth of one-thirteenth. The probability of drawing two kings from one pack, if it is fairly shuffled, will be the probability of drawing one king the first time, which is one-thirteenth, multiplied by the probability of drawing a king the second time, in which case we have three favorable possibilities out of fifty-one; so that the probability of the second drawing independently is three-fifty-firsts, or one-seventeenth.

Since probabilities taken independently combine multiplicatively, while information combines additively, the relation between the amount of information given by a message and the probability of that message will be that between a set of numbers that multiply and a set that add. To the mathematicians, if one set of numbers adds, while the corresponding numbers of the second set multiply, the first set is said to consist of the *logarithms* of the second set, taken to an appropriate base.

The logarithm is, however, not completely determined when the original number is given, because its scale is not yet assigned. This scale determines a factor by which the logarithm can be multiplied, and this factor may be positive or negative. Probabilities are always less than 1 or equal to it, for 1 is the probability of absolute certainty, and there is no probability greater than certainty. This shows that the amount of information will be so determined that it is greater than zero when the probability of the corresponding event is less than one. It follows that the amount of information conveyed by an event which occurs with a certain probability will then be the *negative* logarithm of the probability on some appropriate scale, since the ordinary logarithm of a quantity less than 1 will be negative, and information is naturally taken to be positive.

A measure of information is a measure of order. Its negative will be a measure of disorder, and will be a negative number. It can be made artificially positive by adding a constant quantity, or starting from some value other than zero. This measure of disorder is known to the statistical mechanicist as *entropy,* and almost never spontaneously decreases in an isolated system. This again is the second law of thermodynamics.