The Human Use of Human Beings

By Norbert Wiener

The "mechanical brain" and similar machines can destroy human values or enable us to realize them as never before. A leader of the new scientific revolution tells how and why.

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CYBERNETICS AND SOCIETY

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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

SOME TWO YEARS AGO I published a book entitled *Cybernetics, or Control and Communication in the Animal and the Machine.* In this book, I developed what seemed to me to be a new point of view with respect to communication and its importance both in the machine and the living organism. Upon the publication of this book which possesses a rather forbidding mathematical core, some of my friends urged upon me that I should write a related book for the layman, in which I should avoid mathematical symbolism and ideas as much as possible, and in which I should emphasize the not inconsiderable social consequences of my point of view.

I have accordingly done so, and the present book is the result. In its writing I have been continually helped and supported by the criticism of my friends. Among them I should like to mention especially Dr. Arturo Rosenblueth, of the Instituto Nacional de Cardiologia in Mexico; Professors Jerome Wiesner, Karl Deutsch, and Georgio de Santillana of the Massachusetts Institute of Technology; and Professor Manuel Vallarta of the National University of Mexico.

Above all, I want to pay tribute to the continued understanding help of my secretary, Mrs. Margaret Pickering Zemurray, who has not merely seen the mechanical part of the book through with the utmost care, but has also given me the help of her literary judgment.

INSTITUTO NACIONAL DE CARDIOLOGIA, MEXICO
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THE *Human* Use OF Human Beings

CYBERNETICS AND SOCIETY

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.

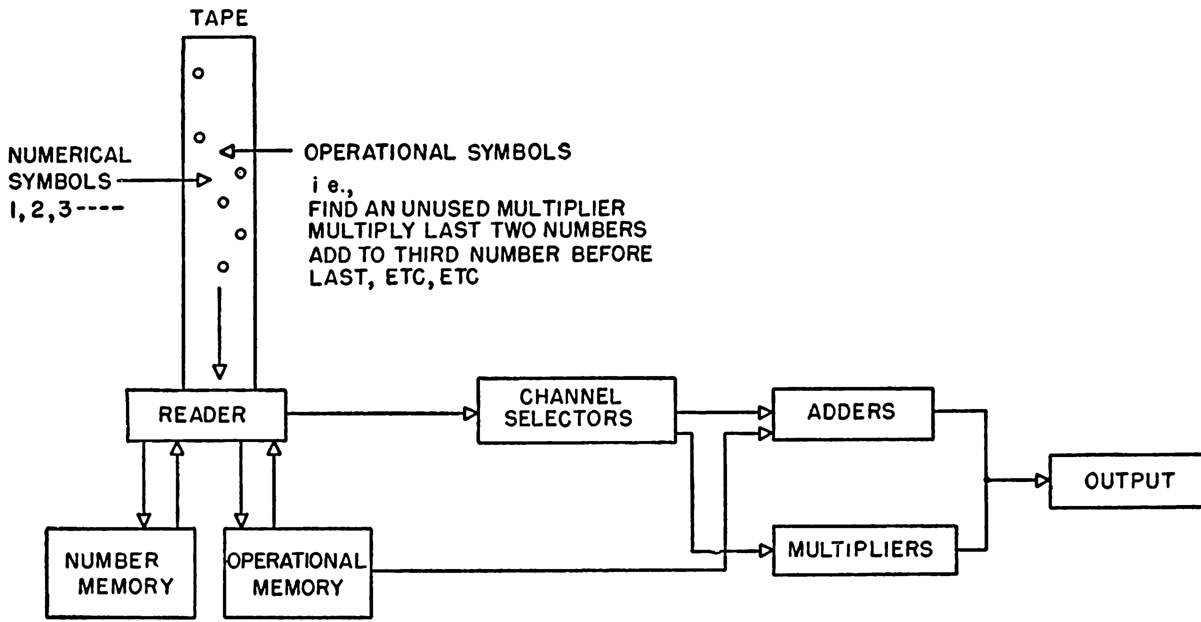
I have contrasted the behavior of the little figures on the music box on the one hand, and the human and animal behavior on the other. It might be supposed that the music box was an example typical of all machine behavior, in contrast to the behavior of living organisms. This is not so. The older machines, 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.

II

PROGRESS AND ENTROPY

One of the first problems which comes up in this book is that of *progress*. It involves essentially an assessment of the direction of change of the world according to certain values. One mode of assessment, as we shall see, is connected with statistical mechanics, and on the basis of this mode of assessment the tendency of the world as a whole is downward. We shall also see that this mode of assessment is not necessarily that which is relevant to our normal human schemes of moral values. Nevertheless, these schemes of moral values are at the present time too often associated with a belief in progress. This has neither deep philosophical roots nor good supporting scientific evidence.

The dispute between optimism and pessimism is as old as civilization. Each generation has brought those who have seen in the progress of time nothing more than a falling-off from a Golden Age, and a downhill progress into an Age of Iron; and each generation has likewise seen those who have counted those improvements which their contemporaries have made and have found them good.

At the present time, both of these tendencies towards pessimism and optimism have taken on a peculiar poignancy, and have made claims of the backing of the contemporary scientific thought. In the case of the pessimists, the scientific idea which has seemed most in accordance with their interpretation of the universe is that of *entropy* which we have mentioned in the appendix to the last chapter. This notion is associated with that of *pattern,* and represents the amount of disorder in a class of patterns. It is also closely associated with the notion of *information,* and of its measure, which is essentially a measure of order. Amount of information is a measure of the degree of order which is peculiarly associated with those patterns which are distributed as messages in time.

I have already explained a message as a pattern distributed in time, and I have introduced the notion of the amount of information in a message. The notion of pattern is however not confined to a pattern distributed in time; and the notion of amount of information is essentially only that particular case of the notion of amount of order which is applied to a time pattern. The general ideas of order and disorder are applicable to patterns of all types, as well as to the special case of *time series.* They are not applicable to a particular pattern in isolation, but rather to a set of patterns selected from a larger set in such a way that the smaller set possesses a measure of probability. The more probable the type of pattern, the less order it contains, because order is essentially lack of randomness. If we appeal to the notion of logarithm, as explained in the note at the end of the last chapter, the usual measure of the degree of order of a set of patterns selected from a larger set is the negative logarithm of the probability of the smaller set, when the probability of the larger set is taken to be one. I am sorry that I have to return here to the vocabulary of high-school mathematics. There is no synonym of which I am aware for the word logarithm, and any attempt to replace it by a definition will put me even more deeply in the position of a pedant.

The selection of this logarithmic scale for order-disorder relations is made on the same basis as the selection of this scale for measuring information. We employ it because it adds the amount of order of two totally independent systems, when we replace them by a single more comprehensive system. However, the tradition of physics is not to measure order, but disorder; and the measure of disorder is the positive logarithm of the probability. Ordinarily, this is taken, not with respect to an absolute level, but with respect to one which is determined by adding to this logarithm an appropriate positive constant, so as to make the measure of disorder a positive one in the cases in which we are interested. This positive measure of disorder is precisely what we have called *entropy* in the appendix to the last chapter. It is one of the most fundamental quantities in physics, and the second law of thermodynamics states that in an isolated system, the probability that the entropy shall decrease is zero.

Another way of formulating this statement more pictorially is to say that an isolated system will tend to a state of maximum disorder; or in other words, to the greatest homogeneity possible. Such a system will die in what was called by Baltzmann the "Wärmetod" – the universal heat death.

Emotionally this may seem the equivalent of a cosmic pessimism – a universal Ragnarök or Judgment Day. However – and this is most important – it is necessary to keep these cosmic physical values well separated from any human system of valuation. The situation is precisely parallel to that which we find in Darwinian evolution. In Darwinian evolution, those species which survive are obviously the residue of a large number of patterns which have not survived. The origin of a species is an extremely rare event, almost infinitely rarer than the successful fertilization of an ovum and the conception and birth of one animal, and even enormously rarer than the most improbable miracle by which a particular spermatazoon ever comes into the position to fertilize an ovum. Again, with an animal like a fish which passes its early stages of development not as a protected foetus, but as a free-swimming larva, an early death is its overwhelmingly most usual fate. Yet in spite of this, some ova do become fertilized; some sperm do succeed in fertilizing ova; and some fish larvae do grow to maturity. From the standpoint of human interest, these miraculously rare successes, and the miraculously rare cases in which a new species is born vastly overwhelm the almost unbroken record of the failures of nature.

In other words we weigh nature, not on an equal scale of probability, but on a scale which is heavily weighted in favor of the new and interesting. It may be that the Lord marks the fall of every sparrow, but if He is an anthropomorphic God, he does not care very much about it.

Let us note that the assertion of the second law of thermodynamics is confined within narrow limits. The statement that we are dealing with an isolated or a substantially isolated system is of the essence. In the non-isolated parts of an isolated system there will be regions in which the entropy, defined according to a suitable definition, may well be seen to decrease. In this connection, the coupling [1] which unites the different parts of the system into a single larger system will in general be both energetic and informational. The light which we receive from the sun both gives us an energetic source for vegetation and weather and tells us what is happening in the sun. Now, the old idea of coupling between the different parts of a dynamical system was one in which energy played by far the greatest rôle. However, the classical physics which preceded quantum theory was exactly the physics in which an arbitrary amount of information could

[1] Two or more systems are said to be coupled if the laws of the motion of the larger system made up of all of them together cannot be stated as a collection of separate laws, each of which only involve an interchange of energy between the partial systems, in which case we shall call it an *energetic* coupling; or it might conceivably only involve an interchange of information between the subordinate systems, in which case we call it an *informational* coupling.

be transferred at an arbitrarily low level of energy. A telegraph message was originally supposed to be something that could be indefinitely faint and yet be legible at the receiving end through the use of the proper apparatus. Thus in the older physics which has now departed, the coupling which was important for the purposes of entropy and the second law of thermodynamics might not involve more than arbitrarily small exchanges of energy.

It is an interesting thing that the development of physics has led to a new association of energy and information. A crude form of this occurs in the theories of line noise in a telephone circuit or an amplifier. This background-noise may be shown to be unavoidable, as it depends on the discrete character of the electrons which carry the current; and yet it has a perfectly definite power of destroying information. More fundamental than this fact, which demands a certain amount of communication power in the circuit in order that the message may not be swamped, is the fact that light itself has an atomic structure, and that light of a given frequency is radiated in lumps which are known as light quanta, which have a perfectly determined energy dependent on that frequency. Thus there can be no radiation of less energy than a single light quantum. The transfer of information cannot take place without a certain minimum transfer of energy, so that there is no sharp boundary between energetic coupling and informational coupling. Nevertheless, for most practical purposes, a light quantum is a very small thing; and the amount of energy transfer which is necessary for an effective informational coupling is quite small. It follows that in considering such a local process as the growth of a tree or of a human being, which depends directly or indirectly on radiation from the sun, an enormous local decrease in entropy may be associated with quite a moderate energy transfer. This is one of the fundamental facts of biology; and in particular of the theory of photo-synthesis, or of the chemical process by which a plant is enabled to use the sun's rays to form starch and other complicated chemicals necessary for life, out of the water and the carbon dioxide of the air.

The question of whether to interpret the second law of thermodynamics pessimistically or without any gloomy connotation depends on the importance we give to the universe at large, on the one hand, and to the islands of locally decreasing entropy which we find in it, on the other. Remember that we ourselves constitute such an island of decreasing entropy, and that we live among other such islands. The result is that the normal prospective difference between the near and the remote leads us to give a much higher weight of importance to the regions of decreasing entropy and increasing order than to the universe at large. For example, it may very well be that life is a rare phenomenon in the universe; perhaps that it is confined to the solar system, or even, if we consider life on any level comparable to that in which we are principally interested, to the earth alone. Nevertheless, we live on this earth, and the possible absence of life elsewhere in the universe is of no great concern to us, and certainly of no concern proportionate to the overwhelming size of the remainder of the universe.

Again, it is quite conceivable that life belongs to a limited stretch of time; that before the earliest geological ages it did not exist, and that the time may well come when the earth is again a lifeless, burnt-out or frozen-out planet. To those of us who know the extremely limited range of physical conditions under which the chemical reactions necessary to life as we know it can take place, it is a forgone conclusion that the lucky accident which permits the continuation of life in any form on this earth, even without restricting life to something like human life, is bound to come to a complete and disastrous end. Yet we may succeed in framing our values so that this temporary accident of living existence, and this much more temporary accident of human existence, may be taken as all-important positive values, notwithstanding their fugitive character.

After all, we are not by any means impartial enough to formulate our important human values on the vast scale of the probabilities of the universe. We are rather forced to weigh the human environment with human standards of values, and this may well lead us into what for us and for the moment is an optimism. Yet behind all this, there is a *memento mori* more pervasive and compelling than the watchword of the Trappists. There is a very true sense in which we are shipwrecked passengers on a doomed planet. Yet even in a shipwreck, human decencies and human values do not necessarily all vanish, and we must make the most of them. We shall go down, but let it be in a manner to which we may look forward as worthy of our dignity.

Up to this point we have been talking of a pessimism which is much more the intellectual pessimism of the professed scientist than an emotional pessimism which touches the average man. We have already seen that the theory of entropy, and the considerations of the ultimate heat-death of the universe, need not have such profoundly depressing moral consequences as they seem to possess at first sight. However, even this limited consideration of the future is foreign to the emotional euphoria of the average man, and particularly to that of the average American.

The education of the average American child of the upper middle class is such as to guard him solicitously against the awareness of death and doom. He is brought up in an atmosphere of Santa Claus; and when he learns that Santa Claus is a myth, he cries bitterly. Indeed, he never fully accepts the removal of Santa Claus from his Pantheon, and spends much of his later life in the search for some emotional substitute.

The fact of individual death, and the possibility of calamity, are forced upon him by the experiences of his later years. Nevertheless, he tries to relegate these unfortunate realities to the rôle of accidents, and to build up a Heaven on Earth in which unpleasantness has no place. This Heaven on Earth consists for him in an eternal progress, and a continual ascent to Bigger and Better Things.

This idea of progress has two aspects: a factual one and an ethical one — that is, one which furnishes standards for approval and disapproval. Factually, it asserts that the earlier advance of geographical discovery, whose inception corresponds to the beginning of modern times, is to be continued into an indefinite period of invention, of the discovery of new techniques for controlling the human environment. This, the believers in progress say, will go on and on without any visible termination in a future not too remote for human contemplation. As an ethical principle, those who uphold the idea of progress regard this unlimited and quasi-spontaneous process of change as a *Good Thing,* and as the basis on which they guarantee to future generations a Heaven on Earth. It is possible to believe in progress as a fact without believing in progress as an ethical principle; but in the catechism of the average American, the one goes with the other.

Most of us are too immersed in this world of progress to take cognizance either of the fact that this belief in progress belongs only to a small part of recorded history, or of the other fact, that it represents a sharp break with our own religious professions and traditions. Neither for Catholicism nor for Protestantism, nor for the matter of that for Judaism, is the world a *good* place and one in which an enduring happiness is to be expected. The Church offers its pay for virtue, not in any coin which passes current among the Kings of the Earth, but as a promissory note on Heaven, It links the World in obloquy with the Flesh and the Devil. It awaits the Second Coming of Christ, and a final Judgment. After this our earth will be destroyed; the blessed will remain throughout all eternity amid the joys of heaven; and the evil will be damned to a suffering unmitigated by the hope of any termination.

In essence, the Calvinist accepts all of this, with the additional dark note that the Elect of God who shall pass the dire final examination of Judgment Day are few, and are to be selected by His arbitrary decree. To secure this, no virtues on earth, no moral righteousness, may be expected to be of the slightest avail. Many a good man will be damned. The blessedness which the Calvinists do not expect to find for themselves even in Heaven, they certainly do not await on earth.

Moreover, the Hebrew prophets are not exactly cheerful in their evaluation of the future of mankind, or even of their chosen Israel; and the great morality play of Job, while it grants him a victory of the spirit, and while the Lord deigns to return to him his flocks and his servants and his wives, nevertheless gives no assurance that such a relatively happy outcome may be expected to take place except through the arbitrariness of God.

The Communist, like the believer in progress, looks for his Heaven on Earth, rather than as a personal reward to be drawn on in a post-earthly individual existence. He believes implicitly that it is not out of the reach of the human race. Nevertheless, he believes that this Heaven-on-Earth will not come of itself without a struggle. He is just as skeptical of the Big Rock Candy Mountains of the Future as of the Pie in the Sky when you Die. Nor is Islam, which means resignation to the will of God, any more receptive to the ideal of progress. Of Buddhism, with its hope for Nirvana and a release from the external Wheel of Circumstance, I need say nothing; it is inexorably opposed to the idea of progress, and this is equally true for all the kindred religions of India.

Perhaps the whole world is too vast a canvas to show the clear contrast between the credo of the present epoch of progress and the many views of things that have gone before it. For the moment, let me then focus down on that small corner of the world which is New England. When the wealth of New England was on the sea and in the cargoes carried by the sea from the ends of the earth, and when the Boston merchant was the proud owner of a great fleet, he worshiped God according to the Gospel of John Calvin. The sailor, whether he walks the quarter-deck or bunks in the forecastle, knows well that there is nothing very automatically propitious about the sea. The possibility of disastrous death is real from day to day; nor is the shipowner immune to all contact with a like reality. One single storm may turn him from a rich man into a beggar on the street. The Elect are very few, nor can any amount of virtue secure a position among them.

After the disaster of the Stone Fleet and the destruction of the whalers in the Great Freeze at Point Barrow, New England capital left the sea, never to return. Why did it leave the sea and where did it go? On the one hand the period of adventure which characterized the New England of Colonial and Federal times had exhausted itself in a generation of *epigonoi*. On the other hand, the geological discoveries of Alexander Agassiz had opened the new copper mines of the Northwest, and many Boston fortunes which had sailed the seven seas now found a safe berth in the stocks and bonds of Calumet and Hecla. New England, from being a community of merchant adventurers, became a community of rentiers, of absentee landlords. At the same time, Boston gave rise to a new religious movement. This was the new gospel of Mary Baker Eddy – the so-called Christian Science.

This new religion is not concerned with salvation. Salvation may appear as a phrase in its sacred books, but the Christian Scientist is far more interested in eliminating the pains and evils of this world by proving himself spiritually superior to indigestion. Disease is a spiritual error, and must be blotted out by denying it. Let us not forget that the owner of gilt-edged bonds is prone to deny any contact with the source of his income, and any responsibility for the means by which it is obtained. In this rentier heaven, the prospect of floating through eternity on a continual magical carpet of other people's inventions seems no more remote than any reality of life. Responsibility has been banished with death and sickness.

Besides this comfortable passive aspect of the belief in progress, there is another one which seems to have a more masculine, vigorous connotation. To the average American, progress means the winning of the West. It means the economic anarchy of the frontier, and the vigorous prose of Owen Wister and Theodore Roosevelt. Historically the frontier is, of course, a perfectly genuine phenomenon. For many years, the development of the United States took place against the background of the empty land that always lay further to the West. Nevertheless, many of those who have waxed poetic concerning this frontier have been praisers of the past. Already in 1890, the census takes cognizance of the end of the true frontier conditions, and the geographical limits of the great backlog of unconsumed and unbespoken resources of the country have been clearly set.

In this connection, the career of Theodore Roosevelt invites many interesting comments. He was the prophet of the Vigorous Life in the open air and the irreconcilable enemy of the Nature-Faker. Nevertheless, the very red-blooded outdoor life to which he devoted himself had already begun to partake of the quality of a myth. His Wild-West Youth in the Dakotas was exactly in that section which last remained as an enclave of the frontier, when the great frontier of the United States had passed beyond it. His adventures as a hunter in Africa belong to the period when the big game had already begun to be confined to great reserves, established to perpetuate a dying sport, and to serve as an outdoor museum for the naturalist of the future. There are not many regions in Brazil now available for exploration after the fashion of the River of Doubt; and one always feels that this *bonne bouche* of the discoverer had been reserved by an especially kind fate as the stage for the aging Roosevelt's last performance. In those montages which adorn the Roosevelt Hall of the New York Museum of Natural History, there should be one which shows a Roosevelt safari against the proper foreground of paper-leaved Veldt vegetation and the proper background of a painted horizon.

It is difficult for the average person to obtain a historical perspective in which progress shall have been reduced to its proper dimensions. The musket with which most of the Civil War was fought was only a slight improvement over that carried at Waterloo, and that in turn was nearly interchangeable with the Brown Bess of Marlborough's army in the Low Countries. Nevertheless, hand firearms had existed since the fifteenth century or earlier, and cannon more than a hundred years earlier still. It is doubtful whether the smooth-bore musket ever much exceeded in range the best of the longbows, and it is certain that it never equaled them in accuracy nor in speed of fire; yet the longbow is the almost unimproved invention of the Stone Age.[2]

[2] This does not contradict the fact that the introduction of firearms made it possible for a less trained man to become a fairly efficient soldier, and this was a great *social* invention in the art of war.

Again, while it was by no means completely stagnant, just before the wooden man-of-war left the seas, it was of a pattern which had been fairly unchanged in its essentials since the early seventeenth century, and which even then displayed an ancestry going back many centuries more. One of Columbus' sailors would have been a valuable able seaman aboard Farragut's ships. Even a sailor from the ship that took Saint Paul to Malta would have been quite reasonably at home as a forecastle hand on one of Joseph Conrad's barks. A Roman cattleman from the Dacian frontier would have made quite a competent vaquero to drive longhorn steers from the plains of Texas to the terminus of the railroad, although he would have been struck with astonishment with what he found when he got there. A Babylonian administrator of a temple estate would have needed no training either in bookeeping or in the handling of slaves to run an early Southern plantation. In short, the period during which the main conditions of life for the vast majority of men have been subject to repeated and revolutionary changes does not even begin until the time of the Renaissance and the great voyages, and does not assume anything like the accelerated pace of the present day until well into the nineteenth century.

Under these circumstances, there is no use in looking anywhere in history for parallels to the successful inventions of the steam engine, the steamboat, the locomotive, the modern smelting of metals, the telegraph, and the transoceanic cable, the introduction of electric power, dynamite and the modern high explosive missile, the airplane, the electric valve, and the atomic bomb. The inventions in metallurgy which heralded the origin of the Bronze Age are neither so concentrated in time nor so manifold as to offer a good counterexample. It is very well for your classical economist to assure us suavely that these changes are purely changes in degree, and that changes in degree do not vitiate historic parallels. The difference between a medicinal dose of strychnine and a fatal one is also only one of degree.

Here I wish to comment on a favorite error of those who are scientifically illiterate: namely, the inability to understand or even to comtemplate any but linear processes. A linear process is one in which, when a certain cause produces a certain effect, twice the cause will have twice the effect. These are by far the simplest processes for even the scientist to describe; and when he has succeded in explaining a complicated phenomenon in linear terms by some technical trick, he is very happy. Nevertheless, none of the really catastrophic phenomena of nature and of experiment are even nearly linear. If I take a piece of glass and throw a steel ball at it, then if the velocity is small, the ball will fly back from it in a nearly elastic manner. Under these conditions, if I double the velocity of the ball, I will not be very far from doubling its velocity after reflection. The linear approximation to the phenomenon, that is, will be satisfactory for most ordinary purposes. However, at a certain point which we cannot specify too precisely, the course of the phenomenon will become very different. A stress will be set up which will be greater than that which the glass is able to stand without a separation of its parts – and we have an incipient crack. In forming this crack, there will be a very great rearrangement of stresses within the glass. The crack will terminate in a region in which the stresses are extremely great because of the sharpness of the crack itself. Thus the crack will tend to extend itself beyond any given terminal point, and will again be subject to separation stresses at the new terminal.

In this state of affairs very small causes will produce very great effects. A totally unforeseen and unknown irregularity of the glass may deflect the crack to the right or to the left.

Such a process is likely to involve the absorption of a considerable amount of energy. The ball itself will no longer be reflected in a quasi-elastic manner, but will fall more nearly dead. The difference between the causes in the unbroken glass and the broken glass will still only be one of degree; but the difference in effect will be that between a simple sort of reflection and a broken pane.

In other words, while it is true within fairly extensive limits that a small change in causes will produce a small change in effects over a sufficiently small interval of time, the scale of this interval of time is not something which we can determine *a priori* without a very detailed knowledge of the dynamics of the system. The long-time results of two nearly identical causes may diverge with the time, until the final discrepancy has reached any degree whatever. For this purpose a thousand years may be a short time or a thousandth of a second a long time, depending on the particular system considered. It only takes a small modification of the impetus of the firing pin of a gun to change a misfire into the effective projection of a bullet; and in case this gun is in the hands of an assassin, this vanishingly small difference may produce the difference between a revolution and a peaceful political development. Therefore, the difference supposed to exist between a large quantitative change in circumstances and a qualitative change will not stand close inspection.

Now, scientific history and scientific sociology are based on the notion that the various special cases treated have a sufficient similarity for the social mechanisms of one period to be relevant to those of another. However, it is certainly true that the whole scale of phenomena has changed sufficiently since the beginning of modern history to preclude any easy transfer to the present time of political, racial, and economic notions derived from earlier stages. What is almost as obvious is that the modern period itself is highly heterogeneous.

In the opinion of the average man, the modern period is characterized by what he considers to be the virtuous rapidity of progress. It will be quite as true to say that the modern period is the age of a consistent and unrestrained exploitation: of an exploitation of natural resources; of an exploitation of conquered so-called primitive peoples; and finally, of a systematic exploitation of the average man. The modern period begins with the age of exploration.

For the first time Europe had become aware of the existence of great thinly settled areas capable of taking up a population exceeding that of the Europe of the time, and full of unexplored resources, not only of gold and silver but of the other commodities of commerce as well. These resources seemed inexhaustible, and indeed on the scale on which the society of 1500 moved, their exhaustion and the saturation of the population of the new countries were very remote. Four hundred and fifty years is farther than most people choose to look ahead.

However, the existence of the new lands encouraged an attitude not unlike that of Alice's Mad Tea Party. When the tea and cakes were exhausted at one seat, the most natural thing for the Mad Hatter and the March Hare was to move on and occupy the next seat. When Alice inquired what would happen when they came around to their original positions again, the March Hare changed the subject. To those whose past span of history was less than five thousand years and who were expecting that the Millennium and the Final Day of Judgment might overtake them in far less time, this Mad Hatter policy seemed most natural. As time passed, the tea table of the Americas has not proved to be infinite;

and as a matter of fact, the rate at which one seat has been abandoned for the next has been increasing at what is probably a still increasing pace.

The stable peace of Europe over much of the last century had greatly reduced the opportunities for the investment of capital at a large risk, and with a large return; and the Consuls, the Consolidated Annuities of the Bank of England and the traditional repository of British great fortunes, had sunk lower and lower in their rate of interest. Under these conditions, the new lands offered a speculative investment with a reasonable chance of large returns; and of these new lands, the United States of America was the first in the money market. Thus American development was pushed well beyond its intrinsically rapid normal rate, by the desire of those in the Eastern States and beyond the seas to share in the new Tom Tiddler's ground.

A new technique of invention had already arisen to catch up with the new geographical frontiers, and the railroad was a rapidly growing success. In 1870, it had already spanned the new lands, and integrated even California into the States, in a way in which that outpost could not otherwise have been integrated. Indeed, if it had not been for the exhaustion of the country during and after the Civil War the advent of the Pacific railroad might have occurred a good many years earlier.

It was the railroad and the electric telegraph which had in fact united the States called United. In 1870, the greater part of the territory wrested from Mexico, and the northern regions of Oregon and Washington were still vast empty spaces. In the opinion of those of the time, they offered inexhaustible room for homesteading and grazing and even sites for industrial development in the remote future. In a bare twenty years more, this newly opened frontier had already begun to vanish. Not a thousand years of the type of life of medieval or even eighteenth-century Europe could have exhausted our resources so thoroughly as a century of our own free-handed procedures.

So long as anything remained of the rich endowment of nature with which we started, our national hero has been the exploiter who has done the most to turn this endowment into ready cash. In our theories of free enterprise, we have exalted him as if he had been the creator of the riches which he has stolen and squandered. We have lived for the day of our prosperity, and we have hoped that some benevolent heaven would forgive our excesses and make life possible for our impoverished grandchildren. This is what is known as the fifth freedom.

Under these conditions, the new resources given by invention have naturally been turned to the even more rapid exploitation of the resources of our soil. The pick-and-shovel miner has given way to the steam-shovel operator. The inexhaustible resources of the Mesabi Range of iron ore have been worked down to tailings. This was, it is true, a result of the last war, but it is also true that we had decided to fight a war according to our own traditions, by the vastly more rapid exhaustion of our own depleted resources. This game has another name than that of war. It is also called beggar-your-neighbor.

In this process of exhaustion of resources, we have found two eager competitors among other countries: England and the pre-war Germany; but neither of them has mastered the art of waste so thoroughly as we. Now we are scraping the bottom of the barrel. Our domestic oil supply is only maintained by the continual discovery of new fields, most of which are not in the United States. From the discovery of a field to its exhaustion is often scarcely a matter of twenty years. Tin, the world over, has become a rare metal; lead is following in its path. Copper is the basis of our electrical industry, and yet the time is near when we can scarcely use copper with the profusion with which the Aztecs used gold. Our beef is beginning to come from the Argentine; our wood pulp has long come from Canada and Sweden.

Obviously, this cannot go on for many centuries, or even many decades, without being terminated by the sheer absence of the material which we seek. I think that if we make as a postulate the continuation of the techniques of the present day, the average intelligent businessman would chime in with this statement. However, he puts his hope in the continued future development of technical skill and of invention.

It is true that technical skill and invention have carried us very far. Aluminum, which was a rare metal in the time of our fathers, is one of the mainstays of modern industry, and has already replaced copper in the construction of many of our long-distance electric transmission lines. We obtain magnesium from the sea. Of all of our resources, the sea is the most inexhaustible. The wooden utensils and containers of our childhood have given way to cardboard and to plastics, and aluminum foil has supplanted the tinfoil with which we used to wrap our packages. Rubber from the oil wells and the chemical factories is a permanent competitor of rubber from the plantations. Silk, too, was displaced by nylon when the war shut us off from the Orient. Not only has invention been a help and a convenience for us, but it has even been something without which we should already have fallen into the clutches of universal want.

However, there are places where invention does not promise to take up the slack of our continuing and increasing demands. At the best, the supply of coal in the world is a matter of a few centuries, as that of oil is of a few decades. These are vital as sources of energy. The total water power of the world, if exploited over the complete fall between its source and the sea, is not adequate to replace our use of coal and oil at the present time. The known supplies of fissionable material for atomic power are already more than bespoken by the claims of a few decades hence; and the use of these resources as weapons has greatly and permanently endangered this value as a source of peacetime energy. In short, the vital needs of the human race but a few generations hence depend upon the forthcoming of inventions which do not as yet exist.

Now, the process by which invention takes place is most complicated, and often is not too well understood even by the inventors themselves. There are certainly large elements of chance in it, but it is not altogether random. The phenomenon according to which an invention is made simultaneously by inventors without contact and in very different parts of the world, is too familiar to be regarded as mere coincidence. The liquefaction of gases and the transmission of speech by the telephone are two examples of this sort of dead heat.

Perhaps in such cases the track is clear for certain inventions to be made, and accordingly more than one person takes advantage of the changed situation. The circumstance that makes possible this diversion of invention or discovery into a new direction may be a radical innovation in technique, such as the vacuum tube. On the other hand, it may be a new intellectual concept, such as that of quantum theory, or of the equivalence of matter and energy. However, to refer the obvious inventions which meet the eye of the public to seminal changes in technique and seminal scientific ideas merely pushes the problem of the statistical incidence of invention farther back. At this higher level, inventions are almost certainly to be regarded as in some sense random and accidental. They are rare occurrences in a system which is too little understood for us even to apply with confidence any such notion as those of probability and statistics.

Thus in depending on the future of invention to extricate us from the situations into which the squandering of our natural resources has brought us we are manifesting our national love for gambling and our national worship of the gambler, but in circumstances under which no intelligent gambler would care to make a bet. Whatever skills your successful poker player must have, he must at the very least know the values of his hands. In this gamble on the future of inventions, nobody knows the value of a hand.

If the food supply is falling short, or a new disease threatens us, inventions to relieve it must be made before famine and pestilence have done their work. Now, we are far nearer to famine and pestilence than we like to think. Let there be an interruption of the water supply of New York for six hours, and it will show in the death rate. Let the usual trains bringing supplies into the city be interrupted for forty-eight hours, and some people will die of hunger. Every engineer who has to deal with the administration of the public facilities of a great city has been struck with terror at the risks which people are willing to undergo and must undergo every day, and at the complacent ignorance of these risks on the part of his charges.

The very increase of commerce and the unification of humanity render the risks of fluctuation ever more deadly. In former days, a catastrophe in one part of the world might pass almost unnoticed elsewhere. The fall of Rome was scarcely realized to exist in a China almost ignorant of Rome itself. Tamerlane could build his pyramids of skulls in Central Asia without more effect in Western Europe than an annoying interruption of the spice and the silk trades. Compare this with the universal misery left by the last World War. Before this century no single cataclysm could at the same time have reduced Germany to the level that had followed the Thirty Years' War, could have devasted China more than all the incursions of the tribes north of the Great Wall, could have filled India with internecine strife, could have brought England to a barren austerity, and completely disordered the ideals and the economic life in the United States. Even when compared with the wars of Tamerlane in what is now Central Asia, the havoc of this newest of all wars has exceeded a hundredfold the local havoc of that master of destruction.

It is not necessary to bring in the consideration of war for us to see how much more naked we lie to disaster than at any time before. In the old days, quarantine gave the nations some protection against disease. At present, it is perfectly possible for a man infected with typhus or malaria or the bubonic plague to get on board a plane to the United States, and to disembark before any symptoms are manifest. Thus it is easy for disease to become rife among us. It is true that our methods of combating disease have reached an ever higher point of development, but never before has the protection of the health of our people been the hair-trigger struggle that it is now, and never before could a mistake of minutes be so deadly.

Even fifty years ago our cities were largely supplied with milk and with garden truck from their immediate neighborhoods. A local crop failure was a serious matter to the people in each region separately, but unless it was due to bad weather of a very wide geographical distribution, it was not of much account as far as the nation as a whole was concerned. Nowadays, we get our garden truck from Delaware, from Southern Texas, from Florida and from California. Our fruit comes largely from the semi-tropical parts of our own country and from the Spanish Main. The less favored suburban truck and fruit gardens have gone out of existence, and even our dairy industry is not in a healthy condition.

A temporary disturbance of train and truck service can so derange food industries dependent on long-distance transportation that it can produce effects of much greater seriousness than it ever could before.

It is true that on the average we now live in greater plenty than ever in the past. What I am claiming is that a serious derangement and destruction of this plenty has become much more likely than in past times. The way in which the tightening of international connections has increased the vulnerability of the world is shown in the effect of the war with Japan on the rubber and the silk industries. As we have said, the occupation of Malaya forced us to depend on our new synthetic rubber, while the interruption of traffic with Japan drove silk off the market and opened that market to nylon. In this case, both synthetic rubber and synthetic silk were already so far developed that there was a reasonable expectation that the loss could be made up by a forced development of these synthetic products. We may not always be so fortunate. I repeat, there is not the slightest assurance that when the need for a new product or process arises, we shall find it at hand; and failure of this replacement even in one important case may be fatal to humanity.

An example of a threatening situation which we have not too much time to relieve is that of the lowered water-table of the soil. This phenomenon is not confined to one region. It is found in California, in our eastern states, and in the London basin in England. Even the best-watered communities have scarcely enough fresh water locally available for the overwhelming needs of modern industry; and in a community like California, they do not even have enough for modern modes of individual life. Thus New York drinks up the brooks of the Adirondacks, Los Angeles waters its parched lawns with the Colorado River, and even smaller communities like Boston must go many miles for their water supply. The result is a continual draft on the water in the soil, with an ever-decreasing bank account to draw on. Some day our drafts will come back marked "no funds."

There have been brilliant suggestions for relieving this situation by the direct extraction of sweet water from sea water. Here the ordinary means of distillation of sea water are most uneconomic. The heat of evaporation of water is large, while the heat of solution of salt in water is so small as to suggest the possibility of finding some chemical to precipitate the salt of sea water. This chemical is then to be used again, after an inexpensive cycle of operations. However, if sea water is to play any rôle in supplying municipalities or in irrigation, no such substance has yet been found which is cheap enough for this tremendous bulk use.

It is true that engineers have developed certain forms of high-pressure distillation which are much more economical than any ordinary distillation. They begin to enable distilled sea water to compete with natural water supplies, if these must be pumped over hundreds of miles. In the case of a city substantially at sea level, like Los Angeles, we may soon hear more of distilled sea water. However, after the water is distilled, it must be raised to whatever level is needed for municipal supply or irrigation; and this, if it is to be done on any large scale, is a task comparable with that of running the rivers of the United States uphill. It is only thinkable on the basis of new and cheap energy supplies. Even atomic energy is not yet ripe for this use, and may never be. If we conquer this problem, we shall only do so after a struggle in which we cannot be sure of victory until we have achieved it.

Many of us are accustomed to think of progress and invention in terms rather of the physical than of the biological sciences. Yet it is perhaps in medicine that the most vital changes of the last century have been registered. Our conquest of infectious diseases, all the way from syphilis to scarlet fever, and from typhus to pneumonia, whether they are due to bacteria, viruses, animal parasites, or rickettsia bodies, has been so dramatic that it has changed the very postulates of our everyday life. In advanced communities, we have forgotten the little row of tombstones which signaled the infant mortality of our grandfather's time. We have forgotten the consumptive poet such as Keats, and the syphilitic poet such as Heine suffering for the sins of his youth in the tortures of the mattress-grave of the tabetic. The skull-rotten patients of the London Dock Hospital no longer furnish the theme for the horrors of a modern Hogarth. Even the diphtheria which played such havoc with our infant uncles and aunts, and the pneumonia which threatened the last generation after a chill, have shrunk to relatively small proportions. These diseases have not yet been wiped out, but with the aid of modern chemo-therapy and of anti-biotics, they are well on the way to disappearance. If they have not completely vanished, they are at least recognized by the community as so disgraceful to its level of sanitation that even a single case is no longer to be tolerated without radical action.

Indeed, there are now many doctors of wide practice who have never in their lives seen a typical case of diphtheria. On the other hand, the best doctor of a century ago would need a rigorous training to be fit to act as a modern hospital attendant. It is true that this overwhelming progress of medicine has gaps in it of which the best medical opinion of the day is not too proud. Cancer still eludes us. Great advances in surgery have indeed been made possible by the discoveries of anaesthesia and of asepsis. They allow us to perform on cancerous patients early radical operations which give a hope of survival which scarcely existed in previous times. The scalpel, the hot wire, and the coagulating electrode share their victories with the new deep-cutting and discriminating knives of the X-ray and of radium. Nevertheless, when it is too late to use these extraneous and destructive tools, which only serve as stop-gaps, it is in general too late to save the patient.

Our great cancer laboratories are indeed seeking to solve the problem by a mass attack, but the hopes they offer us are still acceptances drawn on the future of invention, and the future has not yet taken them up. We have greatly improved the chances of the individual cancerous patient, but we are still helpless before the central problem of cancer.

What we have said about cancer applies with very little modification to the other great degenerative diseases. Most of the degenerative diseases of the nervous system are still beyond us. At best, we can only alleviate the pains of the patient and prolong his life. In the matter of mental diseases, we have done much to improve the status of the patient, and even to make cures in some cases; but to a large extent we do not understand our own cures, and it is only a part of those marginally insane whom we ever expect to see walking the streets again.

These are problems for the future. We can but hope for the best. Whether the future can solve these problems, no man knows. While we admit the existence of these unconquered areas of disease, the last five hundred years of medicine have been a triumphant progress. Nevertheless, they have introduced new dangers which it would be folly to minimize.

In the first place, at the very scene of our greatest triumph, the conquest of infectious diseases, we must never forget that we are fighting an enemy who is multiform and resourceful. Our early use of the sulpha-drugs was so inept that we have given many germs the chance to develop strains relatively immune to these substances. The efficiency of the sulpha-drugs has gone down to a small part of what it was in the beginning. The early users of these drugs had neither the information, nor in many cases the courage, to employ them in doses which would exterminate the disease, not scotch it.

Thus, while we have made enormous progress in the understanding and care of health, there is more than one case in which the word *progress* has a strongly Pickwickian element. For all that, it is in medicine that the idea of progress has received its most valid confirmation. Yet even here there are very serious gaps, not only in our progress, but in our methods of evaluation of progress, which need a serious critical discussion.

In connection with mental cases, but also with many others, I wish to deplore the fast-and-loose way with which most doctors play with statistics. A disease is first recognized in those cases in which it assumes an acute or even fulminating form. Accordingly, the early statistics give a disease, whatever it may be, a high mortality rate, and a large list of complications. Later on, similar physiological or mental changes are recognized in patients who are less ill and who would probably have recovered anyhow. At least, many of them might have led a useful life for several years even without treatment. When treated, these less serious cases respond far better than the cases already doomed. "Ah-ha," says the doctor. "Look at my statistics. My esteemed predecessors saved only half their patients, and I saved nine-tenths." What a triumph for medicine! It is this sort of change, rather in diagnosis than in therapeusis, which is responsible for much of the crowding of our hospitals for the insane and for many of the reported cures.

These are all minor defects. The real danger of modern medicine lies much deeper. The change in the dietary and other medical habits of the human race has been profound and will become more profound with each year, as our natural food supply runs out, and as we have to look further afield to supplement it. These changes may not all be innocent. With our modern chemical technique, we can hydrogenate or dehydrogenate fats as we please. Moreover, it is in part one of the present developments, and in part one of the expected developments of the near future, that we may convert petroleum products into fatty acids and glycerine, and thereby construct synthetic articles of food emanating from our oil wells. In these cases, what we ordinarily call chemical purity may be relatively easy to attain, but this limited chemical purity does not necessarily constitute medical purity. We must always be on the watch that small quantities of catalysts used in transforming our food oils do not have slow poisonous effects, which it may take a lifetime to show. We must be on the watch that if we should come to the use of mineral oil as a raw material for food, we do not retain from the oil or create in it minute quantities of carcinogens or cancer-producing substances. Even minute quantities of these and of other deleterious products may be fatal after many years of apparently innocuous use, and may contribute to the toll of degenerative disease. It is certain that the processing of foods is subjecting us to many risks universal to the nation if not to the race, which may not show themselves until it is too late to do anything much about them.

But it is not in this direction that the most immediate dangers of modern medicine are to be found. Every population expert is aware of the greatly changed and rapidly changing age of our population. The progress of medicine is still increasing the average length of life and the numbers of those who are now alive, but who would otherwise have been dead. This increase is disproportionately large in the upper age-brackets. It conceals the real index of the reproductive power of the population, which instead of being the total number of those alive, is the total number of married women between the age of puberty and that of the menopause. This number is certainly increasing much less rapidly than the population as a whole, and may well be decreasing. The social pressure of maintaining the aged alive is likely to lower the reproductive index of a community still further. We are on the verge of closing our schools and of opening homes for the aged. Are we reproducing rapidly enough to remain alive? At what level should we maintain birth control?

This entire question of balance of population is a delicate one. Among the first to think clearly on the subject was Malthus. He pointed out that there is a general tendency for a freely nourished population to multiply beyond its resources of nourishment. This tendency has indeed been masked since Malthus' time by our increased resources in land and transportation. There have even been economists so bold as to venture to deny that it ever existed. Yet it has only been masked, and the increase of world population in China and India as well as in the Western countries has already been such as to be associated with an incidence of famine which scarcely any other age can show.

This is probably a proper place for me to discuss in detail Darwinian evolution and its historical impact on the popular ideology of progress. The Darwinian theory of evolution must be clearly distinguished from the earlier ideas along these lines which were developed by Lamarck and by Erasmus Darwin, the grandfather of Charles. The earlier forms of evolutionism are in direct contradiction with a passage in the Bible, which says that man by thinking cannot add a cubit to his stature. They presuppose some process by which an animal or a plant which is in need of a certain variation to adapt itself to its present environment will favor that variation in preference to all others. These were vitalistic theories, presupposing the existence of the life forces of which Samuel Butler and Bernard Shaw talk so much, and they have become the favored creed of the element now in power in Soviet Russia. As I understand this creed, it contains two not necessarily equivalent statements. The first, and more defensible, is that the heredity of a species does not directly produce the forms of the descendants, but does so in a manner which also involves the environment. The second, which may be considered to be supported by no adequate evidence, is that the environment will directly summon these variations which make for survival under it.

It is the Lamarckian theory of evolution which has colored the present emotional attitude towards progress. The average advocate of progress believes in a life force favorable to man, driving him continually towards greater and greater successes. In this he is in accord with the least scientific side of Soviet official biology.

Charles Darwin did not completely reject the views of Lamarck, but he added an element which supplemented them and which in the hands of later scholars was destined to replace them. This element is contained in the theory of natural selection. By Darwin's own statement, as well as that of its co-discoverer Wallace, it is directly due to the influence of Malthus.

According to this view, whatever the nature of the process of variation may be, it is a variation which has no particular tendency to be favorable either to the individual in which it occurs or to his progeny. Indeed, most variations are monstrosities and failures. Very occasionally a variation will arise which will more successfully adapt the individual to survival in his particular environment than the state preceding the variation.

In the course of the Malthusian struggle for food and of other forms of competition between individual and individual, these favorable variations will live and will produce progeny, while the merely monstrous ones will die out and leave no descendants. If we assume that variation tends to take inheritable forms, and that the different variant forms would tend to separate themselves from one another so far that there is no interbreeding, or at least no production of viable and fertile hybrids between them, the new favorable variants will tend to supplant the previously normal form, and will ultimately become a new species. This may happen in more than one direction, and accordingly the new surviving forms will often produce more than one species.

In this theory of evolution, the apparent purposiveness of the pattern of surviving species is produced, not by a life force which continually pushes them to higher levels, but by a process of erasure, in which only those forms survive which are reasonably in equilibrium with their environment. On the other hand, those forms which are less in harmony with their environment are pushed out by the competition of the more suited forms. The pattern of a species is then produced by a process of elimination, and in this resembles the pattern which we obtain when we dissolve the blade of a leaf and only retain the lacework of its veins.

I have said that Darwin did not categorically deny Lamarckian evolution. However, his successors, such as Weissman, made a definite effort to secure positive evidence for Lamarckianism, and they failed. In particular, they strove to see if under a continual mutilation the animals of a species would ultimately produce progeny showing that mutilation. It can be objected, of course, that mutilation may be an exception to general Lamarckian process; and in any case, negative evidence, obtained under very particular circumstances, may be no set-off to positive evidence elsewhere. Nevertheless, no clear and unambiguous evidence for Lamarckian evolution has been forthcoming. Indeed, the zeal of the Lysenko party of the Russians for Lamarckian theory has all the earmarks of an attempt to cut short experiment, and to persuade the world to take a form more suitable to their Marxian views. It must also be acknowledged that it contains a strong and perhaps not unjustifiable economic element. The issue at stake is whether the lion's share of Soviet money should go into the long-time work of the Mendelians, or into the less scientific, but not necessarily ineffective, work of the professional animal and plant breeders. It is, in American language, T. H. Morgan versus Burbank.

Burbank and the Russian animal and plant breeders have not been completely and utterly discredited in practice, but the bulk of the evidence is that the geneticists such as T. H. Morgan have been substantially correct in their low evaluation of the Lamarckian element in evolution. T. H. Morgan, among others, has shown that a strictly Darwinian theory of evolution is consistent with the well-established view of genes in modern Mendelism. J. B. S. Haldane and his school have drawn the mathematical conclusions from the views of Morgan and have established a rate of evolution from purely Darwinian sources which is at least not grossly inconsistent with the observed facts. Thus at the present time evolution has been reduced to a by-product of a process which is in no way friendly to the survival of the race, and is morally the full equivalent of Malthusianism.

Indeed, the Soviet opposition to Malthusianism, although indefensible as a matter of scientific fact, contains at least this specious and quasi-moral justification, that Malthusianism has been used quite unjustifiably as a moral excuse for ruthlessness. It is just as far from the essence of Darwinism to assert that those species which survive do so through any moral right to survive, as it is to look for a life force pushing us eternally onward and upward. The tapeworm is the result of a line of evolution at least as long as that of man, and this has had only the consequence of producing animals more fit to be tapeworms. The ruthless businessman who justifies himself as being more fit to survive than his weaker antagonist is merely defending his actions by a bad pun which has nothing to do with his moral worth.

There are, however, modified forms of this quasi-moralistic Malthusianism which seem to have a certain persuasiveness even to those who ought to know better. I have heard it personally argued by anthropologists who consider themselves informed liberals that in the new projects of the growing of peanuts to which England has committed herself in her African colonies, as a way of avoiding her own threatening and unfortunate fate, it will be well to deny to the natives the benefits of modern medical help. Otherwise, they say, infant mortality will go down, and the native will absorb in their own multiplication all the newly created fruitfulness. That some such process of infant extermination may actually take place is not in conflict with the records of colonial history.

Nevertheless, if this denial of medical aid is done with conscious purpose, or even if it is done without purpose, and the facts penetrate home to those Englishmen and Americans who are what the Englishman and the American of the present day like to think they are, it will be so damning of all claim to a high moral status that it will be simply intolerable. Even the loss of the position of the white man will be a calamity much more to be accepted. After all, there is no person of intelligence who does not know that just as his own stay on earth is limited, so is that of the human race, and the average decent citizen would prefer to shorten his own stay, and that of his race as well, rather than have the shame of being responsible for mass murder and massacre.

The anthropologist may say that this is only one of our taboos, and may not be shared by those of other cultures, but the anthropologists know very well that all our morality is one of taboos and cannot be explained away into the need for either individual or racial survival. Pursuit of these lines of thought for the purpose of insuring white supremacy is but a consent to the war of all against all. In those of us who are proud to think of our tradition as civilized, this can lead only to external and internal damnation.

There is a certain cheap optimism in vogue among the more conservative sort of economists, which says substantially that because we have not yet been consumed by calamity, we never shall be. However, the archives of geology and even recent biological history show us that many a race of animals has become extinct. To argue racial immortality from our present continued existence is on the same level as to argue our individual immortality on the basis of the fact that we have never died yet. It is interesting, therefore, and rather important for us, to know something about the circumstances under which other races have perished.

In some of the extinct races of animals the problem of their extinction is clear enough. Some catastrophic change has taken place, as for example, a change in climate or in some other geographical circumstance which the race has been unable to survive. In other cases the problem is of a more complicated nature. As an example, let us take the Titanotheres. They were heavy-bodied mammals with a branched sort of nose-horn, the use of which is not perfectly clear to us. The early Titanotheres had rather simple nose-horns, and were animals of a fairly large but not excessive body weight. As the line proceeds, the nose-horn becomes more and more complicated, and the body weight greater and greater. Both reach their apogee at exactly the same time when the Titanothere is on the edge of extinction.

What determines this sort of development genetically is not known. It seems that the whole complex of Mendelian inheritance and of natural selection had channeled the Titanothere into a path where it is suitable for only a very narrow range of external environment. At any rate, while there is variability and to spare in the size and form of the horns, the Titanotheres show very little variability in other respects. Most of their development went into the increasing elaboration of the horns and into the increase in the size of the body necessary for the animal to bear such an armature. All the Titanotheres' chances for survival were in one basket, and whatever their chosen environment was, they must have been very well accommodated to it. Either they had so narrowed their own line of development that there was no environment whatever left to suit them, or some slight change in the environment wiped them out.

Another interesting example of the problem of extinction is suggested by the remark that there is a general relation between the size of an island and the size of the animals living on it. In general, small islands are inhabited by forms that are physically small. Probably, the outstanding exception to this is constituted by the giant land tortoises of the Galàpagos, but these animated tanks live so long, continue growing so indefinitely, live at so low a metabolic level, that they may be supposed to have a population dynamics of their own.

A large animal needs a large amount of food, and thus a considerable area over which it may range. However, even on this assumption, there must be few of the named East Indian islands which could not furnish food for a dozen or so orangutangs or a brace of elephants. But when the population of a community falls below a certain size, its continued existence becomes subject to extraordinary risks. It is quite clear that only by a miracle could we expect a population of two or three elephants to remain generation after generation with a composition including one male and one female. It would not take a very long time for a herd of one hundred animals all to be attacked by some pestilence, and there is a very real possibility of the disease proving fatal in all cases.

Even more insidious are the effects of Mendelian inheritance itself; effects so noticeable in small and isolated human communities. When a human community falls below a certain size, and has existed for a certain time, family names are no longer any use in it. It is highly probable that every member in the community will be a Smith or a Jones or something of the sort. Corresponding with this, they will have much the same genetic constitution. As J. B. S. Haldane has pointed out, even when a race is as far from extinction as the Indian elephant of the present day, it is probably near enough extinction to have a remarkably uniform genetic constitution and a remarkably small degree of variation. It is thus much more defenseless against change in environment, inasmuch as there is a scarcity of that small class of misfit individuals who would be especially well adapted to a specifically modified environment.

There is also a tendency for inbreeding to bring into the open secret defects of the genetics of the community, such as recessive lethal characteristics. This follows from the fact that the pattern is restricted to mating among close kinsfolk. It is well known that this is one of the chief causes of the high incidence of epilepsy, blindness, and other malformations among small isolated and inbred communities. Thus a permanent community which falls below a certain size ceases thereby to be stable.

It is this size of community, and the grazing space which is necessary for its continued earthly existence, which determines the size of the smallest island capable of maintaining certain species of animals. There is thus a proportionality established between the size of an animal and the size of the smallest island which will support a community of these animals, although this ratio is not that between the size of the individual and the size of its own necessary grazing ground.

The late Professor Lawrence J. Henderson has shown that the environment under which life can exist at all is bounded by very narrow limits. The environment under which a particular form can exist is far narrower. The survival of the race depends on a favorable balance of exchange between the variability and adaptability of the race to different conditions, and the variability of the environment in which it must exist. It is one of the paradoxes of the human race and possibly its last paradox, that the people who control the fortunes of our community should at the same time be wildly radical in matters that concern our own change of our environment, and rigidly conservative in the social matters that determine our adaptation to it.

What then shall we do? Our nostalgia for the "simple life" antedates the success of the industrial revolution to which we have been subject, and must not blind us to the fact that we are not free to return to that pristine state. Our industrial progress has mortgaged our futures. On the farm belonging to the New Hampshire farmhouse in which I have written this book, there are neither trees large enough to furnish the timbers for such a house, nor a soil rich enough to maintain the crops which my predecessors raised. If I do not step into the motorcar of the present generation, and drive to a modern chain store which receives its food from refrigerator cars, I must live on very short rations indeed. I cannot depend for my food on the depleted herds of protected deer; and if I should fish in the waters of my river, almost the only fish which I may expect to find there will have been planted by a state hatchery. If I wish to buy a stove, the iron in it comes from Pittsburgh and not from Tamworth Iron Works, for the bog-iron mines of this locality have long ceased to pay. In short, it is all very well for me to wish to enjoy the amenities of life which still remain in a country community of this sort. I must, however, realize that whereas in the old days the New England cities were tributary to this community and to communities like it, nowadays these communities represent nothing more than economic extensions of our cities. The *Saturday Evening Post* cover is not an adequate representation of the facts of modern life. No, the way to survival does not lie backward. Our fathers have tasted of the tree of knowledge, and even though its fruit is bitter in our mouths, the angel with the flaming sword stands behind us. We must continue to invent and to earn bread, not merely by the sweat of our brows, but by the metabolism of our brains.

It may be thought that the development of invention from a sporadic manifestation of ingenuity to a large and universal technique has been solved by the great industrial laboratories, and by the employment of the mass attack. This is not so. Valuable as the great laboratory is, it is at its best in the process of development of ideas already open to inspection, and at its worst and least economical in the origin of new ideas. *That it stood us in such good stead during the war is due to the fact that at that time we had a huge inventory of past science, not as yet employed for inventive purposes.* Already this inventory is beginning to run low. To replace it, we need a range of thought that will really unite the different sciences, shared among a group of men who are thoroughly trained, each in his own field, but who also possess a competent knowledge of adjoining fields.

No, size is not enough. We need to cultivate fertility of thought as we have cultivated efficiency in administration. We need to find some mechanism by which an invention of interest to the public may effectively be dedicated to the public. We cannot afford to erode the brains of the country as we have eroded its soil. We must not be serfs, written down as property in the books of our entrepreneurs. We need a system in which variability and adaptability are at a premium and not at a discount. We need an organization which is awake to the facts of invention, and of our ever-greater dependence on more invention. If man is to continue to exist, he must not be an afterthought to business. That one attempt to realize this has bogged down in the present ruthless phase of the totalitarianism of Russia should not blind us to the fact that these problems exist, and that if we do not answer them, we shall perish as individuals, and perish as a race. Give us the freedom to face the facts as they are! We need not expect that the race will survive forever, any more than that we shall survive forever as individuals, but we may then hope that both as individuals and as a race we may live long enough to bring into the open those potentialities which lie in us.

III

RIGIDITY AND LEARNING: TWO PATTERNS OF COMMUNICATIVE BEHAVIOR

We have already said that the nature of social communities depends to a large extent upon their intrinsic modes of communication. The anthropologist knows very well that the patterns of communication of human communities are most various. There are communities like the Eskimos, among whom there seems to be no chieftainship and very little subordination, so that the basis of the social community is simply the common desire to survive on the part of individuals working against enormous odds of climate and food supply. There are socially stratified communities such as those of India, in which the relations of communication between two individuals are closely restricted and modified by their ancestry and position. There are the communities ruled by despots, in which every relation between two subjects becomes secondary to the relation between the subject and his king. There are the hierarchical feudal communities of lord and vassal, and the very special techniques of social communication which they involve.

Most of us in the United States prefer to live in a moderately loose social community, in which the blocks to communication between different individuals and different classes are not too great. I will not say that this ideal of communication is attained in the States. Until white supremacy ceases to belong to the creed of a large part of the country it will be an ideal to which we do no more than lip-service. Yet even this modified formless democracy is too anarchic for many of those who make efficiency their first ideal. These worshipers of efficiency would like to have each man move in a social orbit meted out to him from his childhood, and to perform a function to which he is bound as the serf was bound to the clod. Within the American social picture, it is shameful to have these yearnings; and accordingly, many of those who are most attached to this orderly state of permanently allotted functions would be ashamed to admit this publicly. They are only in a position to display their clear preferences through their actions. Yet these actions stand out distinctly enough. The businessman who separates himself from his employees by a shield of "yes men," or the head of a big laboratory who assigns each of his subordinates a particular problem, and begrudges him the degree of thinking for himself which is necessary to move beyond this problem and perceive its relevance, both show that the democracy to which they pay their respects is not really the order in which they would prefer to live. The regularly ordered state of preassigned functions towards which they gravitate is the state of the ants.

In the ant community, each worker performs its proper functions. There is a separate caste of soldiers. Certain highly specialized individuals perform the functions of king and queen. If man were to adopt this community as a pattern, he would live in a Fascist state, in which ideally each individual is conditioned from birth for his proper occupation: in which rulers are perpetually rulers, soldiers perpetually soldiers, the peasant is never more than a peasant, and the worker is doomed to be a worker.

It is the thesis of this chapter that this aspiration of the Fascist for a human state based on the model of the ant is due to a profound misapprehension both of the nature of the ant and of the nature of man. I wish to show that the whole mode of development of the insect conditions it to be an essentially stupid and unlearning individual, cast in a mold which cannot be modified to any great extent; and also how the physiological conditions of the ant make it into a cheap mass-produced article, of no more individual value than a paper pie plate to be thrown away after it is once used. On the other hand, I wish to show that the human individual represents an expensive investment of learning and study, extended under modern conditions for perhaps a quarter of a century, and almost half of his life. While it is possible to throw away this enormous advantage in training which the human being has, and which the ant does not have, and to organize the Fascist ant-state with human material, I shall indicate that this is a degradation of the very nature of man, and economically a waste of the greatest and most human values which man possesses.

I am afraid that I am convinced that a community of human beings is a far more useful thing than a community of ants; and that if the human being is condemned and restricted to perform the functions of the ant and nothing more, he will not even be a good ant, not to mention a good human being. Those who would organize us according to permanent individual functions and permanent individual restrictions like those of the ant thereby condemn the human race to move at much less than half-steam. They throw away the greater part of our variability and of our chances for a reasonably long existence on this earth.

Let us now turn to a discussion of the facts and restrictions on the make-up of the ant which have made the ant community the very special thing it is. These facts and restrictions have a deep-seated origin in the anatomy and the physiology of the individual insect. Both the insect and the man are air-breathing forms, and represent the end of a long transition from the easygoing life of the water-borne animal to the much more exacting demands of the land.

This transition from water to land, wherever it has occurred, has involved radical improvements in breathing, in the circulation generally, in the mechanical support of the organism, and in the sense organs.

The mechanical reinforcement of the bodies of land animals has taken place along several independent lines. In the case of most of the mollusks, as well as in the case of certain other groups which, though unrelated, have taken on generally a mollusk-like form, part of the outer surface secretes a non-living mass of calcareous tissue, the shell. This grows by accretion from an early stage in the animal until the end of its life. The spiral and helical forms of those groups need only this process of accretion to account for them.[1]

If the shell is to remain an adequate protection for the animal, and the animal grows to any considerable size in its later stages, the shell must be a very appreciable burden, suitable only for land animals of the slowly moving and inactive life of the snail. In other shell-bearing animals, the shell is lighter and less of a load, but at the same time much less of a protection. The shell structure, with its heavy mechanical burden, has had only a limited success among land animals.

Man himself represents another direction of development — a direction found throughout the vertebrates, and at least indicated in invertebrates as highly developed as Limulus and the Octopus. In all these, certain internal parts of the connective tissue assume a consistency which is no longer fibrous, but rather that of a very hard, stiff jelly. These parts of the body are called *cartilage,* and they serve for the attachment of the powerful muscles which are needed for animals of an active life. In the higher vertebrates, this primary cartilaginous skeleton serves as a tem-

[1] Professor d'Arcy Thompson, *Growth and Form.*

porary scaffolding for a skeleton of much harder material: namely, bone, which is even more satisfactory for the attachment of powerful muscles. These skeletons, of bone or cartilage, contain a great deal of tissue which is not in any strict sense alive, but throughout this mass of intercellular tissue there is a living structure of cells, cellular membranes, and nutritive blood vessels.

The vertebrates have developed not only internal skeletons, but also other features which suit them for active life. Their respiratory system, whether it takes the form of gills of the fish or the lungs of land-living vertebrates, is beautifully adapted for the active interchange of oxygen between the external medium and a blood, and the latter is made much more efficient than the average invertebrate blood by having its oxygen-carrying respiratory pigment concentrated in corpuscles. This blood is pumped through a closed system of vessels, rather than an open system of irregular sinuses, by a heart of relatively high efficiency. It is true that this situation is approached in certain invertebrates of high activity, such as the squids and the octopuses. It is most interesting that in other matters, such as the beginnings of a cartilaginous skeleton and the possession of effective image-forming eyes, these forms approximate the stage of organization found in the lower vertebrates.

The insects and crustaceans, and in fact all the arthropods, are built on quite another scheme of growth. The outer wall of the body is surrounded by a wall of chitin secreted by the cells of the epidermis. This chitin is a stiff substance rather closely related to cellulose. In the joints the layer of chitin is thin and moderately flexible, but over the rest of the animal it constitutes that hard external skeleton with which we are familiar in the case of the lobster and the cockroach. An internal skeleton can grow with the animal. An external skeleton (unless, like the shell of the snail, it grows by accretion) cannot. It is dead tissue, and possesses no intrinsic capability of growth. It serves to give a firm protection to the body and an attachment for the muscles. In other words, the arthropod lives within a strait-jacket.

Any internal growth can be converted into external growth only by discarding the old strait-jacket, and by developing under it a new one, which is initially soft and pliable and can take a slightly new and larger form, but which is very soon set to the rigidity of its predecessor. In other words, the stages of growth are marked by definite moults, relatively frequent in the crustacean, and much less so in the insect. There are several such stages possible during the larval period. The pupal period represents a transition moult, in which the wings which have not been functional in the larva develop internally towards a functional condition. This becomes realized when the pre-final pupal stage, and the moult which terminates it, give rise to a perfect adult. The adult never moults again. It is the sexual stage of the animal, and although in most cases it remains capable of taking nourishment, there are insects in which the adult mouth-parts and the digestive tube are aborted, so that the imago, as it is called, can only mate, lay eggs, and die.

In more primitive insects, such as the grasshopper or the cockroach, the larva is not essentially different in form from the imago; the pupa is active, and the last moult differs from the others only in degree. In the higher or holometamorphic insects the difference between larva and adult is so profound that the transition involves a complete resting stage, and takes place catastrophically. The greater part of the tissues are attacked by leucocytes, the destroying white corpuscles of the blood. They resolve themselves into a structureless mush, which serves for the nutrition of a few parts called imaginal buds or discs. Structurally, these imaginal discs represent the whole of the imago. Thus the insect is reborn in a very real sense.

The nervous system takes part in this process of tearing down and building up. While there is a certain amount of evidence that some memory persists from the larva through to the imago, in the nature of the case this memory cannot be very extensive. The physiological condition for memory seems to be a certain continuity of organization, which allows the alterations produced by outer sense impressions to be retained as more or less permanent changes of structure or function. The erasure of metamorphosis is too radical to leave much permanent record of these changes. It is indeed hard to conceive of a memory of any precision which can survive this process of radical internal reconstruction.

There is another limitation on the insect, which is due to its method of respiration and circulation. The heart of the insect is a very poor and weak tubular structure, which opens, not into well-defined blood vessels, but into vague cavities or sinuses conveying the blood to the tissues. This blood is without pigmented corpuscles, and carries the blood-pigments in solution. This mode of transferring oxygen seems to be definitely inferior to the corpuscular method.

In addition, the insect method of oxygenation of the tissues makes at most only local use of the blood. The body of the animal contains a system of branched tubules, carrying air directly from the outside into the tissues to be oxygenated. These tubules are stiffened against collapse by spiral fibers of chitin, and are thus passively open, but there is nowhere evidence of an active and effective system of air pumping. Respiration occurs by diffusion alone.

Notice that the same tubules carry by diffusion the good air in and the spent air polluted with carbon dioxide out to the surface. In a diffusion mechanism, the time of diffusion varies not as the length of the tube, but as the square of the length. Thus, in general, the efficiency of this system tends to fall off very rapidly with the size of the animal, and falls below the point of survival for an animal of any considerable size.[2]

To follow the meaning of this limitation in size, let us compare two artificial structures — the cottage and the skyscraper. The ventilation of a cottage is quite adequately taken care of by the leak of air around the window frames, not to mention the draft of the chimney. No special ventilation system is necessary. On the other hand, in a skyscraper with rooms within rooms, a shut-down of the system of forced ventilation will be followed in a very few minutes by an intolerable foulness of the air in the work spaces. Diffusion and even convection are no longer enough to ventilate such a structure.

In an entirely parallel way, the absolute maximum size of an insect is smaller than that attainable by a vertebrate. On the other hand, the ultimate elements of which the insect is composed are not always smaller than they are in man, or even in a whale. The nervous system partakes of this small size, and yet consists of neurons quite as large as those of the human brain. This is impossible unless there are many fewer neurons, and a much more limited complexity of structure. In the matter of intelligence, we should expect that it is not only the relative size of the nervous system which counts, but in a large measure its absolute size. There is simply no room in the reduced structure of an insect for

[2] In saying this, I do not ignore the existence of fossil dragonflies with a wing span of several feet. First let me remark that this wing spread does not demand an extremely large body. Next, let me say that these existed among the lush vegetation of the coal measure, and that it is quite possible that the atmospheric composition was then appreciably different from what it is at the present time. The extreme body size of modern insects, which is only realized in a few tropical beetles, is of that of a mouse.

a nervous system of great complexity, nor for a large stored memory.

In view of the impossibility of a large stored memory, as well as of the fact that the youth of an insect such as an ant is spent in a form which is insulated from the adult form by the intermediate catastrophe of metamorphosis, there is no opportunity for the ant to learn much. Add to this, that its behavior in the adult stage must be substantially perfect from the beginning, and it then becomes clear that the instructions received by the insect nervous system must be substantially those due to the way it is built, and not to any personal experience. If compared with a computing machine, the insect must be the analogue of one with all its instructions set forth in advance on the "tapes," and with a minimal opportunity for changing these instructions. This is meant when we say that the behavior of an ant is much more a matter of instinct than of intelligence. In other words, the physical strait-jacket in which an insect grows up is directly responsible for the mental strait-jacket which regulates its pattern of behavior.

Here the reader may say: "Well, we already know that the ant as an individual is not a very intelligent animal, so why all this fuss about explaining that it cannot be intelligent?" The answer is that the point of view of Cybernetics emphasizes the relation between the animal and the machine, and in the machine emphasizes the particular mode in which the machine functions as an index of what performance may be expected from it. Thus the fact that the mechanical conditions of performance of the insect are such as to limit the intelligence of the individual is highly relevant from the point of view of this book.

Even those naturalists like Fabre, to whom the emotional and the picturesque in the portrayal of the ant community have most appealed, have still kept their fundamental intellectual honesty and are forced to admit that the behavior of the individual ant shows neither much originality nor much intelligence. A line of ants will play a game of follow the leader, but if there is no leader, and the line is made circular, they will continue to run around in this circle until they are exhausted. In general, among the insects, even when an insect of prey, such as the mantis, has already eaten off the abdomen of its victim, so that it is *in articulo mortis,* what is left of the animal will go on with its own task of eating as if nothing had happened. Not even the enthusiasm of the poet can remake the ant into a human individual.

In the matter of rigidity of behavior, the greatest contrast to the ant is not merely the mammal in general, but man in particular. It has frequently been observed that man is a neoteinic form: that is, that if we compare man with the great apes, his closest relatives, we find that mature man in hair, head, shape, body proportions, bony structure, muscles, etc., is nearer to the newborn ape than to the adult ape. Among the animals, man is a Peter Pan who never grows up.

This immaturity of anatomical structure corresponds to the longest relative period of childhood possessed by any animal. Physiologically, man does not reach puberty until he has already completed a fifth of his normal span of life. Let us compare this with the ratio in the case of a mouse, which lives three years and starts breeding at the end of three months. This is a ratio of twelve to one. The mouse's ratio is much more nearly typical of the large majority of mammals than is the human ratio.

Puberty for most mammals either represents the end of their period of tutelage, or is well beyond it. In our community, man is recognized as immature until the age of twenty-one, and the modern period of education for the higher walks of life continues until about thirty, actually beyond the period of most active physical strength. Man thus spends what may amount to forty per cent of his normal life as a learner. It is as completely natural for human society to be based on learning as for an ant society to be based on an inherited pattern. Learning is in its essence a form of feedback, in which the pattern of behavior is modified by past experience. Feedback, as I have pointed out in the first chapter of this book, is a very general characteristic of forms of behavior. In its simplest form, *the feedback principle means that behavior is scanned for its result, and that the success or failure of this result modifies future behavior.* It is known to serve the function of rendering the behavior of an individual or a machine relatively independent of the so-called "load" conditions.

Learning is a most complicated form of feedback, and influences not merely the individual action, but the pattern of action. It is also a mode of rendering behavior less at the mercy of the demands of the environment.

I shall give an example based on actual experimental and design work carried out in Holland at the Einthoven Laboratories of the Philips Lamp Company. Throughout the telephone industry, automatic switching is rapidly completing its victory over manual switching. It may seem to us that the existing forms of automatic switching constitute a very perfect process. Nevertheless, a little thought will show that they must be very wasteful in equipment. The number of people with whom I actually wish to talk over the telephone is limited, and in large measure is the same limited group day after day and week after week. A very large percentage of my use of telephone equipment is for the sake of communicating with members of this group. Now, as the present technique of switching generally goes, the process of reaching one of the people whom we call up four or five times a day is in no way different from the process of reaching those people with whom we may practically never have a conversation. From the standpoint of balanced service, we are using either too little equipment to handle the frequent calls, or too much to handle the infrequent calls.

There is no one of us who does not remember Oliver Wendell Holmes' little poem on the One-Hoss Shay. This hoary vehicle, as you recollect, after one hundred years of service, showed itself to be so carefully designed that neither wheel, nor top, nor shafts, nor seat contained any part which manifested an uneconomical excess of wearing power over any other part. Actually, the one-hoss shay represents the pinnacle of engineering, and is not a humorous fantasy. If the tires had lasted a moment longer than the spokes or the dashboard than the shafts, they would have carried into disuse certain economic values. Then either these values could have been lessened without hurting the durability of the vehicle as a whole, or they could have been transferred to the other parts perishing earlier. Indeed, any structure not of the nature of the one-hoss shay is wastefully designed.

This means that for the greatest economy of service it is not desirable that the process of my connection with Mr. A., whom I call up three times a day, and with Mr. B., who is for me only an unnoticed item in the telephone directory, should be of the same order. If I were allotted a slightly more direct means of connection with Mr. A., then the wasting of my time in having to wait twice as long for Mr. B. will be more than compensated for. If then, it is possible without excessive cost to devise an apparatus which will record my past conversations, and will reapportion to me a degree of service corresponding to the frequency of my past use of the telephone channels, I shall obtain a better service, or a less expensive one, or both. This is what the Philips Lamp Company has succeeded in doing. The quality of my service has been made less dependent on the load, and it has been obtained by means of a feedback of what Bertrand Russell would call a "higher logical type." It will be the same sort of gain in performance which we have obtained at a lower type by a simple feedback not involving learning.

Again, feedback is the control of a system by reinserting into the system the results of its performance. If these results are merely used as numerical data for the criticism of the system and its regulation, we have the simple feedback of the control engineers. If, however, the information which proceeds backward from the performance is able to change the general method and pattern of performance, we have a process which may well be called learning.

Another example of the learning process appears in connection with the problem of the design of prediction machines. At the beginning of the last World War, the comparative inefficiency of anti-aircraft fire made it necessary to introduce apparatus which would follow the position of an airplane, compute its distance, determine its length of time before a shell could reach it, and figure out where it would be at the end of that time, all without further intervention than that of the gun pointer. If the plane were able to take a perfectly arbitrary evasive action, no amount of skill would permit us to fill in the as yet unknown motion of the plane between the time when the gun was fired, and the later time when the shell should arrive approximately at its goal. However, under many circumstances the aviator either does not, or cannot, take arbitrary evasive action. He is limited by the fact that if he makes a rapid turn, the centrifugal force will render him unconscious; and by the other fact that the control mechanism of his plane and the course of instructions which he has received practically force on him certain regular habits of control which show themselves even in his evasive action. These regularities are not a certain thing that he does universally, but are rather statistical preferences which he shows most of the time. They may be different for different aviators, and they will certainly be for different planes. Let us remember that in the pursuit of a target as rapid as an airplane, there is no time for the computer to take out his instruments and figure where the plane is going to be. All the figuring must be built into the gun control itself. This figuring must include data which depend on our past statistical experience of airplanes of a given type under varying flight conditions. The present stage of anti-aircraft fire consists in an apparatus which uses either fixed data of this sort, or a selection among a small number of cases of such fixed data. The proper choice among these may be switched in by means of the voluntary action of the gunner.

However, there is another stage of the control problem which it is not impossible to represent mechanically. The problem of determining the flight statistics of the plane from an actual observation of its flight, and of then transforming these into rules for controlling the gun, is itself a definite and mathematical one. Compared with the actual pursuit of the plane, in accordance with given rules, it is a relatively slow action, and involves considerably more observation of the past flight of the airplane. It is nevertheless not impossible to mechanize this long-time action as well as the short-time action by which it directs the gun. We thus may construct an anti-aircraft gun which observes by itself the statistics concerning the motion of the target plane, which then works these up into a system of control, and which finally adopts this system of control as a quick way for adjusting the position of the gun to the observed position and motion of the plane.

To my knowledge this has not yet been done, but it is a problem which lies along lines which we are considering, and expect to use in other problems of prediction in the Electronics Laboratory of M.I.T. We are thus constructing a machine which contains a certain element of learning.

The adjustment of the general plan of pointing and firing the gun according to the particular system of motions which the target has made is essentially an act of learning. It is a change in the *taping* of the computing machine of the gun, which alters not so much the numerical data, as the process by which they will act, and it is based on past experience. It is, in fact, a most general sort of feedback, affecting the whole method of behavior of the instrument.

The process of learning which we have here discussed is itself a rather mechanical one, and almost certainly does not correspond to the normal process of learning in man. Here we have quite other indications as to the mode in which this process can be mechanized. These indications are given respectively by the Lockean theory of association, and by the Pavlov theory of the conditioned reflex. Before I take these up, I wish to make some general remarks to cover the interpretation of a suggestion which I shall present.

Let me recount the basis on which it is possible to develop a theory of learning. By far the greater part of the work of the nerve physiologist has been on the conduction of impulses by nerve fibers or neurons, and this process is known to be well represented as an all-or-none phenomenon. That is, if a stimulus reaches the point where it will travel along a nerve fiber at all, and not die out in a relatively short distance, the effect which it produces at a comparatively remote point of the nerve fiber is substantially independent of its initial strength.

Now, nerve impulses travel from fiber to fiber across connections known as *synapses*, in which one ingoing fiber may come in contact with many outgoing fibers, and one outgoing fiber in contact with many ingoing fibers. In these synapses, the impulse given by a single incoming nerve fiber is often not enough to produce an effective outgoing impulse. In general, if the impulses arriving at a given outgoing fiber by incoming synaptic connections are too few, the outgoing fiber will not respond. When I say too few, I do not necessarily mean to say that all incoming fibers act alike, nor even to insist that with any set of incoming active synaptic connections the question of whether the outgoing fiber will respond may be settled once for all. I also do not intend to ignore the fact that some incoming fibers, instead of tending to produce a stimulus in the outgoing fibers with which they connect, may tend to prevent these fibers from accepting new stimuli.

Be that as it may, while the problem of the conduction of impulses along a fiber may be described in a rather simple way as an all-or-none phenomenon, the problem of the transmission of an impulse across a layer of synaptic connections depends on a complicated pattern of responses, in which certain combinations of incoming fibers, firing within a certain limited time, will cause the message to go further, while certain other combinations will not. These combinations are not a thing fixed once for all, nor do they even depend solely on the past history of messages received into that synaptic layer. They are known to change with temperature, and may well change with many other things. If a combination of incoming messages will not cause an outgoing fiber to fire, it is said to be *below threshold;* otherwise, it is said to be *above threshold.*

The tradition of the study of nerve fibers has assimilated the nervous system to that type of machine which consists in a sequence of switching devices in which the opening of a later switch depends on those precise combinations of earlier switches leading into it, which are open at the same time. This all-or-none machine is said to be a *digital* machine. It has great advantages for the most varied problems of communication and control. In particular, the sharpness of the decision between "Yes" and "No" creates the possibility of accumulating these decisions in such a way as to allow us to discriminate very small differences in very large numbers.

Besides these machines which work on a yes-and-no scale, there are other computing and control machines in which the quantities with which we deal are measured rather than counted. These machines are known as *analogy* machines, because they operate on the basis of analogous connections between the measured quantities and the quantities they are supposed to represent. An example of an analogy machine is a slide rule, in contrast with a desk computing machine such as a Monroe or a Marchant, which operates digitally. Those who have used a slide rule will realize that the scale on which the marks have to be printed and the degree of accuracy of our eyes give sharp limits to the precision with which a slide rule can be read. These limits are not as easily extended as one might think, by making the slide rule larger. A ten-foot slide rule will only give one decimal place more accuracy than a one-foot slide rule, and in order to do this, not only must each foot of the larger slide rule be constructed with the same precision as the small one, but the orientation of these successive feet must conform to the degree of accuracy to be expected for each one-foot slide rule. Now, the problems of keeping the larger rule rigid are much more serious than those which we find in the case of the smaller rule, and serve further to limit the increase in accuracy which we get by increasing the size. In other words, for practical purposes, machines which measure, as opposed to machines which count, are very greatly limited in their precision.

Thus for many purposes the mathematical machine which counts or makes yes-or-no decisions is a more precise machine than those which measure. Add this to the prejudices of the physiologist in favor of all-or-none action, and we see why the greater part of the work which has been done on the mechanical analogues of the brain has been on machines which are more or less on a digital basis.

However, if we insist too strongly on the brain as a glorified digital machine, we shall be subject to some very just criticism, coming in part from the physiologists and in part from the rather opposite camp of those psychologists who prefer not to make use of a machine analogy. We have said that in a digital machine there is a *taping*, which determines the sequence of operations to be performed, and that a change in this taping on the basis of past experience is a process of learning, or at least may be such a process. In the brain, the thing most analogous to taping is the determination of the synaptic thresholds, or in other words, of the precise combinations of the incoming neurons which will fire an outgoing neuron with which they are connected. We have already seen that these thresholds are variable with temperature, and we have no reason to believe that they may not be variable with the chemistry of the blood and with many other phenomena which are not themselves originally of an all-or-none nature. It is therefore very necessary that in considering the problem of learning, we should be most wary of assuming an all-or-none theory of the nervous system, without having made an intellectual criticism of the notion, and without specific experimental evidence to back our assumption.

It will be said by many that there is no theory of learning whatever which will be reasonable for the machine. It will be said by others that in the present stage of our knowledge, any theory of learning which I may offer will be premature, and will probably not correspond to the actual functioning of the nervous system. I wish to walk a middle path between these two criticisms. On the one hand, I wish to give a method of constructing machines which can learn. This method will not only enable me to build certain special machines of this type, but will give me a general engineering technique for constructing a very large class of such machines. Only if I reach this degree of generality will I have defended myself in some measure from the criticism that the mechanical process which I have claimed to be similar to learning is, in fact, something of an essentially different nature from learning.

On the other hand, I wish to describe such machines in terms which are not too foreign to the actual observables of the nervous system, and of human and animal conduct. I am quite aware that I cannot expect to be right in detail in presenting the actual human mechanism, and that I may even be wrong in principle. Nevertheless, if I give a device which can be verbally formulated in terms of the concepts belonging to the human mind and the human brain, I shall give a point of departure for criticism, and a standard with which to compare the performance to be expected on the basis of other theories.

At the end of the seventeenth century, Locke considered that the content of the mind is made up of what he calls *ideas*. The mind for him is entirely passive. It is no more than a clean blackboard on which the experiences of the individual write their own impressions. However, if these impressions appear often, either under circumstances of simultaneity, or with a certain resemblance, or under the situations which we ordinarily attribute to cause and effect, then according to Locke, these impressions or ideas will form complex ideas, with a certain positive tendency for the component elements to stick together.

Let it be observed that for Locke the mind is absolutely passive. Therefore, any mechanism by which the ideas stick together must lie in the ideas themselves; but there is throughout Locke's writing a singular unwillingness to describe such a mechanism. Locke's theory can only bear the sort of relation to the fact that a picture of a locomotive bears to a working locomotive. This picture indeed is like a diagram without any working parts. This is not remarkable when we consider the date of Locke's theory. It was in astronomy, and not in engineering nor in psychology, that the dynamic point of view, the point of view of working parts, first reached its importance; and this was at the hands of Newton, who was not a predecessor of Locke, but a contemporary.

For a long period of science, the Aristotelean impulse to classify took precedence over the modern impulse to search for the manner of working of a phenomenon. Indeed, with the plants and animals yet to be explored, it is hard to see how biological science could have entered a properly dynamic period except through the continual gathering of more descriptive natural history. The great botanist Linnaeus will serve us as an example. For Linnaeus, species and genera were fixed Aristotelean forms, rather than signposts for a process of evolution; but it was only on the basis of a thoroughly Linnaean description that any cogent case could ever be made for evolution. The early natural historians were the practical frontiersmen of the intellect; too much under the compulsion to seize and occupy new territory to be very precise in treating the problem of explaining the new forms that they had observed. After the frontiersman comes the operative farmer, and after the naturalist comes the scientist of the modern time.

In the last quarter of the last century and the first quarter of the present one, another great scholar, Pavlov, covered in his own way what is in itself essentially much the same ground as that covered by Locke. This field, that of the conditioned reflexes, he treats experimentally, unlike Locke, who had treated it introspectively. Moreover, he treats it as it appears among the lower animals rather than as it appears in man. The lower animals cannot speak in the human language of ideas and introspection; they must be brought to speak in the language of behavior. Much of their more conspicuous behavior is emotional, and a very large part of their emotions is connected with food. It was with food that Pavlov began, and with the physical symptom of salivation. It is easy to insert a canula into the salivary duct of a dog and to observe the secretion. This secretion is stimulated by the presence of food.

Ordinarily many things unconnected with food as objects seen, sounds, etc., produce no effect on salivation, but Pavlov observed that if a certain pattern or a certain sound had been systematically shown to a dog at feeding time, then the display of the pattern or sound alone was sufficient to excite salivation. That is, the reflex of salivation was conditioned by a past association.

Here we have in the animal, and on the level of the reflex, something very analogous to the association of ideas. In particular, it occurs with reflex responses in which the entire behavior of the dog suggests what we should interpret in man as a strong emotional content. Let us notice the rather complicated nature of the antecedents which are needed to produce a conditioned reflex of the Pavlov type. To begin with, they generally center about something rather important to the life of the animal. The salivation reflexes which we have considered involve something connected with the taking of food, even though, in their final form, the food element may have been entirely elided. We may also show the importance to life of the initial stimulus to a Pavlov conditioned reflex by the example of the electric fences.

In cattle farms, the construction of wire fences strong enough to turn a steer is not easy. It is thus economical to replace a heavy fence of this type by one where one or two weak strands of wire carry a sufficiently high electric voltage to impress upon an animal a quite appreciable shock when the animal short-circuits it by contact with its body. Such a fence may have to resist the pressure of the steer one or two times; but after that, the fence acts, not because it can hold up mechanically under pressure, but because the steer has developed a conditioned reflex which tends to prevent it from coming into contact with the fence at all. Here the original trigger to the reflex is what we should interpret as a sensation of pain; and the response to a sensation of pain is one of those most vitally necessary for the continued life of any animal. The transferred trigger is the sight of the fence. There are other triggers which lead to conditioned reflexes besides hunger and pain. It will be using anthropomorphic language to call these emotional situations, but there is no such anthropomorphism needed to describe them as situations which generally carry an emphasis and importance not belonging to many other of the experiences of the animal.

They are experiences which of themselves produce strong reflexes. What happens in the formation of other conditioned reflexes is a transference of the reflex response to one of these trigger situations. This trigger situation is one which has frequently occurred concurrently with the original trigger. The change in the stimulus for which a given response takes place must have some such nervous correlate as the opening of a synaptic pathway which would otherwise have been closed leading to the response, or the closing of one which would otherwise have been open; and thus constitutes what we now call a *change in taping*.

Such a change in taping is preceded by the continued association of the old strong natural stimulus for a particular reaction and the new concomitant one. It is as if the old stimulus had a power to change the permeability of those pathways which were carrying a message at the same time as it was active. The interesting thing is that the new active stimulus need have almost nothing predetermined about it except the fact of repeated concomitance with the original stimulus. Thus the original stimulus seems to produce a long-time effect in all those pathways which were carrying a message at the time of its occurrence or at least in a large number of them. The lack of importance of the nature of the substitute stimulus indicates that the modifying effect of the original stimulus is widespread, and is not confined to a few special pathways. We thus develop the idea that there may be some kind of general message released by the original significant stimulus, but that it is only active in those channels which were carrying a message at about the time of the original stimulus. The effect of this action may perhaps not be permanent, but is at least fairly long-lived. The most logical place at which to suppose this secondary action to take place is in the synapses, where it most probably affects their thresholds.

The concept of an undirected message spreading out until it finds a receiver, which is then stimulated by it, is not an unfamiliar one. We find messages of this sort used very frequently as alarms. The fire siren is a call to all the citizens of the town, and in particular to members of the Fire Department, wherever they may be. In a mine, when we wish to clear out all remote passages because of the presence of fire damp, we break a tube of ethyl mercaptan in the air-intake. There is no reason to suppose that such messages may not occur in the nervous system. If I were to construct a learning machine of a general type, I would be very much disposed to employ this method of the conjunction of general spreading "To-whom-it-may-concern" messages with localized channeled messages. It ought not to be too difficult to devise electrical methods of performing this task. This is a very different thing from saying that learning in the animal actually occurs by such a conjunction of spreading and of channeled messages. Frankly, I think it is quite possible that it does, but our evidence is as yet not enough to make this more than a conjecture.

As to the nature of these "To-whom-it-may-concern" messages, supposing them to exist, I am on still more speculative ground. They might indeed be nervous, but I am rather inclined to attribute them to the non-digital, analogy side of the mechanism responsible for reflexes and thought. It is a truism to attribute synaptic action to chemical phenomena. Actually, throughout the action of a nerve, it is impossible to separate chemical potentials and electrical potentials, and the statement that a certain particular action is chemical is almost devoid of meaning. Nevertheless, it does no violence to current trends of thought to suppose that at least one of the causes or concomitants of synaptic change is a chemical change which manifests itself locally, no matter what its origin may be. The presence of such a change may very well be locally dependent on release signals which are transmitted nervously. It is at least equally conceivable that changes of the sort may be due in part to chemical changes transmitted generally through the blood, and not by the nerves. It is thinkable that there are "To-whom-it-may-concern" messages which are transmitted nervously, and which make themselves locally apparent in the form of that sort of chemical action which accompanies synaptic changes. To me, as an engineer, the transmission of "To-whom-it-may-concern" messages would appear to be more economically performed through the blood than through the nerves. However, I have no evidence.

Let us remember that these "To-whom-it-may-concern" influences bear a certain similarity to the sort of changes in the anti-aircraft control apparatus which carry all new statistics to the instrument, rather than to those which directly carry the numerical data. In both cases, we have an action which has probably been piling up for a long time, and which will produce effects due to continue for a long time.

The rapidity of the responses of the conditioned reflex to stimulus need be no index that the conditioning of the reflex is a process of comparable speed. Thus it seems to me appropriate for a message causing such a conditioning to be carried by the slow but pervasive influence of the blood stream.

It is already a considerable narrowing of what my point of view requires, to suppose that the fixing influence of hunger or pain or whatever stimulus is necessary to determine a conditioned reflex passes through the blood. It would be a still greater restriction if I should try to specify the nature of this unknown blood-borne influence, if any such exists. That the blood carries in it substances which have the possibility of altering nervous action directly or indirectly seems to me very likely, and to be suggested by the actions of some at least of the hormones or internal secretions. This, however, is not the same thing as saying that the influence on thresholds which determines learning is the product of specific hormones. Again, it is tempting to find the common denominator of hunger and the pain caused by the electrified fence in something that we may call an emotion, but it is certainly going too far to attach emotion to all conditioners of reflexes, without any further discussion of their particular nature.

Nevertheless, it is interesting to realize that the sort of phenomenon which is recorded subjectively as emotion may not be merely a useless epiphenomenon of nervous action, but may control some essential stage in learning, and in other similar processes. I definitely do not say that it does, but I do say that those psychologists who draw sharp and uncrossable distinctions between the action of the emotions of man and of other living organisms and the action of the modern type of automatic mechanisms, should be just as careful in their denials as I should be in my assertions.

To sum this chapter up, we have devoted it to the study of two contrasting forms of animal mental organization: that of the ants, in which the degree of dependence on the learning process is minimal, and yet the structure of society seems to be reasonably complicated; and that of man, in which the whole individual and social organization centers around the process of learning. We do not know the mechanism of human and animal learning, but I have attempted to give some hypothetical methods by which a similar process might be represented. Thus I do not consider that learning processes, complicated as they may be, lie entirely outside of the field of invention of the engineer.

IV

THE MECHANISM OF LANGUAGE

I HAVE ALREADY POINTED OUT how language is perhaps the most distinctive feature of man as compared with the lower animals. In this chapter, I wish to show nevertheless that language is not an exclusive attribute of man, but is one which he may share to a certain degree with the machines he has constructed. I wish to show that man's preoccupation with language most certainly represents a possibility which is built into him, and which is not built into his nearest relatives, the great apes. Nevertheless, I shall show that it is built in only as a possibility which must be made good by learning.

We ordinarily think of communication and of language as being directed from person to person. However, it is quite possible for a person to talk to a machine, a machine to a person, and a machine to a machine. In the wilder stretches of our own West and of Northern Canada, there are many possible power sites remote from any settlement where the workers can live, and too small to justify the foundation of new settlements on their own account, though not so small that the power systems are able to neglect them. It is thus desirable to operate these stations in a way that does not involve a resident staff, and in fact leaves the stations unattended for months between the consecutive rounds of a supervising engineer.

To accomplish this, two things are necessary. One of these is the introduction of automatic machinery; making it impossible to switch a generator on to a bus-bar or connecting member until it has come into the right frequency, voltage, and phase; and providing in a similar manner against other disastrous electrical, mechanical, and hydraulic contingencies. This type of operation would be enough if the daily cycle of the station were unbroken and unalterable.

This, however, is not the case. The load on a generating system depends on many variable factors. Among these are the industrial demand; emergencies which may remove a part of the system from operation; and even passing clouds, which may make tens of thousands of offices and homes turn on their electric lights in the middle of the day. It follows that the automatic stations, as well as those operated by a working crew, must be within the constant reach of the load dispatcher. He must therefore be able to give orders to his machines; and this he does by sending appropriately coded signals to the power station, either over a special line designed for the purpose, or over existing telegraph or telephone lines, or over a carrier system making use of the power lines themselves. On the other hand, before the load dispatcher can give his orders intelligently, he must be acquainted with the state of affairs at the generating station. In particular, he must know whether the orders he has given have been executed, or have been held up through some failure in the equipment. Thus the machines in the generating station must be able to send return messages to the load dispatcher. There is a language emanating from man and directed toward the machine, and there is a language emanating from the machine and directed toward man.

It may seem curious to the reader that we admit machines to the field of language and yet almost totally deny language to the ants. Nevertheless, in constructing machines, it is often very important for us to extend to them certain human attributes which are not found among the lower members of the animal community. If the reader wishes to conceive this as a mere extension of our personality as human beings, he is welcome to do so; but he should be cautioned that the new machines will not stop working merely because we have discontinued to give them human support.

The language directed toward the machine actually consists of more than a single step. From the point of view of the line engineer alone, the code transmitted along the line is complete in itself. To this message we may apply all the notions of cybernetics, or the theory of messages. We may evaluate the amount of information it carries by determining its probability in the ensemble of all possible messages, and then taking the negative logarithm of this probability, in accordance with the theory expounded in Chapter I. However, this represents not the information actually carried by the line, but the maximum amount it might carry, if it were to lead into proper terminal equipment. The amount of information carried with actual terminal equipment depends on the ability of the latter to transmit or to employ the information received.

We are thus led to a new conception of the way in which the generating station receives the orders. Its actual performance of opening and closing switches, of pulling generators into phase, of controlling the flow of water in sluices, and of turning the turbines on or off, may be regarded as a language in itself, with a system of probabilities of behavior given by its own history. Within this frame every possible sequence of orders has its own probability, and hence carries its own amount of information.

It is, of course, possible that the relation between the line and the terminal machine is so perfect that the amount of information contained in a message, from the point of view of the carrying capacity of the line, and the amount of information of the fulfilled orders, measured from the point of view of the operation of the machine, will be both identical with the amount of information transmitted over the compound system consisting of the line followed by the machine. In general, however, there will be a stage of translation between the line and the machine; and in this stage, information may be lost, though it never can be gained. Indeed, the process of transmitting information may involve several consecutive stages of transmission following one another in addition to the final or effective stage; and between any two of these there will be an act of translation, capable of dissipating information. This fact, that information may be dissipated but not gained, is the cybernetic form of the second law of thermodynamics.

Up to this point in this chapter we have been discussing communication systems terminating in machines. In a certain sense, all communication systems terminate in machines, but the ordinary communication systems of language terminate in the rather special sort of machine known as a human being. The human being as a terminal machine has a communication network which may be considered at three distinct levels. For ordinary spoken language, the first human level consists of the ear, and of that part of the cerebral mechanism which is in a permanent and rigid connection with the inner ear. This apparatus, when joined onto the apparatus of sound vibrations in the air, or their equivalent in electric circuits, represents the machine concerned with what is called the *phonetic* aspect of language.

The phonetic aspect of language is that which is concerned with sound and the *semantic* aspect of language is that which is concerned with meaning. For example, the difficulties of translating between German and English are due to the lack of precise correspondence between the meanings of words in one tongue and another, and are semantic. On the other hand, it has been shown that one can get a remarkable semblance of a language like English by taking a sequence of words, or pairs of words, or triads of words, according to the statistical frequency with which they occur in the language. The gibberish which one thus obtains has a remarkably persuasive similarity to good English. This meaningless simulacrum of intelligent speech is practically equivalent to significant language from the phonetic point of view, although it is semantically balderdash. The English of an intelligent foreigner whose pronunciation contains the mark of the country of his birth, or who speaks literary English, is semantically good and phonetically bad. The average synthetic after-dinner speech is phonetically good and semantically bad.

To go back to the human communication apparatus, it is possible but difficult to determine the characteristics of this phonetic machine, and therefore also possible but difficult to determine what is phonetically significant information, and to measure it. It is clear, for example, that the ear and the brain have an effective frequency cut-off preventing the reception of some high frequencies which can penetrate the ear and can be transmitted by the telephone. In other words, these high frequencies, whatever information they may give an appropriate receptor, do not carry any significant amount of information for the ear.

When language is received through the eye, there is a similar visual stage. I do not know that the English language has invented any word which, in a visual language like that of Chinese writing, will correspond to phonetics. However, this stage exists, and is always confused with the phonetic stage by those Chinese scholars who have not reached a European degree of sophistication concerning the rôle of the eye and the ear in European languages and in their own speech.

When speech or writing have gone through the phonetic stage of reception or its equivalent, they still have to give rise to the notions and the abstractions which we take effectively to constitute significant speech or meaning. This stage of reception, when combined with its phonetic or visual preliminary, constitutes the *semantic* stage.

Semantic reception is associated with great use of memory, and with its consequent long delays. The types of abstractions belonging to the important semantic stage are not merely those associated with built-in permanent subassemblies of neurons in the brain, such as those which must play a large rôle in the perception of geometrical form; but with abstraction detector-apparatus consisting of parts of the *internuncial pool* which have been temporarily assembled for the purpose: that is, of sets of neurons which are available for larger assemblies, but which are not permanently locked into them.

Besides the highly organized and permanent assemblies in the brain that undoubtedly exist, and are found in those parts of the brain associated with the organs of special sense, as well as in other places, there are particular switchings and connections which seem to have been formed temporarily for special purposes, such as learned reflexes and the like. In order to form such particular switchings, it must be possible to assemble sequences of neurons available for the purpose and not already in use. This question of assembling concerns, of course, the synaptic thresholds of the sequence of neurons assembled. Since neurons exist which can either be within or outside of such temporary assemblies, it is desirable to have a special name for them. As I have already indicated, I consider that they correspond rather closely to what the neurophysiologists have known as internuncial pools.

This is at least a reasonable theory of their behavior. The semantic receiving apparatus neither receives nor translates the language word by word, but idea by idea, and often still more generally. In a certain sense, it is in a position to call on the whole of past experience in its transformations, and these long-time carry-overs are not a trivial part of its work.

There is a third level of communication, which represents a translation partly from the semantic level and partly from the earlier phonetic level. This is the translation of the experiences of the individual, whether conscious or unconscious, into the sort of actions which may be observed externally. We may call this the behavior level of language. In the lower animals, it is the only level of language to which we have any full access beyond the phonetic input. Actually this is true in the case of every human being other than the particular person to whom this passage is addressed in each particular case; in the sense that that person can only have access to the internal thoughts of another person through the actions of the latter. These actions consist of two parts: namely, direct gross actions, of the sort which we also observe in a lower animal; and in the coded and symbolic system of actions which we know as spoken or written language.

It is theoretically not impossible to develop the statistics of the semantic and behavior languages to such a level that we may get a fair measure of the amount of information in each system. At any rate, we can show by general considerations that phonetic language contains less over-all information when compared with the input, or at any rate not more than the transmission system leading to the ear; and that both semantic and behavior language contain less still. This fact again is a form of the second law of thermodynamics, and is only true if at each stage we regard the information transmitted as the maximum information that could be transmitted with an appropriately coded receiving system.

Let me now call the attention of the reader to something which he may not consider a problem at all — namely, the reason that chimpanzees do not talk. The behavior of the chimpanzees has for a long time been a puzzle to those psychologists who have concerned themselves with these interesting beasts. The young chimpanzee is extraordinarily like a child, and clearly his equal or perhaps even his superior in intellectual matters. The animal psychologists have not been able to keep from wondering why a chimpanzee brought up in a human family and subject to the impact of human speech until an age of one or two, does not accept language as a mode of expression, and itself burst into baby talk.

Fortunately, or unfortunately as the case may be, most chimpanzees, in fact all that have as yet been observed, persist in being good chimpanzees, and do not become quasi-human morons or idiots. I nevertheless think that the average animal psychologist is rather longingly hoping for the individual chimpanzee who will disgrace his simian ancestry by adhering to more human modes of conduct. It is not a question of sheer bulk of intelligence, for there are human animals whose brains would shame a chimpanzee. It just does not belong to the nature of the beast to speak, or to want to speak.

Thus, speech is such a peculiarly human activity that it is not even approached by man's closest relatives and his most active imitators. The few sounds emitted by chimpanzees have, it is true, a great deal of emotional content, but they have not the finesse of that clear and repeated accuracy of organization needed to make them into a code much more accurate than the yowlings of a cat. Moreover (and this seems to differentiate them from human speech), at times they belong to the chimpanzee as an unlearned inborn manifestation, rather than as the learned behavior of a member of a given social community.

This fact of speech, that speech in general belongs to man as man, but that a particular form of speech belongs to man as a member of a particular social community, is most remarkable. In the first place, taking the whole wide range of man as we know him today, it is a safe statement that there is no community of individuals, not mutilated by an auditory or a mental defect, which does not have its own mode of speech. In the second place, all modes of speech are learned, and notwithstanding the attempts of the nineteenth century to formulate a genetic evolutionistic theory of languages, there is not the slightest general reason to postulate any single native form of speech from which all the present forms are originated. It is quite clear that if left alone, babies will make attempts at speech. These attempts, however, show their own inclinations to utter something, and do not follow any existing form of language. It is almost equally clear that if a community of children were left out of contact with the language of their seniors through the critical speech-forming years, they would emerge with something, which crude as it might be, would be unmistakably a language.

Why is it then that chimpanzees cannot be forced to talk, and that human children cannot be forced not to? Why is it that the general tendencies to speak and the general visual and psychological aspects of language are so uniform over large groups of people, while the particular linguistic manifestation of these aspects is so multiformly varied? At least partial understanding of these matters is essential to any comprehension of the language-based community. We merely state the fundamental facts by saying that in man, unlike the apes, the impulse to use some sort of language is overwhelming; but that the particular language used is a matter which has to be learned in each special case. It apparently is built into the brain itself, that we are to have a preoccupation with codes and with the sounds of speech, and that the preoccupation with codes can be extended from those dealing with speech to those, like writing and the quipu, which concern themselves with visual stimuli. However, there is not one fragment of these codes which is born into us as a pre-established ritual, like the courting dances of many of the birds, or the system by which ants recognize and exclude intruders into the nest. The gift of speech does not go back to a universal Adamite language disrupted in the Tower of Babel. It is strictly a psychological impulse, and is not a gift of speech, but a gift of the power of speech.

In other words, the block preventing young chimpanzees from learning to talk is a block which concerns the semantic and not the phonetic stage of language. The chimpanzee has simply no built-in mechanism which leads it to translate the sounds that it hears into the basis for its own ideas or into a complex mode of behavior. Of the first of these statements we cannot be sure because we have no direct way of observing it. The second is simply a noticeable empirical fact. It may have its limitations, but that there is such a built-in mechanism in man is perfectly clear.

In this book, we have already emphasized man's extraordinary ability to learn as a distinguishing characteristic of the race, which makes social life a phenomenon of an entirely different nature from the apparent analogous social life among the bees and ants and other social insects. As I have just said, man's use of language is entirely dependent on his ability to learn. The evidence concerning children who have been deprived of the opportunity of contact with their own race over the years normally critical in the ordinary acquisition of language, is perhaps not completely unambiguous. The "Wolf Child" stories, which have led to Kipling's imaginative *Jungle Books,* with their public-school bears and Sandhurst wolves, are almost as little to be relied on in their original stark squalidity as in the Jungle Book idealizations. However, what evidence there is goes to show that there is a critical period during which speech is most readily learned; and that if this period is passed over without contact with one's fellow human beings, of whatever sort they may be, the learning of language becomes limited, slow, and highly imperfect.

This is probably true of most other abilities which we consider to be natural skills. If a child does not walk until it is three or four years old, it may have lost all the desire to walk. Ordinary locomotion may become a task greater than that of the driving of a car for the normal adult. If a person has been blind from childhood, and the blindness has been resolved by a cataract operation or the implantation of a transparent corneal section, the vision that ensues will, for a time, certainly bring nothing but confusion to those activities which have normally been carried out in blindness. This vision may never be more than a carefully learned new attainment of doubtful value. Now, we may fairly take it that the whole of human social life in its normal manifestations centers about speech, and that if speech is not learned at the proper time, the whole social aspect of the individual will be aborted.

To sum up, the human interest in language seems to be an innate interest in coding and decoding, and this seems to be as nearly specifically human as any interest can be. *Speech is the greatest interest and most distinctive achievement of man.*

V

THE HISTORY OF LANGUAGE

THE REALIZATION of the mystery of speech has belonged to man since very early times. The riddle of the sphinx is a primitive form of wisdom. Indeed, the whole notion of the riddle is derived in the English language from the notion "to rede," or to puzzle out. The word "rede" is cognate with the other word "read," in its usual sense. Among many primitive people writing and sorcery are not far apart. The respect for writing goes so far in some parts of China that people are loath to throw away scraps of old newspapers and useless fragments of books.

Close to all these manifestations is the phenomenon of "name magic" in which members of certain cultures go from birth to death under names that are not properly their own, in order that they may not give a sorcerer the advantage of knowing their true names. Most familiar to us of these cases is that of the name of Jehovah of the Jews, in which the vowels are taken over from that other name of God, "Adonai," so that the Name of Power may not be blasphemed by being pronounced in profane mouths.

From the magic of names it is but a step to a deeper and more scientific interest in language. As an interest in textual criticism in the authenticity of oral traditions and of written texts it goes back to the ancients of all civilizations. A holy text must be kept pure. When there are divergent readings they must be resolved by some critical commentator. Accordingly, the Bible of the Christians and the Jews, the sacred books of the Persians and the Hindus, the Buddhist scriptures, the writings of Confucius, all have their early commentators. What has been learned for the maintenance of true religion has been carried out as a literary discipline, and textual criticism is one of the oldest of intellectual studies.

For a large part of the last century philological history was reduced to a series of dogmas which at times shows a surprising ignorance of the nature of language. The model of the Darwinian evolutionism of the times was taken too seriously and too uncritically. As this whole subject depends in the most intimate manner on our views of the nature of communication, I shall comment on it at a certain length.

The early speculations that Hebrew was the language of man in Paradise, and that the confusion of language originated at the building of the Tower of Babel, need not interest us here as anything more than primitive precursors of scientific thought. However, the later developments of philological thought have retained for a long time an almost equal naïveness. That languages are related, and that they undergo progressive changes leading in the end into totally different languages, were observations which could not long remain unnoticed by the keen philological minds of the Renaissance. A book such as Ducange's *Glossarium Mediae atque Infimae Latinitatis* could not exist without making it perfectly clear that the roots of the Romance languages are not only in Latin, but in vulgar Latin. There must have been many learned rabbis who were well aware of the resemblance of Hebrew, Arabic, and Syriac. When, under the advice of the much maligned Warren Hastings, the East India Company founded its School of Oriental Studies at Fort William, it was no longer possible to ignore that Greek and Latin on the one hand, and Sanskrit on the other, were cut out of the same cloth. At the beginning of the last century the work of the brothers Grimm and of the Dane, Rask, showed not only that the Teutonic languages came within the orbit of this so-called Indo-European group, but went further to make clear the linguistic relations of these languages to one another, and to their distant common parent, whatever that might be.

Thus evolutionism in language antedates the refined Darwinian evolutionism in biology. Valid as this evolutionism is, it very soon began to outdo biological evolutionism in places where the latter was not applicable. It assumed, that is, that the languages were independent, quasi-biological entities, with their developments modified entirely by internal forces and needs. In fact, they are epiphenomena of human intercourse, subject to all the social forces due to changes in the pattern of that intercourse.

In the face of the existence of *Mischsprachen,* of languages such as Lingua Franca, Swahili, Yiddish, Chinook Jargon, and even to a considerable extent English, there has been an attempt to trace each language to a single legitimate ancestor, and to treat the other participants in its origin as nothing more than godparents of the newborn child. There has been a distinction between legitimate phonetic formations showing the accepted laws, and such regrettable accidents as nonce words, popular etymologies, and slang. On the grammatical side, the original attempt to force all languages of any origin whatsoever into the strait-jacket manufactured for Latin and Greek has been succeeded by an almost as rigorous attempt to form for each of them its own paradigms of construction.

It is scarcely until the recent work of Otto Jespersen that any considerable group of philologists have had objectivity enough to make of their science a representation of language as it is actually spoken and written, rather than a copybook attempt to teach the Eskimos how to speak Eskimo, and the Chinese how to write Chinese. The effects of misplaced grammatical purism are to be seen well outside of the schools. First among these, perhaps, is the way in which the Latin language, like the earlier generation of classical gods, has been slain by its own children.

During the Middle Ages Latin of a varying quality, the best of it quite acceptable to anyone but a pedant, remained the universal language of the clergy and of all learned men throughout Western Europe, even as Arabic has remained in the Moslem world down to the present day. This continued prestige of Latin was made possible by the willingness of writers and speakers of the language either to borrow from other languages, or to construct within the frame of Latin itself, all that was necessary for the discussion of the live philosophical problems of the age. The Latin of Saint Thomas is not the Latin of a Cicero, but Cicero would have been unable to discuss Thomistic ideas in the Ciceronian Latin.

It may be thought that the rise of the vulgar languages of Europe must necessarily have marked the end of the function of Latin. This is not so. In India, notwithstanding the growth of the neo-Sanskritic languages, Sanskrit has shown a remarkable vitality lasting down to the present day. The Moslem world, as I have said, is united by a tradition of classical Arabic, even though the majority of Moslems are not Arabic speakers and the spoken Arabic of the present day has divided itself into a number of very different dialects. It is quite possible for a language which is no longer the language of vulgar communication to remain the language of scholarship for generations and even for centuries. Modern Hebrew has survived for two thousand years the lack of use of Hebrew in the time of Christ, and indeed has come back as a modern language of daily life. In what I am discussing now, I am referring only to the limited use of Latin as a language of learned men.

With the coming of the Renaissance, the artistic standards of the Latinists became higher, and there was more and more a tendency to throw out all post-classical neologisms. In the hands of the great Italian scholars of the Renaissance, this reformed Latin could be, and often was, a work of art; but the training necessary to wield such a delicate and refined tool was beyond that which would be incidental to the training of the scientist, whose main work must always concern itself with content rather than with perfection of form. The result was that the people who *taught* Latin and the people who *used* Latin became ever more widely separated classes, until the teachers completely eschewed the problem of teaching their disciples anything but the most polished and unusable Ciceronian speech. In this vacuum they ultimately eliminated any function for themselves other than that of specialists; and as the specialty of Latinism thus came to be less and less in general demand, they abolished their own function. For this sin of pride, we now have to pay in the absence of an adequate international language far superior to the artificial ones such as Esperanto, and well suited for the demands of the present day.

Alas, the attitudes of the classicists are often beyond the understanding of the intelligent layman! I recently had the privilege of hearing a commencement address from a classicist who bewailed the increased centrifugal force of modern learning, which drives the natural scientist, the social scientist, and the literary man ever farther from one another. He put it into the form of an imaginary trip which he took through a modern university, as the guide and mentor to a reincarnated Aristotle. His talk began by presenting in the pillory bits of technical jargon from each modern intellectual field, which he supposed himself to have presented to Aristotle as horrible examples. May I remark that all we possess of Aristotle is what amounts to the school note-books of his disciples, written in one of the most crabbed technical jargons in the history of the world, and totally unintelligible to any contemporary Greek who had not been through the discipline of the Lycaeum? That this jargon has been sanctified by history, so that it has become itself an object of classical education, is not relevant; for this happened after Aristotle, not contemporaneously with him. The important thing is that the Greek language of the time of Aristotle was ready to compromise with the technical jargon of a brilliant scholar, while even the English of his learned and reverend successors is not willing to compromise with the similar needs of modern speech.

With these admonitory words, let us return to the modern point of view on language, which assimilates the operation of linguistic translation and the related operations of the interpretation of language by ear and by brain to the performance and the coupling of non-human communication networks. It will be seen that this is really in accordance with the modern and once heretical views of Jespersen and his school. Language is no longer something that is primarily normative. It has become factual. The question is not what code should we use, but what code do we use. It is quite true that in the finer study of language, normative questions do indeed come into play, and are very delicate. Nevertheless, they represent the last fine flower of the communication problem, and not its most fundamental stages.

We have thus established the basis in man for the simplest element of his communication: namely, the communication of man with man by the immediate use of language, when two men are face to face with one another. The inventions of the telephone, the telegraph, and other similar means of communication have shown that this capacity is not intrinsically restricted to the immediate presence of the individual, for we have many means to carry this tool of communication to the ends of the earth.

Among primitive groups the size of the community for an effective communal life is restricted by the difficulty of transmitting language. For many millennia, this difficulty was enough to reduce the optimum size of the State to something of the order of a few million people, and generally fewer. It will be noted that the great empires which transcended this limited size were held together by improved means of communication. The heart of the Persian Empire was the Royal Road and the relay of messengers who conveyed the Royal Word along it. The great empire of Rome was only possible because of the Roman progress in road-building. These roads served to carry not only the legions, but the written authority of the Emperor as well. With the airplane and the radio of today, the word of the rulers extends to the ends of the earth, and very many of the reasons which previously prevented the existence of a World State have been abrogated. It is even possible to maintain that modern communication, which forces us to adjudicate the international claims of different broadcasting systems and different airplane nets, has made the World State inevitable.

VI

THE INDIVIDUAL AS THE WORD

THE EARLIER ACCOUNTS of individuality were associated with some sort of identity of matter, whether of the material substance of the animal or the spiritual substance of the human soul. We are forced nowadays to recognize individuality as something which has to do with continuity of pattern, and consequently with something that shares the nature of communication.

Some forty-five years ago, Kipling wrote a most remarkable little story. This was the time when the flights of the Wright brothers had become familiar to the world, but before aviation was an everyday matter. He called this story "With the Night Mail," and it purports to be an account of the world when aviation should have become a matter of course and the Atlantic a lake to be crossed in one night. He supposed that transportation as facilitated by the airplane had so united the world that war had become obsolete, and that all the world's really important affairs were in the hands of an Aerial Board of Control, whose primary responsibility extended to air traffic, while its secondary responsibility extended to "all that that implies." In this way, he imagined that the various local authorities had gradually been compelled to drop their rights, or had allowed their local rights to lapse; and that the central authority of the Aerial Board of Control had taken these responsibilities over. It is rather a Fascist picture which Kipling gives us, and this is understandable in view of his intellectual presuppositions. It is not a necessary condition of the situation which he envisages. His millennium is the millennium of a British colonel back from India. Moreover, with his love for the gadget as a collection of wheels that rotate and make a noise, he has emphasized the extended physical transportation of man, rather than the transportation of language and ideas. He does not seem to realize that where a man's word goes, and where his power of perception goes, to that point his control and in a sense his physical existence is extended. To see the whole world and to give commands to the whole world is almost the same thing as to be everywhere. Nevertheless, with these natural reservations, Kipling has the poet's insight, and the things he has foreseen are rapidly coming to pass.

To see the greater importance of communication as compared with transportation, let us suppose that we have an architect in Europe supervising the construction of a building in the United States. I am assuming, of course, an adequate working staff of constructors, clerks of the works, etc., on the site of the construction. Under these conditions, even without transmitting or receiving any material commodities, the architect may take an active part in the construction of the building. Let him draw up his plans and specifications as usual. Even at present, there is no reason why the working copies of these plans and specifications must be transmitted to the construction site on the same paper on which they have been drawn up in the architect's drafting-room. The modern Ultrafax gives a means by which a facsimile of all the documents concerned may be transmitted in a fraction of a second, and the received copies are quite as good working plans as the originals. The architect may be kept *au fait* with the progress of the work by photographic records taken every day or several times a day;

and these may be forwarded back to him by Ultrafax. Any remarks or advice he cares to give his representative on the job may be transmitted by telephone, Ultrafax, or teletypewriter. In short, the bodily transmission of the architect and his documents may be replaced very effectively by the message-transmission of communications which do not entail the moving of a particle of matter from one end of the line to the other. We thus have two types of communication: namely, a material transport, and a transport of information alone. At present it is possible for a person to go from one place to another by material transportation, and not as a message. However, even now the transportation of messages serves to forward an extension of his senses and his capabilities of action from one end of the world to another. Is this distinction between material transportation and message transportation absolutely permanent and unbridgeable?

To pose this question raises very fundamental issues concerning the nature of human individuality. The problem of the nature of human individuality and of the barrier which separates one personality from another is as old as history. The Christian religion and its Mediterranean antecedents have embodied it in the notion of *soul.* The individual possesses a soul, so say the Christians, which has come into being by the act of conception, but which will continue in existence for all eternity, either among the Blessed or among the Damned, or in one of the little intermediate lacunae of Limbo which the Christian faith allows.

The Buddhists follow a tradition which agrees with the Christian tradition in giving to the soul a continuity after death, but this continuity is in the body of another animal or another human being, rather than in some Heaven or Hell. There are indeed Buddhist Heavens and Hells, although the stay of the individual there is generally temporary. In the most final Heaven of the Buddhists, however, the state of Nirvana, the soul loses its identity and is absorbed into the Great Soul of the World.

These views have been without the benefit of the influence of science. The most interesting early scientific account of the continuity of the soul is that of Leibniz. Leibniz conceived the soul as belonging to a larger class of permanent spiritual substances which he called *monads*. These monads spend their whole existence from the creation on in the act of perceiving one another; although some perceive with a great clarity and distinctness, and others in a blurred and confused manner. This perception does not however represent any true interaction of the monads. The monads "have no windows," and have been wound up by God at the creation of the world so that they shall keep in time with one another through all eternity. They are indestructible.

Behind Leibniz's philosophical views of the monads there lie some very interesting biological speculations. It was in Leibniz's time that Leeuwenhoek first applied the simple microscope to the study of very minute animals and plants. Among the animals that he saw were spermatozoa. In the mammal, spermatozoa are infinitely easier to find and to see than ova. The human ova are emitted one at a time, and unfertilized uterine ova or very early embryos were until recently rarities in the anatomical collections. Thus the early microscopists were under the very natural temptation to regard the spermatozoon as the only important element in the development of the young, and to ignore entirely the possibility of the as yet unobserved phenomenon of fertilization. Furthermore, their imagination displayed to them in the front segment or head of the spermatozoon a minute foetus, rolled up with head forward. This foetus was supposed to contain in itself spermatozoa which were to develop into the next generation of foetuses and adults, and so on *ad infinitum.* The female was supposed to be merely the nurse of the spermatozoon.

Of course, from the point of view of the present time, this biology is simply false. The spermatozoon and the ovum are nearly equal participants in the overwhelmingly more important part of heredity. Furthermore, the germ cells of the future generation are only contained in them in *posse,* and not in *esse.* Matter is not infinitely divisible, nor indeed from any absolute standpoint is it very finitely divisible; and the successive diminutions required to form the Leeuwenhoek spermatozoon of a moderately high order would very quickly lead us down beyond electronic levels.

In the present view, as opposed to the Leibnizian view, the continuity of an individual has a very definite beginning in time, but it may even have a termination in time quite apart from the death of the individual. It is well known that the first cell division of the fertilized ovum of a frog leads to two cells, which can be separated under appropriate conditions. If they are so separated, each will grow into a complete frog. This is nothing but the normal phenomenon of identical twinning in a case in which the anatomical accessibility of the embryo is sufficient to permit experimentation. It is exactly what occurs in human identical twins, and is the normal phenomenon in one of the armadillos which bears a set of identical quadruplets at each birth. It is the phenomenon, moreover, which gives rise to double monsters, when the separation of the two parts of the embryo is incomplete.

This problem of twinning may however not appear as important at first sight as it really is, because it does not concern animals or human beings with what may be considered well-developed minds and souls. Not even the problem of the double monster, the imperfectly separated twins, is too serious in this respect. Viable double monsters must always have either a single central nervous system or a well-developed pair of separate brains. The difficulty arises at another level in the problem of split personalities.

A generation ago, Dr. Morton Prince of Harvard gave the case history of a girl, within whose body several better-or-worse-developed personalities seemed to succeed one another, and even to a certain extent to coexist. It is the fashion nowadays for the psychiatrists to look down their noses a little bit when Dr. Prince's work is mentioned, and to attribute the phenomenon to hysteria. It is quite possible that the separation of the personalities was never as complete as Prince sometimes appears to have thought it to be, but for all that it was a separation. The word "hysteria" refers to a phenomenon well observed by the doctors, but so little explained that it may be considered but another question-begging epithet.

One thing at any rate is clear. The physical identity of an individual does not consist in the matter of which it is made. Modern methods of tagging the elements participating in metabolism have shown a much higher turnover than was long thought possible, not only of the body as a whole, but of each and every component part of it. The biological individuality of an organism seems to lie in a certain continuity of process, and in the memory by the organism of the effects of its past development. This appears to hold also of its mental development. From the standpoint of the computing machine, the individuality of a mind lies in the retention of its earlier tapings and memory, and in its continued development along lines already laid out.

Under these conditions, just as a computing machine may be used as a pattern on which to tape other computing machines, and just as the future development of these two machines will continue parallel except for future changes in taping and experience, so too, there is no inconsistency in a living individual forking or divaricating into two individuals sharing the same past, but growing more and more different. This is what happens with identical twins; but there is no reason why it could not happen with what we call the mind, without a similar split of the body. To use computing-machine language again, at some stage a machine which was previously assembled in an all-over manner may find its connections divided into partial assemblies with a higher or lower degree of independence. This would be the best explanation of the cases of Dr. Morton Prince.

Moreover, it is conceivable that two large machines which had previously not been coupled may become coupled so as to work from that stage on as a single machine. Indeed this occurs on the level of the union of the germ cells, although perhaps not on what we would ordinarily call a purely mental level. The mental identity necessary for the Church's view of the individuality of the soul certainly does not exist in any absolute sense which would be acceptable to the Church.

To recapitulate: the individuality of the body is that of a flame rather than that of a stone, is that of a form rather than that of a bit of substance. This form can be transmitted or be modified and duplicated, although at present we only know how to duplicate it over a short distance. When one cell divides into two, or when one of the genes which carries our corporeal and mental birthright is split in order to make ready for a reduction division of a germ cell, we have a separation in matter which is conditioned by the power of a pattern of living tissue to duplicate itself. Since this is so, there is no fundamental absolute line between the types of transmission which we can use for sending a telegram from country to country and the types of transmission which at least are theoretically possible for a living organism such as a human being.

Let us then admit that the old idea of the child, that in addition to traveling by train or airplane, one might conceivably travel by telegraph, is not intrinsically absurd, far as it may be from realization. The difficulties are, of course, enormous. It is possible to evaluate something like the order of the significant information covered by all the genes in a germ cell, and answer the question of the amount of hereditary information, as compared with learned information, that a human being possesses. The smallest order which makes any sense whatever is that of the amount of information contained in a complete set of the *Encyclopaedia Britannica.* If we try to compare, for example, the number of asymmetric carbon atoms [1] in all the molecules of a germ cell with the number of dots and dashes needed to code the *Encyclopaedia Britannica,* we find that they constitute an even more enormous message; and this is still more impressive when we realize what the conditions for telegraphic transmission of such a message must be. Any scanning of the human organism must be a probe going through all parts, and must have a greater or less tendency to destroy the tissue on its way. To hold an organism stable while part of it is being slowly destroyed, with the intention of recreating it out of other material elsewhere, involves a lowering of its degree of activity, which in most cases we should consider to prevent life in the tissue.

In other words, the fact that we cannot telegraph the pattern of a man from one place to another is probably due to technical difficulties, and in particular, to the difficulty of keeping an organism in being during such a radical reconstruction. It is not due to any impossibility of the idea. As to the problem of the radical reconstruction of the living

[1] It is perfectly clear that the message is *not* carried by the asymmetric carbon atoms; but they represent the sort of mark that can be conceived to carry a message.

organism, it would be hard to find any such reconstruction much more radical than the actual one of a butterfly during its period as a pupa.

I have stated these things, not because I want to write a science fiction story concerning itself with the possibility of telegraphing a man, but because it may help us understand that the fundamental idea of communication is that of the transmission of messages, and that the bodily transmission of matter and messages is only one conceivable way of attaining that end. It will be well to reconsider Kipling's test of the importance of traffic in the modern world from the point of view of a traffic which is overwhelmingly not so much the transmission of human bodies as the transmission of human information.

VII

LAW AND COMMUNICATION

LAW MAY BE DEFINED as the ethical aspect of communication and of language as a form of communication, especially when this normative aspect is under the control of some authority sufficiently secure to give its decisions an effective social sanction. It is the art of adjusting the "couplings" connecting the behavior of different individuals in such a way that something which we call justice may be accomplished, and disputes may be avoided, or at least adjudicated. Thus the theory and practice of the law involves two sets of problems: those of its general purpose, of its conception of justice; and those of the technique by which these concepts of justice can be made effective.

Empirically, the concepts of justice which have been maintained are as varied as the religions of the world, or the cultures recognized by anthropologists. I doubt if it is possible to justify them by any higher sanction than our code of morality itself, which is indeed only another name for our conception of justice. As a participant in a liberal outlook which has its main roots in the European-American tradition of civilization, but which has extended itself to those Eastern countries which have a strong intellectual-moral tradition, and has indeed borrowed deeply from them, I can only state what I myself and those about me consider necessary for the existence of justice. The best words to express these requirements are the words of the French Revolution: Liberté, Egalité, Fraternité. These mean: the liberty of each human being to develop in his freedom the full measure of the human possibilities embodied in him; the equality by which what is just for A and B remains just when the positions of A and B are interchanged; and a good will between man and man that knows no limits short of humanity. These great principles of justice mean and demand that no person, by virtue of the personal strength of his position, shall enforce a sharp bargain by duress. What compulsion the very existence of the Community and the State may demand must be exercised in such a way as to produce no unnecessary infringement of freedom.

Even the greatest human decency and liberalism in the general conception of the law will not of itself produce a fair and administrable legal code. Besides the general principles of justice, the law must be so clear and reproducible that the individual citizen can assess his rights and duties in advance, even where they appear to conflict with those of others. He must be able to ascertain with a reasonable certainty what view a judge or a jury will take of his position. If he cannot do this, not all the good intentions of the legal code will enable him to lead a life free from litigation and confusion.

Let us look at the matter from the simplest point of view – that of the contract. Here A takes on the responsibility of performing a certain service which in general will be advantageous to B; whereas B assumes in return the responsibility of performing a service or making a payment advantageous to A. If it is unambiguously clear what each task and each payment is to be, and if one of the parties does not invoke methods of imposing his will on the other party which are foreign to the contract itself, then the decision, whether the bargain is equitable, may safely be left to the judgment of the two contracting parties. If it is manifestly inequitable, at least one of the contracting parties may be supposed to be in the position of being able to reject the bargain altogether. What, however, they cannot be expected to settle with any justice among themselves is the meaning of the bargain, if the terms employed have no established significance, or if the significance varies from court to court. Thus it is the first duty of the law to see that the obligations and rights given to an individual in a certain stated situation be unambiguous. Moreover, there should be a body of legal interpretation which is as far as possible independent of the will and the interpretation of the particular authorities consulted. Reproducibility is prior to equity, for without it there can be no equity.

It appears from this why precedent has a very important theoretical weight in most legal systems, and why in all legal systems it has an important practical weight. There are those legal systems which purport to be based on certain abstract principles of justice. The Roman law and its descendants, which indeed constitute the greater part of the law of the European continent, belong to this class. There are other systems like that of the English law, in which it is openly stated that precedent is the main basis of legal thought. In either case, no new legal term has a completely secure meaning until it and its limitations have been determined in practice; and this is a matter of precedent. To fly in the face of a decision which has been made in an already existing case is to attack the uniqueness of the interpretation of legal language and is *ipso facto* a cause of indeterminateness and very probably of a consequent injustice. Every case decided should advance the definition of the legal terms involved in a manner consistent with past decisions, and it should lead naturally on to new ones. Every piece of phraseology should be tested by the custom of the place and of the field of human activity to which it is relevant. The judges, those to whom is confided the task of the interpretation of the law, should perform their function in such a spirit that if Judge A is replaced by Judge B, the fact cannot be expected to make a material change in the court interpretation of customs and of statutes. This naturally must remain to some extent an ideal rather than a *fait accompli;* but unless we approximate to this ideal closely, we shall have chaos, and what is worse a no-man's land in which dishonest men prey on the differences in possible interpretation of the statutes.

All of this is very obvious in the matter of contracts; but in fact it extends quite far into other branches of the law, and particularly of the civil law. Let me give an example. A, because of the carelessness of an employee B, damages a piece of property belonging to C. Who is to take the loss, and in what proportion? If these matters are known equally in advance to everybody, then it is possible for the person normally taking the greatest risk to charge a greater price for his undertakings and thus to insure himself. By these means he may cancel some considerable part of his disadvantage. The general effect of this is to spread the loss over the community, so that no man's share of it shall be ruinous. Thus the law of torts tends to partake somewhat of the same nature as the law of contracts. Any legal responsibility which involves exorbitant possibilities of loss will generally make the person incurring the loss pass his risk on to the community at large in the form of an increased price for his goods, or increased fees for his services. Here, as well as in the case of contracts, unambiguity, precedent, and a good clear tradition of interpretation are worth more than a theoretical equity, particularly in the assessment of responsibilities.

There are, of course, exceptions to these statements. For example, the old law of imprisonment for debt was inequitable in that it put the individual responsible for paying the debt in exactly that position in which he was least capable of acquiring the means to pay. There are many laws at present which are inequitable, because, for example, they assume a freedom of choice on the part of one party which under existing social circumstances is not there. What has been said about imprisonment for debt is equally valid in the case of peonage, and of many other similarly abused social customs.

If we are to carry out our philosophy of liberty, equality, and fraternity, then in addition to the demand that legal responsibility should be unambiguous, we must add the demand that it should not be of such a nature that one party acts under duress, leaving the other free. The history of our dealings with the Indians is full of instances in point, both for the dangers of duress and the dangers of ambiguity. From the very early times of the Colonies, the Indians had neither the bulk of population nor the equality of arms to meet the whites on a fair basis, especially when the so-called land treaties between white and Indian were being negotiated. Besides this gross injustice, there was a semantic injustice, which was perhaps even greater. The Indians as a hunting people had no idea of land as an individual possession. For them there was no such ownership as ownership in fee simple. They did have the notion of hunting rights over specific territories. In their treaties with the settlers, what they wished to convey were hunting rights, and generally only concomitant hunting rights over certain regions. On the other hand, the whites believed, if we are to give their conduct the most favorable interpretation which can be assigned to it, that the Indians were conveying to them a title to ownership in fee simple. Under these circumstances, not even a semblance of justice was possible, nor did it exist.

Where the law of Western countries is at present least satisfactory is on the criminal side. Law seems to consider punishment, now as a threat to discourage other possible criminals, now as a ritual act of expiation on the part of the guilty man, now as a device for removing him from society and for protecting the latter from the danger of repeated misconduct, and now as an agency for the social and the moral reform of the individual. These are four different tasks, to be accomplished by four different methods; and unless we know an accurate way of proportioning them, our whole attitude to the criminal will be at cross-purposes. At present, the criminal law speaks now in one language, and now in another. Until we in the community have made up our minds that what we really want is expiation, or removal, or reform or the discouragement of potential criminals, we shall get none of these, but only a confusion in which crime breeds more crime. Any code which is made, one-fourth on the eighteenth-century British prejudice in favor of hanging, one-fourth on the removal of the criminal from society, one-fourth on a halfhearted policy of reform, and one-fourth on the policy of hanging up a dead crow to scare away the rest, is going to get us precisely nowhere.

Let us put it this way: the first duty of the law, whatever the second and third ones are, is to know what it wants. The first duty of the legislator or the judge is to make clear, unambiguous statements, which not only experts, but the common man of the times will interpret in one way and in one way only. The technique of the interpretation of past judgments must be such that a lawyer should know, not only what a court has said, but even with high probability what the court is going to say. The problems of law are communicative and cybernetic — that is, they are the problems of the orderly and repeatable control of certain critical situations.

There are vast fields of law where there is no satisfactory semantic agreement between what the law intends to say, and the actual situation which it contemplates. Whenever such a theoretical agreement fails to exist, we shall have the same sort of no-man's land that faces us when we have two currency systems without an accepted basis of parity. In the zone of unconformity between one court and another or one coinage and another, there is always a refuge for the dishonest middleman, who will accept payment neither financially nor morally except in the system most favorable to him, and will give it only in the system in which he sacrifices least. The greatest opportunity of the criminal in the modern community lies in this position as a dishonest broker in the interstices of the law.

Our patent law is based on a misapprehension of the fact of invention. In this chapter, I shall confine myself to discussing the legal aspects of the results of this misapprehension, and the way in which it has lead to confusion and injustice. In the next chapter I shall take up the intrinsic nature of this confusion, showing how it is associated with the fundamental error concerning the nature of communication itself. For the present, however, a gross statement of the difficulties will suffice.

The law of invention is particularly well endowed with unreal legal premises in the interstices of which the smaller negatively phototropic fauna of the courts may take refuge. To begin with, it is based on a misapprehension. It accepts a theory of invention which may have been reasonably valid in the older days of the small workshop and the ingenious artisan, but which represents a process less and less common at the present time.

In the early days of the engineering discipline, any new discovery was largely a matter of seeking new combinations, and required ingenuity, but no particular understanding.

The early investigations of Edison and others concerning various forms of multiplex telegraphy were of this nature. They bore no particular relation to any other work, and it is not too far from the facts to consider each of them as the construction and the intellectual property of some one man. However, as the several fields of science received more thorough and better investigation, their structure and outlines began to emerge in strokes of greater clarity. For example, at the present time the problem of designing an electric circuit for a particular purpose has come to be merged in the problem of designing all electric circuits for any purposes. At such a stage, the next step is likely to clarify a whole field simultaneously. In the language of the Patent Office, this new step will be, not an invention extending the previous set of inventions, but the discovery of a law of nature. As such it is essentially unpatentable, although a sufficiently skillful patent lawyer may put it on his bed of Procrustes, and maim or stretch it into conformity with the regulations of the Patent Office.

In other words, an invention is only an invention if it is based on a not too complete understanding of its subject matter. Make an electric circuit by a process of trial and error, and if it has any perceptible features to differentiate it from existing circuits, it is a good invention. Make the optimum circuit possible by the clever use of statistical principles and the calculus of variations, and you have only the new application of a prior art, which itself is scarcely an art of invention.

The change from the old process of invention to the new is not merely a theory of the books. The old patent policy of our great firms has been forced to modify itself radically in the last few years. Before the last war, the usual effort of a great firm was to maintain a ring-fence of unused patents, in order to restrict the activity of powerful competitors and to prevent weaker ones from getting any start whatever. At present, particularly because of the pooling of patents in the war, but even more because of the very great reluctance of the Supreme Court to see in patents an act of genuine invention, the companies are confining their efforts more and more merely to the securing for themselves of the freedom of their future work rather than the collection of tribute from competitors.

Now, we have said that when there is a serious discrepancy between the theory on which a law is based and the actual facts of the situation, there is always a loophole for injustice. The very sharp contrast between the theory of invention and the practice of what modern invention actually is, has led to the usual region of lawlessness within the law. In the first place, the expectation that a patent will be upheld when brought to the Supreme Court has become so low that a United States patent is not a certificate of the ownership of any invention, but merely a ticket to litigation. It is well recognized that a strong patent in weak hands is always less effective than a weak patent in strong hands. In most fields of law, if a lawyer encourages litigation, or if he recommends a client to proceed in a certain course of conduct, with the knowledge that the only security which this course of conduct has is the expense to which the adversary will be put to defend his rights, he is guilty of a serious offense, which is often sufficient to cause his disbarment. In the field of patent law, this course of conduct will make him rich and respected.

This is not the only manner in which the moral level of patent law is distinctly lower than that in other branches of the profession. In all branches of law, the rôle of the expert witness is unsatisfactory and even disgraceful; but in no other field is the abuse of the function of the expert witness so common and well-nigh universal as in patent practice. It is most certainly to the interest of honesty and of good legal practice to have the rôle of the advocate and that of the witness sharply separated. The expert witness, apart from his professional qualifications, has the same legal and moral responsibility as any ordinary witness, but is retained for one side or the other like an advocate. It is difficult enough to reconcile these two functions when the witness is giving evidence in a field in which there is a general agreement as to the main facts, and in which the legal concepts form a fairly adequate description of the true situation. The moment there is any discrepancy between the theory of the law and the concrete facts of the case, the discretion which the expert witness must assume lies between such wide limits that there is almost always a way open for him to square his conscience with whatever report it is to the interest of his employer to make. This situation not only permits abuse, but even demands it.

If the expert witness delivers an opinion not corresponding to the interest of his employer, he will lose a very profitable business. It is too much to ask of human honesty that it should withstand the temptation to color testimony, so that it may further the interest of whichever side employs one, and it is practically impossible to prove that that testimony is not the honest opinion of the witness and has been offered on illegitimate grounds. The result is that a large part of the expert evidence in patent suits, and perhaps the prevailing part, belongs more to the domain of the compurgator [1] than to that of the witness.

What suggestions shall we make for improving the situation? There are at least two which others have made from

[1] In the middle ages, when direct evidence concerning a suit was available, and even in cases where it was not, it became the custom to judge in favor of that man who could produce in court the largest number of people who were willing to swear that he was right, whether they had any direct knowledge of the affair or not. This practice of compurgation is scarcely to be distinguished from what is the actual everyday procedure in patent cases.

time to time, but which do not correspond to the average patent practice. One is that sitting on the same bench with the judge there should also be an assessor with training rather technical than legal, to assist the judge in passing on points where a conventional legal training is not adequate. The other is that apart from this, expert witnesses should be retained by the judge rather than by the litigants, and should be paid either by the court or from a fund to which both of the litigants contribute equally. These witnesses might be selected from a panel to which both litigants have access, but in any case they should speak as *amici curiae,* as friends of the court, and not *ex parte.* So long as the court remains a miniature battle between hired witnesses, patent law will be in bad odor, and will deserve to be so.

I have heard the objection raised to this procedure that the panel of court official experts would naturally be chosen from among the most conservative scientists and engineers. This is a real difficulty, though it seems to me more a difficulty of administration than a difficulty of principle. To some extent, the best policy might be to allow the interested parties to nominate additional experts, but to have their status a neutral one, and to make their fees a charge on the action itself. Whatever the final answer may be as a matter of policy, its proper working is of course dependent on the good will of all concerned. No merely formal change in the present arrangements will work unless it is undertaken seriously and in good faith.

I do not wish to go into the larger problem of the relation between the laws of evidence and the scientific method of collecting information. While there are many parts of the rules of evidence that have a rational basis, their general effect on scientific-minded laymen is that legal evidence and scientific information have a resemblance which is purely coincidental.

VIII

COMMUNICATION AND SECRECY IN THE MODERN WORLD

THE LAST FEW YEARS have been characterized by two opposite and even contradictory trends. On the one hand, we have a network of communication, intranational and international, of a degree of completeness never before found in history. The news-gathering services are to our public press, the scientific journals and the review publications are to our specialists, merely means by which a cross-section of the news of the world is brought to them at frequent and regular intervals. On the other hand, under the impetus of the Dies, Rankin, and Mundt Committees, the classification of military information, and the recent disclosures of incredible laxness somewhere in the State Department, we are approaching a frame of mind paralleled in history only in the Venice of the Renaissance.

There the extraordinarily precise news-gathering services of the Venetian ambassadors (which form one of our chief sources of European history) accompanied a national jealousy of secrets, exaggerated to such an extent that the state ordered the private assassination of emigrant artisans, to maintain the monopoly of certain chosen arts and crafts. Thus the modern game of cops and robbers which seems to characterize both Russia and the United States, the two principal contestants for world power of this century, is nothing but the old Italian cloak-and-dagger melodrama presented on a larger scale.

The Italy of the Renaissance was also the scene of the birthpangs of modern science. However, the science of the present day is not that of Renaissance Italy. It should be possible to examine all the elements of information and secrecy in the modern world with a somewhat greater maturity and objectivity than belongs to the thought of the times of Machiavelli. This is particularly true in view of the fact that the study of communication has now reached a degree of independence and authority making it a science in its own right. What does modern science have to say concerning the status and functions of communication and secrecy?

Let us recapitulate our general attitude toward information. A living organism such as man is immersed in a world about him which he perceives through his sense organs. This information is co-ordinated through his brain and nervous system until, after the proper process of storage, collation, and selection, it emerges through effector organs which are generally 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 the already accumulated store of information to influence future action.

Information is thus 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 outer environment, and of our living effectively under 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, have been developed to meet the needs of this process. To live effectively is to live with adequate information.

I am writing this book primarily for the Americans in the American environment. In this environment, questions of information will be evaluated according to the standard American criterion of evaluation: a thing is valuable as a commodity for what it will bring in the open market. This is the official doctrine of an orthodoxy which it is becoming more and more perilous for a resident of the United States to resist. It is perhaps worth while to point out that it does not represent a universal basis of human values: that it corresponds neither to the doctrine of the Church, which seeks for the salvation of the human soul, nor to that of Marxism, which values a society for its realization of ideals of human well-being. The fate of information in the typically American world is to become something with a price which can be bought or sold.

It is not my business to cavil whether this mercantile attitude is moral or immoral, crass or subtle. It is my business to show that it leads to the misunderstanding and the mistreatment of information and its associated concepts. I shall take this up in several fields, beginning with that of patent law. Here I shall continue and develop some of the ideas and remarks of the last chapter.

The letters patent granting to an inventor a limited monopoly over the subject matter of his invention are what a charter is to a chartered company. Behind these is a certain implicit philosophy of intellectual property and of the rights thereto. This philosophy represents a fairly close approximation to the actual situation in the period of shop inventions by skilled handicraftsmen. It does not represent even a passable picture of the inventions of the present day.

It presupposes that by a system of trial and error implying what is generally called mechanical ingenuity, a craftsman has advanced from an art of his own time to a further stage, embodied in a specific apparatus. The law distinguishes the ingenuity which is necessary to make this new combination from the other sort of ingenuity which is necessary to find out scientific facts about the world. This second sort of ingenuity is labeled the *discovery of a law of nature;* and in the United States, as well as in many other countries with similar industrial practices, the legal code denies to the discoverer any property rights in a law of nature which he may have discovered. It will be seen that this distinction is fairly practical, when the shop inventor has one sort of tradition and background, and the man of science has a totally different one.

The Daniel Doyce of Dickens' *Little Dorrit,* is clearly not to be mistaken for the members of the Mudfog Association, which Dickens treats elsewhere. The first, Dickens glorifies as the common-sense craftsman, with the broad thumb of the hand worker, and the honesty of the man who is always facing facts; whereas the Mudfog Association is nothing but a derogatory alias for the British Association for the Advancement of Science in its early days. Dickens reviles the latter as an assemblage of chimerical and useless dreamers, in language which Swift would not have found inadequate to describe the projectors of Laputa.

Now a modern research laboratory such as that of the Bell Telephone Company, while it retains the contact with practice belonging to a Doyce, actually consists of the spiritual great-grandchildren of the Mudfog Association. If we take Faraday as a typical member of the early British Association for the Advancement of Science, the chain to the research men of the Bell Telephone Laboratories of the present day, by way of Maxwell and Heaviside to Campbell and Shannon, is perfectly complete.

In the early days of modern invention, science was far ahead of the workman. The level of the mechanical competence was that of the locksmith. A piston was considered to fit an engine-cylinder when, according to Watt, a thin sixpence could just be slipped between the two. Steel was a craftman's product, for swords and armor; iron was the stringy, slag-filled product of the puddler. Daniel Doyce had a long way indeed to go before so practical a scientist as Faraday could begin to supplant him. It is not strange that the policy of his country, even when expressed through such a purblind organ as the Circumlocution Office,[1] was directed towards him as the true inventor, rather than to the gentlemen of the Mudfog Society. The Barnacle family might wear Doyce to a shadow, before they ceased to refer him from office to office, but they secretly feared him, as the representative of the new industrialism which was displacing them. They neither feared, respected, nor understood the gentlemen of the Mudfog Association.

In the United States, Edison represents the precise transition between the Doyces and the men of the Mudfog Association. He was himself very much of a Doyce, and was even more desirous of appearing to be one. Nevertheless, he chose much of his staff from the Mudfog camp. His greatest invention was that of the industrial research laboratory, turning out inventions as a business. The General Electric Company, the Westinghouse interests, and the Bell Telephone Laboratories followed in his footsteps, employing scientists by hundreds where Edison employed them by tens. Invention came to mean, not the gadget-insight of a shop worker, but the result of a careful, comprehensive search by a team of competent scientists.

At present, the invention is losing its identity as a commodity in the face of the general intellectual structure of emergent inventions. What makes a thing a good com-

[1] The Circumlocution Office, under the domination of the Barnacle family, represents Dickens' contempt for the reactionary nature of established power in the England of his day, especially in matters concerning patents and inventions.

modity? Essentially, that it can pass from hand to hand with the substantial retention of its value, and that the pieces of this commodity should combine additively in the same way as the money paid for them. A law of conservation is a very convenient property for a good commodity to have. For example, an amount of electrical energy, except for minute losses, goes into the same amount of energy at the other end of a transmission line, and the problem of putting a fair price on electric energy in kilowatt-hours is not too difficult to receive a practical solution. The situation is very similar with respect to the law of the conservation of matter; and our ordinary standards of value are quantities of gold, which is a particularly stable sort of matter.

Energy and matter were the scientific darlings of the nineteenth century. At that time, they were regarded as distinct. At present, we know them to be nothing but the two halves of a Siamese twin. The nineteenth-century sociologists searched for "sociological energies," and the nineteenth and twentieth-century psychologists for "psychological energy," and the nineteenth-century experimental biologists for "energy of organization."

For all this, the notion of energy is not the whole of physics, and even less is it the whole of the new sciences which are growing up after the pattern of physics. It was during the last century, indeed, that another notion came into being, related to energy but much more important than energy in the problems of communication and information. This notion is that of *entropy*, which we have already discussed. We have seen that this entropy is not conserved. It can increase spontaneously, but in a closed system it cannot decrease. Because of this tendency to change, entropy is not directly suited to be a commodity.

In the first chapter, we have seen that communication is based on a notion allied to entropy, known as the amount of information. This amount of information is a quantity which differs from entropy merely by its algebraic sign and a possible numerical factor. Just as entropy tends to increase spontaneously in a closed system, so information tends to decrease; just as entropy is a measure of disorder, so information is a measure of order. Information and entropy are not conserved, and are equally unsuited to being commodities.

In considering information or order from the economic point of view, let us take as an example a piece of gold jewelry. The value is composed of two parts, that of the gold, and that of the "façon," or workmanship. When an old piece of jewelry is taken to the pawnbroker or the appraiser, the firm value of the piece is that of the gold only. Whether a further allowance is made for the façon or not depends on many factors, such as the persistence of the seller, the style in favor when it was made, the purely artistic craftsmanship, the historical value of the piece for museum purposes, and the resistance of the buyer. Many a fortune has been lost by ignoring the difference between these two types of values, that of the gold and that of the façon. The stamp market, the rare-book market, the market for Sandwich glass and for Duncan Phyfe furniture are all artificial, in the sense that in addition to the real pleasure which the possession of such an object gives to its owner, much of the value of the façon pertains not only to the rarity of the object itself, but to the momentary existence of an active group of buyers competing for it. A depression, which limits the group of possible buyers, may divide it by a factor of four or five, and a great treasure vanishes into nothing just for want of a competitive purchaser. Let another new popular craze supplant the old in the attention of the prospective collectors, and again the bottom may drop out of the market. There is no permanent common denominator of collectors' taste, at least until one approaches the highest level of aesthetic value. Even then the prices paid for great paintings are colossal reflections of the desire of the purchaser for the reputation of wealth and connoisseurdom.

The problem of the work of art as a commodity raises a large number of questions important in the theory of information. In the first place, except in the case of the narrowest sort of collector who keeps all his possessions under permanent lock and key, the physical possession of a work of art is neither sufficient nor necessary for the benefits of appreciation which it conveys. Indeed, there are certain sorts of works of art which are essentially public rather than private in their appeal, and concerning which the problem of possession is almost irrelevant. A great fresco is scarcely a negotiable document, nor for that matter is the building on whose walls it is placed. Whoever is technically the possessor of such works of art must share them at least with the limited public that frequents the buildings, and very often with the world at large. He cannot place them in a fireproof cabinet and gloat over them at a small dinner for a few connoisseurs, nor shut them up altogether as private possessions. There are very few frescos which are given the adventitious privacy of the one by Siqueiros which adorns a large wall of the Mexican jail where he served a sentence for a political offense.

So much for the mere physical possession of a work of art. The problems of property in art lie much deeper. Let us consider the matter of the reproduction of artistic works. It is without a doubt true that the finest flower of artistic appreciation is only possible with originals, but it is equally true that a broad and cultivated taste may be built up by a man who has never seen an original of a great work, and that by far the greater part of the aesthetic appeal of an artistic creation is transmitted in competent reproductions.

The case of music is similar. While the hearer gains something very important in the appreciation of a musical composition if he is physically present at the performance, nevertheless his preparation for an understanding of this performance will be so greatly enhanced by a hearing of good records of the composition that it is hard to say which of the two is the larger experience.

From the standpoint of property, reproduction-rights are covered by our copyright law. There are other rights which no copyright law can cover, which almost equally raise the question of the capacity of any man to own an artistic creation in an effective sense. Here the problem of the nature of genuine originality arises. For example, during the period of the high Renaissance, the discovery by the artists of geometric perspective was new, and an artist was able to give great pleasure by the skillful exploitation of this element in the world about him. Dürer, Da Vinci, and their contemporaries exemplify the interest which the leading artistic minds of the time found in this new device. As the art of perspective is one which, once mastered, rapidly loses its interest, the same thing that was great in the hands of its originators is now at the disposal of every sentimental pictorialist who designs trade calendars. What has been said before may not be worth saying again; and the informative value of a painting or a piece of literature cannot be judged without knowing what it contains that is not easily available to the public in contemporary or earlier works. It is only independent information which is additive. The derivative information of the second-rate copyist is far from independent of what has gone before. Thus the conventional love story, the conventional detective story, the average acceptable success tale of the slicks, all avoid the letter but not the spirit of the law of copyright. There is no form of copyright law that prevents a movie success from being followed by a stream of inferior pictures exploiting the second and third layers of the public's interest in the same emotional situation. Neither is there a way of copyrighting a new mathematical idea, or a new theory such as that of natural selection, or anything except the identical reproduction of the same idea in the same words.

I repeat, this is no accident, but inherent in the nature of information. Property in information suffers from the necessary disadvantage that a piece of information, in order to contribute to the general information of the community, must say something substantially different from the community's previous common stock of information. Even in the great classics of literature and art, much of the obvious informative value has gone out of them, merely by the fact that the public has become acquainted with their contents. Schoolboys do not like Shakespeare, because he seems to them nothing but a mass of familiar quotations. It is only when the study of such an author has penetrated to a layer deeper than that which has been absorbed into the superficial clichés of the time, that we can re-establish with him an informative rapport, and give him a new and fresh literary value.

It is interesting from this point of view that there are authors and painters who, by their wide exploration of the aesthetic and intellectual avenues open to a given age, have an almost destructive influence on their contemporaries and successors for many years. A painter like Picasso, who runs through many periods and phases, ends up by saying all those things which are on the tip of the tongue of the age to say, and finally sterilizes the originality of his contemporaries and juniors.

The intrinsic limitations to the commodity nature of communication are scarcely understood by any important part of the public at large. The man in the street considers that the

Maecenas has as his function the purchase and storage of works of art, rather than the encouragement of their creation by the artists of his own time. In a quite analogous way, he believes that it is possible to store up the military and scientific know-how of the nation in static libraries and laboratories, just as it is possible to store up the military weapons of the last war in the arsenals. Indeed, he goes further, and considers that information which has been developed in the laboratories of his own country is, in some moral extralegal sense the property of that country; and that the use of this information by other nationalities not only may be the result of treason, but intrinsically partakes of the nature of theft. He cannot conceive of a piece of information without an owner.

The idea that information can be stored in a changing world without an overwhelming depreciation in its value is false. It is scarcely less false than the more plausible claim, that after a war we may take our existing weapons, fill their barrels with cylinder oil, and coat their outsides with sprayed rubber film, and let them statically await the next emergency. Now, in view of the changes in the technique of war, rifles store fairly well, tanks poorly, and battleships and submarines not at all. The fact is that the efficacy of a weapon depends on precisely what other weapons there are to meet it at a given time, and on the whole intellectual concept of war at that time. This has the result – as has been proved in more than one case – that the existence of excessive stockpiles of stored weapons is likely to stereotype the military policy in a wrong form, so that there is a very appreciable advantage to approaching a new emergency with the freedom of choosing exactly the right tools to meet it.

On another level, that of economics, this is conspicuously true, as the British example shows. England was the first country to go through a full-scale industrial revolution; and from this early age it inherited the narrow gauge of its railways, the heavy investment of its cotton mills in obsolete equipment, and the limitations of its social system, which have made the cumulative needs of the present day into an overwhelming emergency, only to be met by what amounts to a social and industrial revolution. All this is taking place while the newest countries to industrialize are able to enjoy the latest, most economical equipment; are able to construct an adequate system of railroads to carry their goods on economically sized cars; and in general, are able to live in the present day rather than in that of a century ago.

What is true of England in Europe, is true of New England in the United States. It is often a far more expensive matter to modernize an industry than to scrap it and to start somewhere else. Quite apart from the difficulties of having a relatively strict industrial law and advanced labor policy, one of the chief reasons why New England is being deserted by the textile mills is that, frankly, they prefer not to be hampered by a century of traditions. Thus, even in the most material field, production and security are in the long run matters of continued invention and development.

Information is even more a matter of process than a matter of storage. That country will have the greatest security whose informational and scientific situation is adequate to meet the demands that may be put on it — the country in which it is fully realized that information is important as a stage in the continuous process by which we observe the outer world, and make our acts effective upon it. In other words, no amount of scientific research, carefully recorded in books and papers, and then put into our libraries with labels of secrecy, will be adequate to protect us for any length of time in a world where the effective level of information is perpetually advancing. There is no Maginot Line of the brain.

I repeat, to be alive is to participate in a continuous stream of influences from the outer world and acts on the outer world, in which we are merely the transitional stage. To be alive in the figurative sense to what is happening in the world, means to participate in a continual development of knowledge and its unhampered exchange. Under anything like a normal situation, it is both far more difficult and far more important for us to ensure that we have such an adequate knowledge than to ensure that some possible enemy does *not* have it. The whole arrangement of a military research laboratory is along lines hostile to our own optimum use and development of information.

During the last war an integral equation of a type which I have been to some extent responsible for solving arose, not only in my own work, but in at least two totally unrelated projects. In one of these I was aware that it was bound to arise; and in the other a very slight amount of consultation should have made me so aware. As these three employments of the same idea belonged to three totally different military projects of totally different levels of secrecy and in diverse places, there was no way by which the information of any one of them could penetrate through to the others. The result was that it took the equivalent of three independent discoveries to make the results accessible in all three fields. In matter of time, the delay thus created was of the order of some six months to a year, and probably considerably more. From the standpoint of money, which of course is less important in war, it amounted to a large number of man-years at a very expensive level. It would take a considerable valuable employment of this work by an enemy to be as disadvantageous as the need for reproducing all the work on our part. Remember that an enemy unable to participate in that residual discussion which takes place quite illegally, even under our setup of secrecy, would not have been in the position to evaluate and use our results.

This matter of the consideration of time is essential in all estimates of information. It is well recognized that as far as the actual use of codes and ciphers[2] in the field is concerned, there is a certain principle of *duality*. A code or cipher which will cover any considerable amount of material at high-secrecy level is not only a lock which is hard to force, but also one which takes a considerable time to open legitimately. Tactical information which is useful in the combat of small units will almost certainly be obsolete in an hour or two. It is a matter of very little importance whether it can be broken in three hours; but it is of great importance that any sergeant or officer receiving the message should be able to read it in something like two minutes. On the other hand, the larger plan of battle is too important a matter to entrust to this limited degree of security. Nevertheless, if it took a whole day for an officer receiving this plan to disentangle it, the delay might well be more serious than any leak. The codes and ciphers for a whole campaign or for a diplomatic policy might and should be still less easy to penetrate; but there are none which cannot be penetrated in any finite period, and which at the same time can carry a significant amount of information rather than a small set of disconnected individual decisions.

The ordinary way of breaking a cipher is to find an example of the use of this cipher sufficiently long so that the pattern of encodement becomes obvious to the skilled investigator. In general, there must be at least a minimum degree of repetition of patterns; and the very short passages

A code is a transformation of a message which only can be carried through for a significant message; whereas a cipher can be carried through on the characters constituting the message apart from the meaning. Thus a code book published by the Telegraph Company is completely unusable for garbled sequences or letters. A code is semantic — a cipher is visual or phonetic.

without repetition cannot be deciphered. However, when a number of passages are enciphered in a type of cipher which is common to the whole set even though the detailed encipherment varies, there may be enough in common between the different passages to lead to a breaking, first of the general type of cipher, and then of the particular ciphers used.

Probably much of the greatest ingenuity which has been shown in the breaking of ciphers appears not in the annals of the various secret services, but in the work of the epigrapher. We all know how the Rosetta Stone was decoded through an interpretation of certain characters in the Egyptian version, which turned out to be the names of the Ptolemies. There is however one act of decoding which is greater still. This greatest single example of the art of decoding is the decoding of the secrets of nature itself and is the province of the scientist.

Scientific discovery consists in the interpretation for our own convenience of a system of existence which has been made with no eye to our convenience at all. The result is that the last thing in the world to be protected by secrecy and elaborate code system is a law of nature. Besides the possibility of breaking the secrecy by a direct attack on the human or documentary vehicles of this secrecy, there is always the possibility of attacking the code upstream of all these. It is perhaps impossible to devise any secondary code as hard to break as the natural code of the atomic nucleus.

In the problem of decoding, the most important information which we can possess is the knowledge that the message which we are reading is not gibberish. A perfectly recognized method of disconcerting codebreakers is to mix in with the legitimate message a message that cannot be decoded; because it is in fact not a significant message, but a mere assemblage of characters. In a similar way, when we consider a problem of nature such as that of atomic reactions and atomic explosives, the largest single item of information which we can make public is that they exist. Once a scientist attacks a problem which he knows to have an answer, his entire attitude is changed. He is already some fifty per cent of his way towards that answer.

In view of this, it is perfectly fair to say that the one secret concerning the atomic bomb which might have been kept and which was given to the public and to all potential enemies without the least inhibition, was that of the possibility of its construction. Take a problem of this importance and assure the scientific world that it has an answer; then both the intellectual ability of the scientists and the existing laboratory facilities are so widely distributed that the quasi-independent realization of the task will be a matter of merely a few years anywhere in the world.

There is at present a touching belief in this country that we are the sole possessors of a certain type of information called "know-how," which secures for us not only priority on all engineering and scientific developments and all major inventions, but, as we have said, the moral right to that priority. Certainly, this "know-how" has nothing to do with the national origins of those who have worked on such problems as that of the atomic bomb. It would have been impossible at most times of history to secure the combined services of such scientists as the Dane, Bohr; the Italian, Fermi; the Hungarian, Szilard; and many others involved in the project. What made it possible was the extreme consciousness of emergency and the sense of universal affront excited by the Nazi threat. Something more than inflated propaganda will be necessary to hold such a group together over the long period of rearmament to which we are committed by the policy of the State Department.

Without any doubt, we possess the world's most highly developed technique of combining the efforts of large numbers of scientists and large quantities of money towards the realization of a single project. This should not lead us to any undue complacency concerning our scientific position, for it is equally clear that we are bringing up a generation of young men who cannot think of any scientific project except in terms of large numbers of men and large quantities of money. The skill by which the French and English do great amounts of work with apparatus which an American high-school teacher would scorn as a casual stick-and-string job is not to be found among any but a vanishingly small minority of our young men. The present vogue of the big laboratory is a new thing in science. There are those of us who wish to think that it may never last to be an old thing. When the time comes at which the scientific ideas of this generation are exhausted, or at least have come to show vastly diminishing returns on their intellectual investment, I do not see the prospect that the next generation will be able to furnish the colossal ideas on which colossal projects naturally rest.

A clear understanding of the notion of information as applied to scientific work will show that the simple coexistence of two items of information is of relatively small value, unless these two items can be effectively combined in some mind or organ which is able to fertilize one by means of the other. This is the very opposite of the organization in which each member travels a preassigned path, and in which the sentinels of science, when they come to the ends of their beats, present arms, do an about face, and march back in the direction from which they have come. There is a great fertilizing and revivifying value in the contact of two scientists with one another; but this can only come when one or both of the human beings representing the science has penetrated far enough across the frontier to be able to absorb the ideas of his neighbor into an effective plan of thinking. The natural vehicle for this type of organization is a plan in which the orbit of each scientist is assigned rather by the scope of his interests than as a predetermined beat.

Such loose human organizations do exist even in the United States; but at present they represent the result of the efforts of a few disinterested men, and not the planned frame into which we are being forced by those who imagine they know what is good for us. However, it will not do for the masses of our scientific population to blame their appointed and self-appointed betters for their futility, and for the dangers of the present day. It is the great public which is demanding the utmost of secrecy for modern science in all things which may touch its military uses. This demand for secrecy is scarcely more than the wish of a sick civilization not to learn of the progress of its own disease. So long as we can continue to pretend that all is right with the world, we plug up our ears against the sound of "Ancestral voices prophesying war."

In this new attitude of the masses at large to research, there is a revolution in science far beyond what is realized by the public. Indeed the lords of the present science themselves do not realize the full extent of the consequences of what is going on. In the past the direction of research had largely been left to the interest of the individual scholar and to the trend of the times. At present, there is a distinct attempt so to direct research in matters of public security that as far as possible, all significant avenues will be developed with the objective of securing an impenetrable stockade of scientific protection. Now, science is impersonal, and the result of a further pushing forward of the frontiers of science is not merely to show us many weapons which we may employ against possible enemies, but also many dangers of these weapons. These may be due to the fact that they either are precisely those weapons which are more effectively employable against us than against any enemy of ours, or are dangers, such as that of radioactive poisoning, which are inherent in our very use of the weapon. All this has been pointed out to me by Professor J. B. Wiesner of the Electronics Laboratory of the Massachusetts Institute of Technology. The hurrying up, owing to our active simultaneous search for all means of attacking our enemies and of protecting ourselves, leads to ever-increasing demands for new research. For example, the concentrated effort of Oak Ridge and Los Alamos in time of war has made the question of the protection of the people of the United States, not only from the possible enemies employing an atomic bomb, but from the atomic radiation of our new industry, a thing which concerns us *now*. Had the war not occurred, it would probably not have concerned us for twenty years. In our present militaristic frame of mind, this has forced on us the problem of possible countermeasures to a new employment of these agencies on the part of an enemy. To a large extent, this enemy is not Russia, but the reflection of ourselves in a mirage. To defend ourselves against this phantom, we must look to new scientific measures, each more terrible than the last. There is no end to this vast apocalyptic spiral.

We are in the position of the man who has only two ambitions in life. One is to invent the universal solvent which will dissolve any solid substance, and the second is to invent the universal container which will hold any liquid. Whatever this inventor does, he will be frustrated. Furthermore, as I have already said, no secret will ever be as safe when its protection is a matter of human integrity, as when it was dependent on the difficulties of scientific discovery itself.

I have already said the dissemination of any scientific secret whatever is merely a matter of time, that in this game a decade is a long time and that in the long run, there is no distinction between arming ourselves and arming our enemies. Thus each terrifying discovery merely increases our subjection to the need of making a new discovery. This is bound to go on and on, until the entire intellectual potential of the land is drained from any possible constructive application to the manifold needs of the race, old and new. The effect of these weapons must be to increase the entropy of this planet, until all distinctions of hot and cold, good and bad, man and matter have vanished in the formation of the white furnace of a new star.

We have taken unto us the devils of the age like so many Gadarene swine, and the compulsion neurosis of scientific warfare is driving us pell-mell, head over heels into the ocean of our own destruction. Or perhaps we may say that the gentlemen who have made it their business to be our mentors, and to administer the new program of science, are so many apprentice sorcerers, fascinated with the incantation which starts a devilment that they are totally unable to stop. Even the new psychology of advertising and salesmanship becomes in their hands a way for obliterating the conscientious scruples of the working scientists, and for destroying such inhibitions as they may have against rowing into this maelstrom of destruction.

Let these wise men who have summoned this demoniac sanction for their own purposes remember that in the natural course of events, a conscience which has been bought once will be bought twice. The loyalty to humanity which can be subverted by a skillful distribution of administrative sugar plums will be followed by a loyalty to official superiors lasting just so long as we have the bigger sugar plums to distribute. The day may well come when it constitutes the biggest potential threat to our own security. In that moment in which some other power, be it Fascist or Communist, is in the position to offer the greater rewards, our good friends who have rushed to our defense per account rendered will equally rush to our subjection and annihilation. May those who have summoned from the vasty deep the spirits of atomic warfare remember that for their own sake, if not for ours, they must not wait beyond the first glimmerings of success on the part of our opponents to put to death those whom they have already corrupted!

IX

ROLE OF THE INTELLECTUAL AND THE SCIENTIST

WE HAVE SEEN that communication is the cement of society, and that those who have made the clear maintenance of the channels of communication their business are those who have most to do with the continued existence or the fall of our civilization. Unfortunately, these priests of communication are divided rather sharply into two orders or sects, maintaining different principles, and subject to different trainings. These two orders of the priests of communication are the intellectuals or men of letters on the one hand, and the scientists on the other. There have been past periods when the balance between the man of letters and the scientist has been fairly maintained. However, the present age is anomalous in more than its physical environment. It is anomalous also in the distribution of its intellectual effort. On the one hand, it has until recently been a good age for the scientist, even for the more theoretical type of scientist. More than one of the great scientists of the present time need fear no comparison with the best of recorded history, and this is equally true in England and the United States. It is not only the journalists who compare Einstein with Newton, for Einstein's contributions have been fully as revolutionary against the present background as were those of Newton in his own time. Moreover, the men who surround Einstein form a group difficult to match among Newton's contemporaries. Niels Bohr of Copenhagen, Heisenberg of Goettingen, Planck of Berlin and Dirac of Cambridge are a few among the many names which come to one without effort, to match the Bernouillis, Taylor, Halley, and Maclaurin in the eighteenth century. Nor is pure mathematics secondary in this respect. The German mathematician Hilbert is but recently dead, and Hilbert would have been among the great names of any age. Weyl of Princeton and Kolmogoroff of Moscow are still among us. Poincaré, the great French mathematician, lived well along into the present century, and America has had her Birkhoff, at Harvard.

If it cannot be expected of any of these to have done the bulk of work of an Euler, or to have opened as many fields as a Gauss, they have handled problems of the greatest possible difficulty, beyond the horizons of an already well-developed mathematical pale of settlement, and they have shown a technical facility as great as that of their greatest predecessors, or even greater.

History shows a general concomitance between the development of the sciences and the development of the arts. However, the pattern of the artistic development of the past half-century has departed widely from that of its scientific development. In music, we have seen the dwindling of the race of composers. Performers we have in plenty; but it must be confessed that it is the composers, not the performers, who keep the flame of music burning. Only a relatively small part of our great performers show much interest in the compositions of the present age.

The situation is a little better in painting, although here again we must leave the confines of the United States. The newer modes have already developed their grand old men, such as Matisse and Picasso. In Mexico, a national school of fresco painting has shown remarkable resources of originality and of vigor. Nevertheless, for each competent artist of today, with a new message of beauty or truth, there are probably ten scientists who equal him in their relative rank, as compared with the great names of the past.

After all, music and painting cross national frontiers almost as readily as does science. The appreciation of literature, on the other hand, is largely confined to the compatriots and co-linguals of the authors. It is therefore much more difficult to give a comprehensive view of the subject. I have the impression, nevertheless, that both in England and in the United States, the present writers are distinguished more for a rather high level of technical competence in the use of language than for any particular creative power. Whether this is so in other countries, I am not competent to say.

I cannot believe that despair and discouragement are responsible for the whole modern picture. Much of the best of Greek writing belongs to the period of the Peloponnesian wars; and the fall of the Roman Empire is the great age of the fathers of the Church. More than one of the finest of the religious poems of the Middle Ages begins by bewailing the evils of the times and the lateness of the hour. Neither Voltaire, nor Swift, nor Heine is enthralled with the goodness and the hopefulness of his time.

There must then be some other cause or causes conditioning the relative artistic and literary sterility of the present age, especially in the United States. One of them lies near the surface. It consists in the development of methods of communication which, although inexpensive in per capita cost to those participating in them, are so expensive when taken in the smallest bulk in which they are commercially practicable as to preclude any but conventional and dull undertakings. I refer, of course, to the vast modern periodicals, to the phonograph, to the radio, to the movies, and to television. Note well that their effect is on writing and music, and that the desire of the rich connoisseur to possess authentic originals by masters minimizes the effect of these influences on painting, the art which I believe to possess a more considerable vitality at the present time.

The great rotary presses of our magazines are able to carry a bulk of work which could never have been thought of in the old printing shops, but they also constitute a capital investment far beyond what any old-fashioned printer could afford. The radio sells at a reasonable price, but this reasonable price is conditioned by a market well up in the tens of thousands. The movie maintains a seventy-five cent admission fee only at the cost of a demand sufficiently great for the producer, the exhibitor, and a host of middlemen to make a profit on a picture costing over a million dollars. All of this has the effect that these arts are in the hands of entrepreneurs who cannot afford to take a risk.

In the days of the legitimate theater and of the stock company it might have been unfortunate for the actors if the play which they performed was a flop, but the expense was limited. If the idea of a play was good, a few hundred appreciative people would constitute a paying audience. The country editor wrote for the few hundred or so readers of his country town. He could gauge their pulse. In many cases, similarity of environment made him think like them. Even if he wished to take on the rôle of Savonarola and castigate their shortcomings and vices, these very remarks were likely to be of interest to them, and to sell more papers. Finally, if in one way or another he had to leave town, he could still set up a new journal in a new place, with the added support of the valuable experience which he had received, and with a very reasonable hope of success.

Compare his lot with that of the syndicated columnist of the present day. The greater his success, the greater the audience to which he must appeal, and the more essential it is for him not to say anything which will be unpopular among any large element of his public. He must at the same time remember the Catholic, the Protestant, the Jew, the Negro, the businessman, the farmer, the laborer, and the unemployed. Should he overstep the walls of his prison in the slightest, this fact will appear sooner or later in some rating or other, to the scrutiny of which his owner subjects his work. He must conform, recant, or go under.

Up to this point, we have been discussing only that part of the necessary restriction of the freedom of the artist caused by size itself, and the great investment which is involved in modern enterprises. However, with the great investment in modern means of communication goes also great *power.* This power often has other interests besides its own direct profit. We all know of cases where municipal newspapers belong to lumber and electric interests, and have not been unready to conduct a special campaign in favor of the undertakings of their owners. On the other hand, there is no more cogent tool for the rich adventurer of fascist leanings than a great illustrated weekly.

This is a tune on which one can play an unlimited number of variations. It is enough to say that the newspaper-owner or the film-magnate who combines his undertakings with other sources of profit than the edification or amusement of his public is likely to be able to afford to stay in business, where his more straightforward competitor goes bankrupt. Accordingly, the best sources of income for a writer, or even for a musician, are tainted, not only by that pressure which arises from bigness alone, but from the fact that they must be subservient to some extraneous interest not revelant to their work, and very probably opposed to their opinions.

But this is not the worst. There is a third source of humiliation from which they suffer. The fact is that a business run by a person who is primarily a trader is likely to be run on the ruthless dog-eat-dog principles of trade. If the boss thinks it is good business to collect twenty stories for one he uses, nineteen out of twenty stories are going into the waste-basket. The writer is left with the humiliation of doing a sterile job. He may indeed be well paid for this subordination, but he will not be paid in the coin of self-respect.

There is still another cause for despair among the young artists who are dependent on the mass modes of distribution of their art. It is that through their very bulk, these projects are able to employ a relatively small number of writers, of musicians, or of photographers who are most proficient in the particular talents which mean money for the employer. The public of the slicks may not be very discriminating in ideas, but it certainly has the opportunity to become very discriminating in techniques. Accordingly, the young writer who has something to say, and who some day is going to say it well, now has no market for his manuscripts during precisely the stage when he needs it most. This has indeed already come to the attention of certain of the mass purveyors of the arts. They have been forced to do something about it, in order to prevent the drying up of their supplies of artists at the source. The movies have been compelled to subsidize the theater, and particularly the stock theater, in order to keep up the supply of competent actors. Moreover, the movies have been forced to do something similar in music. It is only through this type of subsidization, direct or indirect, that there are in fact any considerable number of artists active at the present time.

It is thus easy to see what is wrong with the artist who has to depend on his art for his bread and butter. He has always needed patrons, but never have his chief patrons been confined to so narrow a controlling group as at the present day. Yet this cannot be the sole explanation of the doldrums in which the creative arts find themselves. At all times there have been many fine writers who made their living from some other source than their art. Ruskin was the son of a rich wine merchant, and never needed to turn his writing into pounds, shillings, and pence. Much of Milton's writing was secondary to his activity as Secretary of State for the Commonwealth. It is not necessary to multiply examples. There are enough to suggest that the literary sterility of the present time has in its cause something besides the direct economic motive.

In America, as well as in those countries which are gradually beginning to follow our example, one of these causes is the bankruptcy of education. The German gymnasium of the last generation, like the French lycée, and even the English public school, was based on a pretty definite idea of what an educated man should be. In the first place, it was required that he should know the classics. Latin and Greek were drummed into him for so many years that they became part of him; and exercises of composition in these languages were not merely formal tasks, confined within the bounds of the textbooks, but were real essays, and even extended to the writing of passable poetry. The education of the student in his mother-tongue demanded not only the writing of compositions of very indifferent merit, but the organization of good sound prose in conformity with the best standards of the language. If the pupil learned a foreign language, if he were a French or English boy, but not if he were a German boy, he might indeed trifle somewhat with the pronunciation. However, his reading and understanding of it had to be such as to render it a ready tool. His mathematics teacher did not attempt to propel him to his destination over a royal macadamized road. He was required to know his theorems, and to know that he knew them, as well as to carry out so-called original exercises of a considerable degree of sophistication. If he were an English boy of the upper class and went to a Public School, he did this under the threat of the cane or the birch; and if he were a German boy, under the shouted insults of a not-too-gentle teacher. If he were a French boy, he studied under the greater threat of the possibility that if he should fail even once in a concours, he might never be given a second chance. He might ruin his career for his whole lifetime, and stand condemned to a permanent loss of social status.

While the earlier stages of American education followed the English pattern, it is not the pattern out of which modern American education has developed. Harvard began, not as an English University, but much more as what we should now call an English public school. This is well shown by the youthful age of its early students. Its emphasis on the classics and on mathematics differed in no respect from that of its English prototype. In the course of time, Harvard and other American institutions of learning were pushed upwards in student age and in prestige, until they came to occupy the position of the English university college, and later of the English or German university, rather than that of the public school. A handful of secondary institutions, such as Andover, Exeter, Groton, St. Paul's, and the like, have followed something like the English public-school pattern, to fill the vacancy which the early colleges left in their advance; but these have had a continually decreasing influence with respect to the country at large. The actual secondary education of America has been in the hands of the public high schools, which have even succeeded in imposing much of their pattern on the private secondary schools.

The high school, while it has assimilated much from the Exeter-Andover type of academy, is an outgrowth of a public-school system started in the Little Red School House. Here, during the season when work was slack, the farm boys and farm girls betook themselves, partly to learn their three

R's, but equally to keep themselves out of mischief. The picture given by Eggleston in his *Hoosier Schoolmaster* was valid in many rural schools until the end of the century.

From the beginning, the city public schools were superior to the Little Red School House in their subdivision into grades, and in very little else. The curriculum consisted of reading, writing, a very thin layer of arithmetic, and a highly conventionalized geography. They contained nothing calculated to prepare the student for a later high-school curriculum based on that of the private institutions. Furthermore, this high-school curriculum was postponed until the age of fourteen, so that the student of even moderate brightness arrived at that critical period without ever having undergone one day of school work severe enough to test his powers.

When discipline was spoken of, it meant the discipline of not throwing blackboard erasers around, and not the discipline of study. Under the frontier conditions, it was customary for some of the older lads to show their mettle by trying to lick the schoolmaster. Accordingly the schoolmaster had to become an army sergeant, rather than a man of learning. This raw and unbroken human material of half-grown lads then went to the high school, where it was expected to master in four years a reading knowledge of Latin, possibly Greek, mathematics up to and including trigonometry, the ability to converse in at least one foreign language, some history and an appreciation of Shakespeare. The remarkable thing is that even some small communities possessed teachers so devoted that some exceptional students actually managed to do all this successfully. For the overwhelming majority, the result of this blind effort toward culture was pure frustration.

It is no wonder that to the average American high-school student and to his parents the more meaty subjects of education came to have the significance of a special privilege for the brilliant and those of unusual opportunities, and a trap and a torture for the rest. Inasmuch as the American idea of education was something in which the whole community should participate, rather than any privileged class – even the class privileged only by its ability to make use of this education – it was clear very early that high-school education would have to undergo a radical change.

This change took place first in Greek, which had nearly always been no more than a voluntary subject, and which many years ago had completely disappeared from the average high-school curriculum. What hurried this was the gradual but continual devaluation of the clergyman in the community. If he attempted to be anything of a scholar, Greek was an essential tool for him; but it seemed to be a useful tool for almost no one else. In the time of my boyhood, Greek had gone, and Latin was getting very shaky. The education in Latin as in fact the whole high-school curriculum in languages and mathematics had lost much of its connection with American life, and had become rather more of a ritual prerequisite to admission to college than a subject of living study.

The position of modern languages in our high schools has been subject to influences some of which have been favorable and some of which have been predominatingly hostile. On the favorable side comes the need for modern languages, and especially French and German, as tools in the education of the natural scientist; and the desire to cultivate a trade with Spanish-speaking countries to the South of us. In a period in which a continental education was considered essential for the advanced training of every aspiring American scientist, and even man of letters, French and German had a much greater vogue than they do now. At that time, French partook much more than at present of the character of a language of culture. Now, the more vital aspects of the French language and the appreciation of French culture in its full sense have long failed to play a significant rôle in high-school French.

To a large extent, high-school teaching in German was very sick during the first World War, and died in the second. Both French and German, when they are now needed by advanced students as tools and as necessary vehicles for a scientific education, have become relegated to the efforts of the individual student and to the later years of college or to the graduate school. There are undoubtedly places in Texas, and elsewhere near the Mexican frontier, where a knowledge of Spanish is a sufficiently important matter for the high schools to give it real attention. Nevertheless, among those who need Spanish for business purposes in Mexico and in South America, the level of the Spanish which they have received in their secondary education is seldom such as to permit them to participate even in a simple social evening in a Spanish-speaking household.

Behind this lack of linguistic training lies the fact that we represent what is geographically one of the largest blocks of population under a single language. Your Dutchman cannot carry on his business for one day without the probability that he will have to use English, French, and German. Even your Englishman values his holidays on the Continent. On the other hand, the American will not meet the need for a foreign language between Montreal and Laredo. The many foreigners with whom he may come into contact are damned for him by their non-Americanism, and he expects them to take the initiative in speaking his language. This hostility to other languages is carried by the American tourist as a protective cloak wherever he goes; and if in Mexico or in French Canada the natives will not adapt themselves to his habits, he is perfectly content to confine his contacts to those who do so defer to him.

Thus, for the average high-school student, even the living languages are dead issues. This is also true for the study of living cultures other than his own. It is only in American history that he has received what may be a thorough historical course. These courses in American history are often so colored by prevailing public opinion, and even by statute, that they constitute rather exhortations to patriotism than attempts to find out what really happened. When our authors of high-school textbooks must publish two variations of a history of the Civil War, one for the North and one for the South, there is not much impartiality to be expected, nor can such courses in history well serve the purpose of orienting the student in the world in which he lives.

The engineering schools and other technical institutions of college grade have requirements which in some cases have been able to keep alive an adequate training in mathematics, physics, chemistry, and even some of the other sciences. This applies however only to those schools which, like the Massachusetts Institute of Technology, are sufficiently in demand to be able to enforce their own entrance requirements. In the state colleges, even the engineering students are admitted at so low a level of training in these basic subjects that two years of college are spent in bringing the student to the level which the graduate of a continental *Gymnasium* or *Realschule* has attained at the age of sixteen. Under normal conditions, only those who go on to graduate-school work have much hope of becoming any more than cook-book engineers, bound for their life to one of the comprehensive engineers' handbooks.

There remains the course in English as a high-school subject which may have some cultural value. In the hands of a devoted teacher with personal cultural interests, this value may well be present and even high. Against this, it must be remembered that neither the material rewards nor the social status of the teacher in the average high school is enough to secure teachers of any particular cultural interest. The great majority of high-school teachers of English are young women of no special intellectual attainments, who are awaiting the time for marriage in genteel, but not exacting employment. The average student entering the average college is able neither to write a passage of acceptable English nor to read a literary book with any understanding.

What I have just said of the technical school holds, *mutatis mutandis*, of the universities. The result is to transfer the burden of serious education to the period from eighteen to twenty. This is desperately late for the average young man or woman who has not already formed cultural tastes and good habits of study. From this time on, these tastes and habits are progressively more difficult to attain. In particular, the student must narrow the field of his efforts so stringently that it is almost hopeless for him to achieve in the scanty time that remains even a modicum of proficiency in more than one direction. If he has cultural interests, he has no time to learn what science is about, and if he has scientific interests, he generally finds the books of culture to be forbidden territory.

The various fill-in subjects, such as Economics and Government, with which the student has supplemented his diluted high-school schedule, and which in many cases have altogether replaced it, do not offer either sufficient discipline or sufficient objective firmness of ground to supplant the studies more traditional in the education of the young. If they are to be taken seriously at all, and not merely as makeshifts to keep the high-school student busy during the years when the state laws withold him from employment, they must be studied at a level of experience and maturity which are generally only available to the thoroughly grown-up.

The subjects which used to form the mainstay of education, and which are now less popular for one reason or another, are under a continual attack by the teaching profession and by the state legislatures. There is a curious idea which is in vogue in this country to the effect that democracy involves an education which is not beyond the capacity of the dullest, and that any discrimination on the basis of intellectual ability, or any relegation of the backward to a further year of school, is pernicious. The youngster of exceptional abilities generally is either ignored or else is treated as an offender who breaks up the smooth trend of American democratic school life. Only rarely is it realized that he is likely to make an irreplaceable contribution to the future of his community; and only rarely is he given the opportunity to try his powers against problems proportional to his abilities.

Thus the material which comes to the colleges and the universities seldom rises above a drab mediocrity. This low-grade ore must undergo a special processing before it is to yield usable metal. The present fashionable mode of processing in cultural subjects is the survey course. Now, a survey course may be very useful to convey a general orientation to the student who is already full of special knowledge. For the student who first meets Plato and Aristotle, Bacon and Locke, in such a course, it can only serve the purpose of sophistry: that is, of the ability to talk with a certain amount of conviction on subjects of which one knows nothing. When it goes outside of philosophy and literature, and is used (of all places!) in mathematics, and when in particular it is confined to the rather perfunctory reading of a few great books, it is not only useless, but definitely harmful; for it gives a false picture of what mathematics is at the present day, and of what constitutes its present intellectual development. This is equally true in the physical and biological sciences.

I have said that the college students who have come through the usual United States high-school system find their time much too short to make substantial progress in more than one subject. Some of them become tolerable engineers and even tolerable laboratory scientists, provided the requirements of their sciences do not extend beyond one or two fields. Some of them, who have found a technique of learning outside of their courses, and particularly in their graduate work, have developed themselves into passably cultured people. Those who fail to do this, and whose lines of activity lie in literature and the social sciences, find themselves restricted to one field quite as much as do the votaries of the natural sciences, but without the advantage of the at least partial intellectual discipline to which the latter are subject. Some go to law school, and follow the most limited and least instructive of all techniques. Finally, some become artists and literary men. Most of these have no more time to learn their trade through a proper apprenticeship. These generally become critics.

The psychology of these critics takes a very definite form. They are for the most part doubly frustrated men: frustrated first in their lack of contact with the developments of modern culture and civilization; secondly, by their inability to perform primarily creative work along the lines of their own interests. It is perfectly true that this inability is due quite as much to an emotional block as to ignorance; but in the final effort to produce something new, it is easier to get the better of emotional hazards if there is a sound tradition of craftsmanship to summon up. A generation ago, the first academic refuge of the intellectual out of touch with his times was the Department of the Classics. It is now above all the Department of English.

Theoretically, the Professor of English should find his self-expression in writing, or at any rate in the appreciation and the conservation of the literary treasures of the past, and in the evaluation of the new names coming to the fore. Actually, there are few professors of English who are able to devote themselves to such congenial work; and in fact, these prize positions are always only to be won at the price of years of servitude. The Professor of English spends the good half of his time in attempting to give the college freshman the stark bones of a training in writing which he should have received some five to ten years earlier. The result is that for every man in whom he has a moderate pride there are ten of his pupils whose education represents conscious failure on his part. The time that is left is so limited that there is very little opportunity for the teacher to develop either the writing ability or the technique of his students with the proper leisure that is necessary for real progress. The result is again the survey course.

This often consists in a number of texts which make good sense when taken one by one, and whose sequence is understandable by the man who already has a certain background in cultural history. At the pace at which they must be taken in a comprehensive course, however, they form almost as meager a consistent development as the Encyclopaedia. Under proper circumstances, hash may be very nutritive, but it is not a suitable way to educate the palate of the gourmet.

The result of all this is a professional disease or deformation, which might well be called "English teacher's acidity." In its fully developed form, it is not unaffected by the fact that literature is akin to the stage, and that a certain pose of

Olympian discontent enhances the teacher's reputation for individuality and for scholarship. The ivory tower and the personal orientation accompanying it would not matter very much if the task of the literary critic and the protector of culture were really as irresponsible and unimportant as many seem to take it to be. It is far from unimportant, and it should be undertaken responsibly. Never was there an age so little cognizant of its own presuppositions as the present time. This is not because it is an inferior age. It is because it is a confused age, and because the path to its understanding has not yet been clearly marked out. We often deplore it as an age lacking in craftsmanship. Yet the average country garage mechanic or radio repair man is a superb craftsman. In comparison with these men, the old-fashioned village blacksmith was often no more than a crude bungler. If he took refuge from the barrenness of the run of his trade in an occasional fine piece of wrought-iron work, why, so does the radio repairman in the construction of a radio set of unusual purity of tone. The fact that one of these men appeals to the eye, and the other to the ear, or even to the intellect, does not degrade the art and the artisanship of the present generation.

In this connection, there is a curious misunderstanding of this generation by those who should be the conservators of its ideals. Because the craftsmanship of the present age employs the plane and the lathe, it tends to produce articles with large flat or cylindrical surfaces. The airplane, that high point of modern technique, involves wings, propellers, and struts with certain aerodynamical properties, and these properties demand sweeping, smooth surfaces. These superficial accidents of technique have gone to the heads of the industrial designers and the interior decorators. These gentlemen are subject to an understandable but not justifiable impulse to streamline egg beaters, floor lamps, and pieces of statuary. This habit of design is as unfunctional and as meretricious as was the custom of the sewing-machine designers fifty years ago to support their machines with elaborately twisty cast-iron frames in the semblance of wrought iron.

In literature too, there is much more attention to the appearance of the present day than to the things that make the present day tick. If a novel has the squalor of the city slums or the stench of the Tobacco Road outhouse, it is great and realistic. There are indeed novels which show how the South Chicago slums fit into the general picture of the age, and what the factors are which keep Tobacco Road what it is, but these are none too common, and in general tend to lose themselves in a highly partisan didactiveness. The larger picture of the modern age, tracing the decade or half-century against its background, and observing the mutual interplay of technical and political circumstances and the life of genuine individual characters, not propagandist dummies, has yet to be written.

I am composing this book from the point of view of a professor at an American technical school – in particular, at M.I.T. I am well aware of the fact that a large part of our students are by training and disposition more responsive to technical education than to cultural education. I am, nevertheless, equally well aware of the great demand for cultural information and cultural orientation on the part of a very appreciable fraction of our better students. There is a freshness and aliveness in their interest in music and literature, in philosophy, and in the intellectual understanding of their own task and position, which is missing in many of those whose primary purpose at the university is supposed to be cultural. These young men are participants in the modern world, not spectators. If we are to develop a culture which fully comprehends and understands the world in which it lives, it must be from men like these that it is to come.

The overrefined individual of the ivory-tower culture, whose strongest emotion is a gregarious desire to be like other cultured people, is too etiolated and asthenic a form to have much to contribute to an understanding of the present state of the world. Indeed his very critical purity of outlook is the purity of self-defense. If he attempts a taste and a jargon of his own, they are always the taste and jargon of a cult or coterie, to protect him from the harshness of the outer world, while he huddles together with his fellows like blind kittens in a basket. The Gospel according to Freud represents just the proper combinations of scholarship and mumbo-jumbo to appeal to his self-importance.

On the other hand, the great source of intellects for the future, if not intellectuals, is the body of men trained for a profession like engineering or medicine or natural science — professions demanding intellectual stamina and encouraging intellectual curiosity. If these men can be given the entrée to the social sciences and to literature, not in the form of a few courses of clichés, but through the understanding interest of teachers with a sociological or literary bent, already acquainted with scientific methods and habits of thought, then they will furnish a far better, even far more truly American source for the sociology and literature of the coming age than any earlier age or country has known. They must be taught that knowledge and culture are not private treasures to be locked up in a safe, and to be inspected only by the élite, and that all knowledge and all cultures are one and indivisible. They must learn to approve what they already feel, that nothing less than the whole man is enough to constitute the scholar, the artist, and the man of action. It is this wholeness, this integrity, that a considerable group of us at M.I.T. are trying to evoke and to render conscious in our students.

I do not blame the American intellectual for a hostile attitude to science and the machine age. A hostile attitude is something positive and constructive, and there is much of the impact of the machine age which needs active and intelligent resistance. I do blame him for a lack of interest in the machine age. He does not consider it important enough for him to learn the main facts concerning science and machinery, and for him to take an active position toward these. What attitude he has is hostile, but the hostility does not go so far as to make him do anything about it. It is more of a nostalgia for the past and a meaningless discontent with the present than any maturely considered attitude. He shows a willingness to accept the trends of the day as disagreeable but inevitable. In fact, he reminds one of the refined creatures in a fable of Lord Dunsany. These delicate and refined beings have become so used to being consumed by a grosser and more brutal race that they accept their fate as natural and proper, and welcome the axe which takes their heads off.

X

THE FIRST AND THE SECOND INDUSTRIAL REVOLUTION

I HAVE DEVOTED the preceding chapters of this book to the study of man as a communicative organism. However, as we have already seen, the machine may also be a communicative organism. In this chapter, I shall discuss that field in which the communicative characters of man and of the machine impinge upon one another, and I shall try to ascertain what the direction of the development of the machine will be, and what we may expect as its impact on human society.

Once before in history, the machine has impinged upon human culture with an effect of the greatest moment. This previous impact is known as the Industrial Revolution, and it concerns the machine purely as an alternative to human muscle. In order to study the present crisis, which we shall term the second industrial revolution, it is perhaps wise to discuss the history of the earlier crisis as something of a model to which we may go back.

The first industrial revolution had its roots in the intellectual ferment of the eighteenth century, which found the scientific techniques of Newton and Huygens already well developed, but with applications which had yet scarcely transcended astronomy. It had, however, become manifest to all intelligent scientists that the new techniques were going to have a profound effect on the other sciences. The first field in which this came to pass was that of navigation and of clockmaking.

Navigation is an art which dates to ancient times, but it had one conspicuous weakness until the seventeen-thirties. The problem of determining latitude has always been an easy one even in the days of the Greeks. It is simply the problem of determining the angular height of the celestial pole. This may be done roughly by taking the pole star as the actual pole of the heavens and it may be done very precisely by further refinements which locate the center of the apparent circular path of the pole star. On the other hand, the problem of longitudes is always more difficult. Short of a geodetic survey, it can only be solved by a comparison of local time with some standard time such as that of Greenwich. In order to do this, we must either carry the Greenwich time with us on a chronometer or we must find some heavenly clock other than the sun to take the place of a chronometer.

Before either of these two methods had become available for the practical navigator, he was very considerably hampered in his techniques of navigation. He was accustomed to sail along the coast until he reached the latitude he wanted. Then he would strike out on an east or west course, along a parallel of latitude, until he made a landfall. Except by an approximate dead-reckoning, he could not tell how far he was along the course. It was therefore a matter of great importance to him that he should not come unawares onto a dangerous coast. Having made his landfall, he again sailed along the coast until he came to his destination. It will be seen that under these circumstances every voyage was very much of an adventure. Nevertheless, this was the pattern of voyages for many centuries. It can be recognized in the course taken by Columbus, in that of the Silver Fleet, and that of the Acapulco galleons.

This slow and risky procedure was not satisfactory for the admiralties of the eighteenth century. In the first place, the overseas interests of England and France, unlike those of Spain, lay in high latitudes, where the advantage of a direct great-circle course over an east-and-west course is most conspicuous. In the second place, there was a great competition between the two northern powers for the supremacy of the seas, and the advantage of a better navigation was a serious one. It is not a surprise that both governments offered large rewards for an accurate technique of finding longitudes.

The history of these prize contests is complicated and not too edifying. More than one able man was deprived of his rightful triumph, and went bankrupt. In the end, these prizes were awarded in both countries for two very different achievements. One was the design of an accurate ship's chronometer — that is of a clock sufficiently well constructed and compensated to be able to keep the time within a few seconds over a voyage in which it was subject to the continual violent motion of the ship. The other was the construction of good mathematical tables of the motion of the moon, which enabled the navigator to use that body as the clock with which to check the apparent motion of the sun. These two methods have dominated all navigation until the recent development of radio and radar techniques.

Accordingly, the advance guard of the craftsmen of the industrial revolution consisted on the one hand of clockmakers, who used the new mathematics of Newton in the design of their pendulums and their balance wheels; and on the other hand, of optical-instrument makers, with their sextants and their telescopes. The two trades had very much in common. They both demanded the construction of accurate circles and accurate straight lines, and the graduation of these in degrees or in inches. Their tools were the lathe and the dividing engine. These machine tools for delicate work are the ancestors of our whole machine-tool industry of the present day.

It is an interesting reflection that every tool has a genealogy, and that it is descended from the tools by which it has itself been constructed. The clockmakers' lathes of the eighteenth century have led through a clear historical chain of intermediate tools to the great turret lathes of the present day. The series of intervening steps might conceivably have been foreshortened somewhat, but it has necessarily had a certain minimum length. In order to construct a great turret lathe, it is clearly impossible to depend on the unaided human hand for the pouring of the metal, for the placing of the castings on the instruments to machine them, and above all for the power needed in the task of machining them. These must be done through machines that have themselves been manufactured by other machines, and it is only through many stages of this that one reaches back to the original hand or foot lathes of the eighteenth century.

It is thus entirely natural that those who were to develop new inventions were either clockmakers or scientific-instrument makers themselves, or called on people of these crafts to help them. For instance, Watt was a scientific-instrument maker. To show how even a man like Watt had to bide his time before he could extend the precision of clockmaking techniques to larger undertakings, we must remember, as I have said earlier, that his standard of the fit of a piston in a cylinder was that it should be barely possible to insert and move a thin sixpence between them.

We must thus consider navigation and the instruments necessary for it as the locus of an industrial revolution before the main industrial revolution. The main industrial revolution begins with the steam engine. The first form of the steam engine was the crude and wasteful Newcomen engine, which was used for pumping mines. In the middle of the eighteenth century there were abortive attempts to use it for generating power, by making it pump water into elevated reservoirs, and employing the fall of this water to turn waterwheels. Such clumsy devices became obsolete with the introduction of the perfected engines of Watt, which were employed quite early in their history for factory purposes as well as for mine pumping. The end of the eighteenth century saw the steam engine thoroughly established in industry, and the promise of the steamboat on the rivers and of steam traction on land was not far away.

Let us notice that the first place where steam power came into practical use was in replacing one of the most brutal forms of human or animal labor: the pumping of water out of mines. At best, this had been done by draft animals or by crude machines turned by horses. At worst, as in the silver mines of New Spain it was done by the labor of human slaves. It is a work that is never finished and which can never be interrupted without the possible closing-down of the mine forever. The use of the steam engine to replace this servitude must certainly be regarded as a great humanitarian step forward.

However, slaves do not only pump mines: they also drag loaded riverboats upstream. A second great triumph of the steam engine was the invention of the steamboat, and in particular of the river steamboat. The steam engine at sea was for many years but a supplement of questionable value to the sails carried by every seagoing steamboat; but it was steam transportation on the Mississippi which opened up the interior of the United States. Like the steamboat, the steam locomotive started where it seems now about to die, as a means of hauling heavy freight.

The next place where the Industrial Revolution made itself felt, perhaps a little later than in the field of the heavy labor of mine workers, and simultaneously with the revolution in transportation, was in the textile industry. This was already a sick industry. Even before the power spindle and the power looms, the condition of the spinners and the weavers left much to be desired. The bulk of production which they could perform fell far short of the demands of the day. It might thus appear to have been scarcely possible to conceive that the transition to the machine could have worsened their condition; but worsen it, it most certainly did.

The beginnings of textile-machine development go back of the steam engine. The stocking frame has existed in a form worked by hand ever since the time of Queen Elizabeth. Machine spinning first became necessary in order to furnish warps for hand looms. The complete mechanization of the textile industry, covering weaving as well as spinning, did not occur until the beginning of the nineteenth century. The first textile machines were for hand operation, although the use of horsepower and water power followed very quickly. Part of the impetus behind the development of the Watt engine, as contrasted with the Newcomen engine, was the desire to furnish power in the rotary form needed for textile purposes.

The textile mills furnished the model for almost the whole course of the mechanization of industry. On the social side, they began the transfer of the workers from the home to the factory and from the country to the city. There was an exploitation of the labor of children and women to an extent, and of a brutality, scarcely conceivable at the present time; that is, if we forget the South African diamond mines and ignore the new industrialization of China and India and the general terms of plantation labor in every country. A great deal of this was due to the fact that new techniques had produced new responsibilities, at a time at which no code had yet arisen to take care of these responsibilities. There was, however, a phase which was more technical than moral. This lay in the very nature of early steam power and its transmission. The steam engine was very uneconomical of fuel by modern standards, although this is not as important as it might seem, considering the fact that early engines had none of the more modern type with which to compete. However, among themselves they were much more economical to run on a large scale than on a small one. In contrast with the prime mover, the textile machine, whether it be loom or spindle, is a comparatively light machine, and uses little power. It was therefore economically necessary to assemble these machines in large factories, where many looms and spindles could be run from one steam engine.

At that time the only available means of transmission of power were mechanical. The first among these were the line of shafting, supplemented by the belt and the pulley. Even as late as the time of my own childhood, the typical picture of a factory was that of a great shed with long lines of shafts suspended from the rafters, and pulleys connected by belts to the individual machines. This sort of factory still exists; although in very many cases it has given way to the modern arrangement where the machines are driven individually by electric motors.

Indeed this second picture is the typical one at the present time. The trade of the millwright has taken on a totally new form. Here there is an important fact relevant to the whole history of invention. It was exactly these millwrights and other new craftsmen of the machine age who were to develop the inventions lying at the foundation of our patent system. Now, the mechanical connection of machines involves difficulties that are quite serious, but not easy to cover by any simple mathematical formulation. In the first place, long lines of shafting either have to be well aligned, or to employ ingenious modes of connection, such as universal joints or parallel couplings, which allow for a certain amount of freedom. In the second place, the long lines of bearings needed for such shafts are very high in their power consumption. In the individual machine, the rotating and reciprocating parts are subject to similar demands of rigidity, and to similar demands that the number of bearings must be reduced as far as possible for the sake of low power consumption and simple manufacture. These prescriptions are not easily filled on the basis of general formulas, and they offer an excellent opportunity for ingenuity and inventive skill of the old-fashioned artisan sort.

It is in view of this fact that the change-over in engineering between mechanical connections and electrical connections has had so great an effect. The electrical motor is a mode of distributing power which it is very convenient to construct in small sizes, so that the individual machine may have its own motor. The transmission losses in the wiring of a factory are relatively low, and the efficiency of the motor itself is relatively high. The connection of the motor with its wiring is not necessarily rigid, nor does it consist of many parts. There are still motives of traffic and convenience which may induce us to continue the custom of mounting the different machines of an industrial process in a single factory; but the need of connecting all the machines to a single source of power is no longer a serious reason for geographical proximity. In other words, we are now in a position to return to cottage industry, in places where it would otherwise be suitable.

Moreover, if it should be so desired, a single piece of machinery may contain several motors, each introducing power at the proper place. This relieves the designer of much of the need for the ingenuity in mechanical design which he would otherwise have been compelled to use. In an electrical design, the mere problem of the connection of the parts seldom involves much difficulty of a nature which does not lend itself to easy mathematical formulation and solution. This is an example of the way in which the art of invention is conditioned by the existing means.

In the third quarter of the last century, when the electric motor began to be employed in industry, it was at first supposed to be nothing more than an alternative device for carrying out existing industrial techniques. It was probably not foreseen that its final effect would be to give rise to a new concept of the factory.

That other great electrical invention, the vacuum tube, has had a similar history. Before the invention of the vacuum tube, it was a matter of a large number of separate tasks of design to develop the regulation of systems of great power. Indeed, most of the regulatory means employed did not involve a particularly low level of power. There were exceptions to this lack of development of methods of control, but they were in specific fields, such as the steering of ships.

As late as 1915, I crossed the ocean on one of the old ships of the American Line. It belonged to the transitional period when ships still carried sails and the masts on which to stretch them, as well as a pointed bow to carry a bowsprit. In a well-deck not far aft of the main superstructure, there was a formidable engine, consisting of four or five six-foot wheels with hand-spokes. These wheels were supposed to be the method of controlling the ship when its automatic steering engine had broken down. In a storm, it would have taken ten men or more, exerting their full strength, to keep that great ship on its course.

This was not the usual method of control of the ship, but an emergency replacement, or as sailors call it, a "jury steering wheel." For normal control, the ship carried, as had all other large ships for years, a steering engine which translated the relatively small forces of the quartermaster at the wheel into the movement of the massive rudder. Thus even on a purely mechanical basis, some progress had been made toward the solution of the problem of amplification of forces or torques. Nevertheless, at that time, this solution of the amplification problem did not range over extreme differences between the levels of input and of output, nor was it embodied in a convenient universal type of apparatus.

The most flexible universal apparatus for amplifying small energy-levels into high energy-levels is the vacuum tube, or electron valve. The history of this is interesting, though it is too complex for us to discuss here. It is however amusing to reflect that the invention of the electron valve goes back to the greatest scientific discovery of Edison, and perhaps the only one which he did not capitalize into an invention.

He observed that when an electrode was placed inside an electric lamp, and was taken as electrically positive with respect to the filament, then a current would flow, if the filament were heated, but not otherwise. Through a series of inventions by other people, this led to a more effective way than any known before of controlling a large current by a small voltage. This is the basis of the modern radio industry, but it is also an industrial tool which is spreading widely into new fields. It is thus no longer necessary to control a process at high energy-levels by a mechanism in which the important details of control are carried out at these levels. It is quite possible to form a certain pattern of behavior response at levels even much lower than those found in usual radio sets, and then to employ a series of amplifying tubes to control by this apparatus a machine as heavy as a steel-rolling mill. The work of discriminating and of forming the pattern of behavior for this is done under conditions under which the power losses are insignificant, and yet the final employment of this discriminatory process is at arbitrarily high levels of power.

It will be seen that this is an invention which alters the fundamental postulational conditions of industry, quite as vitally as the transmission and subdivision of power through the use of the small electric motor. The study of the pattern of behavior is transferred to a special part of the instrument in which power-economy is of very little importance. We have thus deprived of much of their importance the dodges and devices previously used to insure that a mechanical linkage should consist of the fewest possible elements, as well as the devices used to minimize friction and lost motion. The design of machines involving such parts has been transferred from the domain of the skilled shopworker to that of the research-laboratory man; and in this he has all the available tools of circuit theory to replace a mechanical ingenuity by the old sort. Invention in the old sense has been supplanted by the intelligent employment of the laws of nature. The step from the laws of nature to their employment has been reduced a hundred times.

I have previously said that when an invention is made, it is generally a considerable period before its full implications are understood. It was long before people became aware of the full impact of the airplane on international relations and on the conditions of human life. The effect of atomic energy on mankind and the future is yet to be assessed, although many stupid people of the present day assess it merely as a new weapon like all older weapons.

The situation with the vacuum tube was similar. In the beginning, it was regarded merely as an extra tool to supplement an already existing technique of telephone communication. The electrical engineers first mistook its real importance to such an extent that for years the vacuum tubes were relegated to a particular part of the communication network. This part was connected up with other parts consisting only of the traditional so-called inactive circuit elements — the resistance, the capacitances and the inductances. Only since the war have engineers felt free enough in their employment of vacuum tubes to insert them where necessary, with the same freedom with which they have previously inserted passive elements of these three kinds.

The vacuum tube was first used to replace previously existing components of long-distance telephone circuits and of the wireless telegraphy of the time. It was not long, however, until it had become clear that the radio-telephone had achieved the stature of the radio-telegraph, and that broadcasting was possible. Let not the fact that this great triumph of invention has been given over to the soap-opera and the hillbilly singer blind one to the excellent work which was done in developing it, and to the great civilizing possiblities which have been perverted into a national medicine-show.

Thus the vacuum tube received its début in the communications industry. The boundaries and extent of this industry were not fully understood for a long period. There were sporadic uses of the vacuum tube and of its sister invention, the photo-electric cell, for scanning the products of industry; as for example, for regulating the thickness of a web coming out of a paper machine, or for inspecting the color of a can of pineapples. These uses did not as yet form a reasoned new technique, nor were they associated in the engineering line with the task of communication.

All this changed in the war. One of the few things to be salvaged from the great conflict was the rapid development of invention, under the stimulus of necessity and the unlimited employment of money; and above all, the new blood called in to industrial research. At the beginning of the war, our greatest need was to keep England from being knocked out by an overwhelming air attack. Accordingly, the anti-aircraft cannon was one of the first objects of our scientific war effort, especially when combined with the airplane-detecting device of radar or ultra-high-frequency Hertzian waves. The technique of radar used the same modalities as the existing technique of radio besides inventing new ones of its own. It was thus natural to consider radar as a branch of communication theory.

I have discussed the problem of fire control in the first chapter of this book. I have shown how the speed of the airplane made it necessary to give the predicting machine itself communication functions which had previously been assigned to human beings. Thus the problem of anti-aircraft fire control made familiar the notion of a communication addressed to a machine rather than to a person. Indeed, in our discussions of language, we have already mentioned another field in which for a considerable time this notion had been familiar to a limited group of engineers. This is the field of the automatic hydro-electric power station.

During the same pre-war period other uses were found for the vacuum tube coupled directly with the machine rather than with the human agent. The concept of the large-scale computing machine as developed by Vannevar Bush among others was originally a purely mechanical one. The integration was done by rolling disks engaging one another in a frictional manner; and the interchange of outputs and inputs between these disks was the task of a classical train of shafts and gears.

The mother idea of these first computing machines is much older than the work of Vannevar Bush. In certain respects it goes back to the work of Babbage early in the last century. Babbage had an idea of the computing machine which is surprisingly modern, but his mechanical means fell far behind his ambitions. The first difficulty he met, and with which he could not cope, was that a long train of gears requires a considerable energy to run it, so that its output of power and torque very soon becomes too small to actuate the remaining parts of the apparatus. Bush saw this difficulty and overcame it in a very ingenious way. Besides the electrical amplifiers depending on vacuum tubes and on similar devices, there are certain mechanical torque-amplifiers which are familiar to everyone acquainted with ships and the unloading of cargo. The stevedore raises the cargo-slings by taking a purchase of his load around the drum of a donkey-engine or cargo-hoist. In this way, the tension which he exerts mechanically is increased by a factor which grows extremely rapidly with the angle of contact between his rope and the rotating drum. Thus one man is able to control the lifting of a load of many tons.

This device is fundamentally a force- or torque-amplifier. By an ingenious bit of design, Bush inserted such mechanical amplifiers between the stages of his computing machine; and was thereby able to do effectively the sort of thing which Babbage had only dreamed of theoretically.

In one of the earlier models of the Bush Differential Analyzer, this sort of mechanical device performed all the principal amplification functions. The only use of electricity was to give power to the motors running the machine as a whole. This state of computing-mechanisms was intermediate and transitory. It very soon became clear that amplifiers of an electric nature, connected by wires rather than by shafts, were both less expensive and more flexible than mechanical amplifiers and mechanical connections. Accordingly, the later forms of Bush's machine made an adequate use of vacuum-tube devices. This has been continued in all their successors; whether they were what is called now analogy machines, which work primarily by the measurement of physical quantities, or digital machines, which work primarily by counting and the operations of arithmetic.

The development of these computing machines has been very rapid since the war. For a large range of computational work, they have shown themselves vastly more rapid and vastly more accurate than the human computer. Their speed has long since reached such a level that any intermediate human intervention in their work is out of the question. Thus they offer the same need to replace human capacities by machine capacities as those which we found in the anti-aircraft computer. The parts of the machine must speak to one another through an appropriate language, without speaking to any person or listening to any person, except in the terminal and initial stages of the process. Here again we have an element which has contributed to the general acceptance of the extension to machines of the idea of communication.

In this conversation between the parts of a machine, it is often necessary to take cognizance of what the machine has already said. Here there enters the notion of feedback, which we have already discussed, and which is older than its exemplification in the ship's steering engine, and is as old, in fact, as the governor which regulates the speed of Watts' steam engine. This governor is needed to keep the engine from running wild when its load is removed. If it starts to run wild, the balls of the governor fly upward from centrifugal action, and in their upward flight they move a lever which partly cuts off the admission of steam. Thus the tendency to speed up produces a partly compensatory tendency to slow down. This method of regulation received a thorough mathematical analysis at the hands of Clerk Maxwell in 1868.

Here feedback is used to regulate the velocity of a machine. In the ship's steering engine it regulates the position of the rudder. The man at the wheel operates a light transmission system, employing chains or hydraulic transmission, which moves a member in the room containing the steering engine. There is some sort of apparatus which notes the distance between this member and the tiller; and this distance controls the admission of steam to the ports of a steam steering-engine, or some similar electrical admission in the case of an electrical steering-engine. Whatever the particular connections may be, this change of admission is always in such a direction as to bring into coincidence the tiller and the member actuated from the wheel. Thus one man at the wheel can do with ease what a whole crew could only do with difficulty at the old man-power wheel.

We have so far given examples where the feedback process takes primarily a mechanical form. However, a series of operations of the same structure can be carried out through electrical and even vacuum-tube means. These means promise to be the future standard method of designing control apparatus.

Quite apart from the vacuum tube and the method of feedback, there has long been a tendency to render factories and machines automatic. Except for some special purpose, one would no longer think of producing screws by the use of the ordinary lathe, in which a mechanic must watch the progress of his cutter and regulate it by hand. The production of screws in quantity without serious human intervention is now the normal task of the ordinary screw machine. Although this does not make any special use of the process of feedback nor of the vacuum tube, it accomplishes a somewhat similar end. What the feedback and the vacuum tube have made possible is not the sporadic design of individual automatic mechanisms, but a general policy for the construction of automatic mechanisms of the most varied type. In this they have been reinforced by our new theoretical treatment of communication, which takes full cognizance of the possibilities of communication between machine and machine. It is this conjunction of circumstances which now renders possible the new automatic age.

The existing state of industrial techniques includes the whole of the results of the first industrial revolution, together with many inventions which we now see to be precursors of the second industrial revolution. What the precise boundary between these two revolutions may be, it is still too early to say. In its potential significance, the vacuum tube certainly belongs to an industrial revolution different from that of the age of power; and yet it is only at present that the true significance of the invention of the vacuum tube has been sufficiently realized to allow us to attribute the present age to a new and second industrial revolution.

Up to now we have been talking about the existing state of affairs. We have not covered more than a small part of the aspects of the previous industrial revolution. We have not mentioned the airplane, nor the bulldozer, together with the other mechanical tools of construction, nor the automobile, nor even one-tenth of those factors which have converted the form of modern life to something totally unlike the life of any other period. It is fair to say, however, that except for a considerable number of isolated examples, the industrial revolution up to the present has displaced man and the beast as a source of power, without making any great impression on other human functions. The best that a pick-and-shovel worker can do to make a living at the present time is to act as a sort of gleaner after the bulldozer. In all important respects, the man who has nothing but his physical power to sell has nothing to sell which it is worth anyone's money to buy.

Let us now go on to a picture of a more completely automatic age. Let us consider what for example the automobile factory of the future will be like; and in particular the assembly line, which is that one of the component parts of that sort of factory which employs the most labor. In the first place, the sequence of operations will be controlled by something like a modern high-speed computing machine. In this book and elsewhere, I have often said that the high-speed computing machine is primarily a logical machine, which confronts different propositions with one another and draws some of their consequences. It is possible to translate the whole of mathematics into the performance of a sequence of purely logical tasks. If this representation of mathematics is embodied in the machine, the machine will be a computing machine in the ordinary sense. Nevertheless, such a computing machine, besides ordinary mathematical tasks, will involve the logical task of channeling a series of orders concerning mathematical operations. Therefore, as present high-speed computing machines in fact do, it will contain at least one large assembly which is purely logical.

The instructions to such a machine, and here too I am speaking of present practice, are given by what we have called a taping. The orders given the machine may be fed into it by a taping which is completely predetermined. It is also possible that the actual contingencies met in the performance of the machine may be handed over as a basis of further regulation to a new control tape constructed by the machine itself, or to a modification of the old one. I have already explained how I think such processes are related to learning.

It may be thought that the present great expense of computing machines bars them from use in industrial processes; and furthermore that the delicacy of the work needed in their construction and the variability of their functions precludes the use of the methods of mass production in constructing them. Neither of these charges is correct. In the first place, the enormous computing machines now used for the highest level of mathematical work cost something of the order of hundreds of thousands of dollars. Even this price would not be forbidding for the control machine of a really large factory, but it is not the relevant price. The present computing machines are developing so rapidly that practically every one constructed is a new model. In other words, a large part of these apparently exorbitant prices goes into new work of design, and into new parts, which are produced by a very high quality of labor under the most expensive circumstances. If one of these computing machines were therefore established in price and model, and put to use in quantities of tens or twenties, it is very doubtful whether its price would be in a higher range than that of tens of thousands of dollars. A similar machine of less capacity, not suited for the most difficult computational problems, but nevertheless quite adequate for factory control, would probably cost no more than a few thousand dollars in any sort of moderate-scale production.

Now let us consider the problem of mass production. If the only opportunity for mass production were the mass production of completed machines, it is quite clear that for a considerable period the best we could hope for would be a moderate-scale production. However, in each machine the parts are largely repetitive in very considerable numbers. This is true, whether we consider the memory apparatus, the logical apparatus, or the arithmetical subassembly. Thus production of a few dozen machines only, represents a potential mass production of the parts, and is accompanied with the same economic advantages.

It may still seem that the delicacy of the machines must mean that each job demands a special new model. This is also false. Given even a rough similarity in the type of mathematical and logical operations demanded of the mathematical and logical units of the machine, the over-all performance is regulated by the taping, or at any rate by the *original* taping. The taping of such a machine is a highly skilled intellectual task for a professional man of a very specialized type; but it is largely or entirely a once-for-all job, and need only be partly repeated when the machine is modified for a new industrial setup. Thus the cost of such a skilled technician will be distributed over a tremendous output, and will not really be a significant factor in the use of the machine.

The computing machine represents the center of the automatic factory, but it will never be the whole factory. On the one hand, it receives its detailed instructions from elements of the nature of sense organs. I am thinking of sense organs such as photo-electric cells, condensers for the reading of the thickness of a web of paper, thermometers, hydrogen-ion-concentration meters, and the general run of apparatus now built by instrument companies for the manual control of industrial processes. These instruments are already built to report electrically at remote stations. All they need to enable them to introduce their information into an automatic high-speed computor is a reading apparatus which will translate position or scale into a pattern of consecutive digits. Such apparatus already exists, and offers no great difficulty, either of principle or of constructional detail. The sense-organ problem is not new, and it is already effectively solved.

Besides these sense organs, the control system must contain effectors, or components which act on the outer world. Some of these are of a type already familiar, such as valve-turning motors, electric clutches, and the like. Some of them will have to be invented, to duplicate more nearly the functions of the human hand as supplemented by the human eye. It is altogether possible in the machining of automobile frames to leave on certain metal lugs, machined into smooth surfaces as points of reference. The tool, whether it be drill or riveter or whatever else we want, may be led to the rough neighborhood of these surfaces by a photo-electric mechanism, actuated for example by spots of paint. The final positioning may bring the tool up against the reference surfaces, so as to establish a firm contact, but not a destructively firm one. This is only one way of doing the job. Any competent engineer can think of a dozen more.

Of course, we assume that the instruments which act as sense organs to the system record not only the original state of the work, but also the result of the functioning of all previous processes. Thus the machine may carry out feedback operations, either those of the simple type now so thoroughly understood, or those involving more complicated processes of discrimination, regulated by the central control as a logical or mathematical system. In other words, the all-over system will correspond to the complete animal with sense organs, effectors and proprioceptors, and not, as in the ultra-rapid computing machine, to an isolated brain, dependent for its experiences and for its effectiveness on our intervention.

The speed with which these new devices are likely to come into industrial use will vary greatly with the different industries. Automatic devices, which may not be precisely like those described here, but which perform roughly the same functions, have already come into extensive use in continuous-process industries like canneries, steel-rolling mills, and especially wire and tin-plate factories. They are also familiar in paper factories, which likewise produce a continuous output. Another place where they are indispensable is in that sort of factory which is too dangerous for any considerable number of workers to risk their lives in its control, and in which an emergency is likely to be so serious and costly that its possibilities should have been considered in advance, rather than left to the excited judgment of some-body on the spot. If a policy can be thought out in advance, it can be committed to a taping which will regulate the conduct to be followed in accordance with the readings of the instrument. In other words, such factories should be under a régime rather like that of the interlocking signals and switches of the railroad signal-tower. This régime is already followed in oil-cracking factories, in many other chemical works, and in the handling of the sort of dangerous materials found in the exploitation of atomic energy.

We have already mentioned the assembly line as a place for applying the same sorts of technique. In the assembly line, as in the chemical factory or the continuous-process paper mill, it is necessary to exert a certain statistical control on the quality of the product. This control depends on a sampling process. These sampling processes have now been developed by Wald and others into a technique called *sequential analysis*, in which the sampling is no longer taken in a lump, but is a continuous process going along with the production. That which can be done then by a technique so standardized that it can be put in the hands of a statistical computer who does not understand the logic behind it, may also be executed by a computing machine. In other words, except again at the highest levels, the machine takes care of the routine statistical controls, as well as of the production process.

In general, factories have an accounting procedure which is independent of the production. As far as the data which occur in cost-accounting are concerned, that part which comes from the machine or assembly line may be fed directly into the computing machine. Other data may be fed in from time to time by human operators, but the bulk of necessary clerical work will be cut to that not of a completely routine nature. For example, girls will be needed to take care of outside correspondence and the like. Even a large part of this may be received from the correspondents on punched cards, or transferred to punched cards by extremely low-grade labor. From this stage on, everything may go by machine. This mechanization also may apply to a not inappreciable part of the library and filing facilities of an industrial plant.

In other words, the machine plays no favorites as between overall labor and white collar labor. Thus the possible fields into which the new industrial revolution is likely to penetrate are very extensive; and include all labor performing judgments of a low level, in much the same way as the displaced labor of the earlier industrial revolution included every aspect of human power. There will, of course, be trades into which the new industrial revolution of judgment will not penetrate: either because the new control machines are not economical in industries on so small a scale as not to be able to carry the considerable capital costs involved, or because their work is so varied that a new taping will be necessary for almost every job. I cannot see automatic machinery of the judgment-replacing type coming into use in the corner grocery, or in the corner garage, although I can very well see it employed by the wholesale grocer and the automobile manufacturer. The farm laborer too, although he is beginning to be pressed by automatic machinery, is protected from the full pressure of it, because of the ground he has to cover, the variability of the crops he must till, and the special conditions of weather and the like that he must meet. Even here, the large-scale or plantation farmer is becoming increasingly dependent on cotton-picking and weed-burning machinery, as the wheat farmer has long been dependent on the McCormick reaper. Where such machines may be used, some use of machinery of judgment is not inconceivable.

The introduction of the new devices and the dates at which they are to be expected are, of course, largely economic matters, on which I am not an expert. Short of any violent political changes or another great war, I should give a rough estimate that it will take the new tools ten to twenty years to come into their own. A war would change all this overnight. If we should engage in a war with a major power like Russia, which would make serious demands on the infantry, and consequently on our man-power, we may be hard put to it to keep up our industrial production. Under these circumstances, the matter of replacing human production by other modes may well be a life-or-death matter to the nation. We are already as far along in the process of developing a unified system of automatic control machines as we were in the development of radar in 1939. Just as the emergency of the Battle of Britain made it necessary to attack the radar problem in a massive manner, and to hurry up the natural development of the field by what may have been decades, so too, the needs of labor replacement are likely to act on us in a similar way in the case of another war. The personnel of skilled radio amateurs, mathematicians, and physicists, who were so rapidly turned into competent electrical engineers for the purposes of radar design, is still available for the very similar task of automatic-machine design. There is a new and skilled generation coming up, which they have trained.

Under these circumstances, the period of about two years which it took for radar to get onto the battlefield with a high degree of effectiveness is scarcely likely to be exceeded by the period of evolution of the automatic factory. At the end of such a war, the "know-how" needed to construct such factories will be common. There will even be a considerable backlog of equipment manufactured for the government, which is likely to be on sale or available to the industrialists. Thus a new war will almost inevitably see the automatic age in full swing within less than five years.

I have spoken of the actuality and the imminence of this new possibility. What can we expect of its economic and social consequences? In the first place, we can expect an abrupt and final cessation of the demand for the type of factory labor performing purely repetitive tasks. In the long run, the deadly uninteresting nature of the repetitive task may make this a good thing, and the source of the leisure which is necessary for the full cultural development of man on all sides. It may also produce cultural results as trivial and wasteful as the greater part of those so far obtained from the radio and the movies.

Be that as it may, the intermediate period of the introduction of the new means, especially if it comes in the fulminating manner to be expected from a new war, will lead to an immediate transitional period of disastrous confusion. We have a good deal of experience as to how the industrialists regard a new industrial potential. Their whole propaganda is to the effect that it must not be considered as the business of the government but must be left open to whatever entrepreneurs wish to invest money in it. We also know that they have very few inhibitions when it comes to taking all the profit out of an industry that there is to be taken, and then letting the public pick up the pieces. This is the history of the lumber and mining industries, and is part of what we have called in another chapter the traditional American philosophy of progress.

Under these circumstances, industry will be flooded with the new tools to the extent that they appear to yield immediate profits, irrespective of what long-time damage they can do. We shall see a process parallel to the way in which the use of atomic energy for bombs has been allowed to compromise the very necessary potentialities of the long-time use of atomic power to replace our oil and coal supplies, which are within centuries, if not decades, of utter exhaustion. Note well that atomic bombs do not compete with power companies.

Let us remember that the automatic machine, whatever we think of any feelings it may have or may not have, is the precise economic equivalent of slave labor. Any labor which competes with slave labor must accept the economic conditions of slave labor. It is perfectly clear that this will produce an unemployment situation, in comparison with which the present recession and even the depression of the thirties will seem a pleasant joke. This depression will ruin many industries — possibly even the industries which have taken advantage of the new potentialities. However, there is nothing in the industrial tradition which forbids an industrialist to make a sure and quick profit, and to get out before the crash touches him personally.

Thus the new industrial revolution is a two-edged sword. It may be used for the benefit of humanity, assuming that humanity survives long enough to enter a period in which such a benefit is possible. If, however, we proceed along the clear and obvious lines of our traditional behavior, and follow our traditional worship of progress and the fifth freedom — the freedom to exploit — it is practically certain that we shall have to face a decade or more of ruin and despair.

XI

SOME COMMUNICATION MACHINES AND THEIR FUTURE

We have just been considering the general problem of the systematic mechanization of the operation of decision in the industries, and of the impact of all this on humanity. I now wish to discuss a few machines in whose suggestion or design I have played a personal part and which are associated with rather special problems concerning communication. The first of these machines was designed as an illustration to an earlier piece of work which had been done on a theoretical basis some years ago by my colleagues Dr. Arturo Rosenbluth and Mr. Julian Bigelow. In this work, we conjectured that the mechanism of voluntary activity was of a feedback nature, and accordingly, we sought in the human voluntary activity for the phenomena of breakdown which feedback mechanisms exhibit when they are overloaded.

The simplest type of breakdown exhibits itself as an oscillation in a goal-seeking process which appears only when that process is actively invoked. This corresponds rather closely to the human phenomenon known as *intention tremor*, in which, for example, when the patient reaches for a glass of water, his hand swings wider and wider, and he cannot lift up the glass.

There is another type of human tremor which is in some ways diametrically opposite to intention tremor. It is known as *Parkinsonianism*, and is familiar to all of us as the shaking palsy of old men. Here the patient displays the tremor even at rest; and, in fact, if the disease is not too greatly marked, only at rest. When he attempts to accomplish a definite purpose this tremor subsides to such an extent that the victim of an early stage of Parkinsonianism can even be a successful eye surgeon.

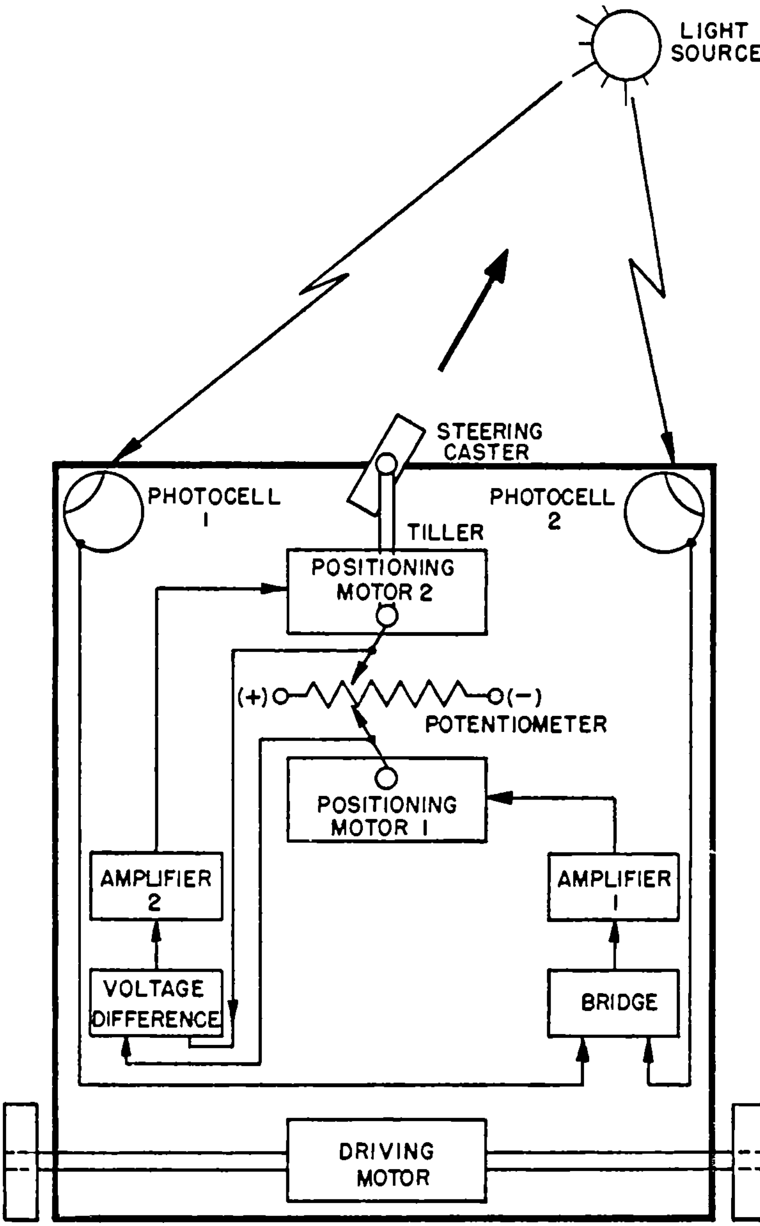
The three of us associated this Parkinsonian tremor with an aspect of feedback slightly different from the feedback associated with the accomplishment of purpose. In order to accomplish a purpose successfully, the various joints which are not directly associated with purposive movement must be kept in such a condition of *tonus*, or mild tension, that the final purposive contraction of the muscles is properly backed up. In order to do this, a secondary feedback mechanism is required whose locus in the brain does not seem to be the cerebellum, which is the central control station of the mechanism which breaks down in intention tremor. This second sort of feedback is known as postural feedback.

It can be shown mathematically that in both cases of tremor what happens is a feedback which is excessively large. Now, when we consider the feedback which is important in Parkinsonianism, it turns out that the voluntary feedback which regulates the main motion is in the opposite direction to the postural feedback as far as the motion of the parts regulated by the postural feedback is concerned. Therefore, the existence of a purpose tends to cut down the excessive amplication of postural feedback, and may very well bring it below the oscillation level. These things were very well known to us theoretically, but until recently we had not gone to the trouble of making a working model of them. However, it became desirable for us to construct a demonstration apparatus which would act according to our theories.

Accordingly, Professor J. B. Wiesner of the Electronics Laboratory of the Massachusetts Institute of Technology discussed with me the possibility of constructing a tropism machine or machine with a simple fixed built-in purpose, with parts sufficiently adjustable to show the main phenomena of voluntary feedback, and of what we have just called postural feedback, and their breakdown. At our suggestion, Mr. Henry Singleton took up the problem of building such a machine, and carried it to a brilliant and successful conclusion. This machine has two principal modes of action, in one of which it is positively photo-tropic and searches for light, and in the other of which it is negatively photo-tropic and runs away from light. This corresponds to the two respective nicknames, the *Moth* or the *Bedbug.* The machine consists of a little three-wheeled cart with a propelling motor on the rear axle. The front wheel is a caster steered by a tiller. The cart carries a pair of forwardly directed photo cells, one of which takes in the left quadrant, while the other takes in the right quadrant. These cells are the opposite arms of a bridge. The output of the bridge which is reversible, is put through an adjustable amplifier. After this it goes to a positioning motor which regulates the position of one contact with a potentiometer.[1] The other contact is also regulated by a positioning motor which moves the tiller as well. The output of the potentiometer which represents the difference between the position of the two positioning motors leads through a second adjustable amplifier to the second positioning motor, thus regulating the tiller.

According to the direction of the output of the bridge, this instrument will be steered either toward the quadrant with more intense light or away from it. In either case, it automatically tends to balance itself. There is thus a feedback dependent on the source of light proceeding from the light to the photo-electric cells, and thence to the rudder control system, by which it finally regulates the direction of its own

[1] A potentiometer is a resistance across which a fixed voltage is maintained so that a variable voltage may be obtained between two taps and will be proportional to the difference of the position of the taps.



THE MOTH OR BEDBUG

motion and changes the angle of incidence of the light.

This feedback tends to accomplish the purpose of either positive or negative photo-tropism. It is the analogue of a voluntary feedback, for in man we consider that a voluntary action is essentially a choice among tropisms. When this feedback is overloaded by increasing the amplification, the little cart or "the moth" or "the bedbug" according to the direction of its tropism will seek the light or avoid it in an oscillatory manner, in which the oscillations grow ever larger. This is a close analogue to the phenomenon of intention tremor, which is associated with injury to the cerebellum.

The positioning mechanism for the rudder contains a second feedback which may be considered as postural. This feedback runs from the potentiometer to the second motor and back to the potentiometer, and its zero point is regulated by the output of the first feedback. If this is overloaded, the rudder goes into a second sort of tremor. This second tremor appears in the absence of light: that is, when the machine is not given a purpose. Theoretically, this is due to the fact that as far as the second mechanism is concerned, the action of the first mechanism is antagonistic to its feedback, and tends to decrease its amount. This phenomenon in man is what we have described as Parkinsonianism.

I have recently received a letter from Dr. Grey Walter of the Burden Neurological Institute at Bristol, England, in which he expresses interest in "the moth" or "bedbug," and in which he tells me of a similar mechanism of his own, which differs from mine in having a determined but variable purpose. In his own language, "We have included features other than inverse feedback which gives to it an exploratory and ethical attitude to the universe as well as a purely tropistic one." The possibility of such a change in behavior pattern is discussed in the chapter of this book concerning learning, and this discussion is directly relevant to the Walter machine, although at present I do not know just what means he uses to secure such a type of behavior.

The moth and Dr. Walter's further development of a tropism machine seem to be at first sight exercises in virtuosity, or at most mechanical commentaries to a philosophical text. Nevertheless, they have a certain definite usefulness. The United States Army Medical Corps has taken photographs of "the moth" to compare with photographs of actual cases of nervous tremor, so that they are thus of assistance in the instruction of Army neurologists.

There is a second class of machines with which we have also been concerned which has a much more direct and immediately important medical value. The machine may be used to make up for the losses of the maimed and of the sensorily deficient, as well as to give new and dangerous powers to the already powerful. The help of the machine may extend to the construction of better artificial limbs; to instruments to help the blind to read pages of ordinary text by translating the visual pattern into auditory terms; and to other similar aids to make them aware of approaching dangers and to give them freedom of locomotion. In particular, we may use the machine to aid the totally deaf. Aids of this last class are probably the easiest to construct; partly because the technique of the telephone is the best studied and most familiar technique of communication; partly because the deprivation of hearing is overwhelmingly a deprivation of one thing — free participation in human conversation [2]; and partly because the useful information carried

[2] It is because of this primary preoccupation of hearing with speech that the deprivation of hearing in its isolation of the individual from his companions produces emotional results far more serious than that due to the intrinsically worse deprivation of blindness. It is a familiar fact that the deaf man tends to be morose and self-centered, while the blind man who has made any considerable headway in social compensation is, if anything, cocky and assertive.

by speech can be compressed into such a narrow compass that it is beyond the carrying-power of the sense of touch.

Some time ago, Professor Wiesner told me that he was interested in the possibility of constructing an aid for the totally deaf, and that he would like to hear my views on the subject. I gave my views, and it turned out that we were much of the same opinion. We were aware of the work that had already been done on visible speech at the Bell Telephone Laboratories, and its relation to their earlier work on the Vocoder. We knew that the Vocoder work gave us a measure of the amount of information which it was necessary to transmit for the intelligibility of speech more favorable than that of any previous method. We felt, however, that visible speech had two disadvantages; namely, that it did not seem to be easy to produce in a portable form, and that it made too heavy demands on the sense of vision, which is relatively more important for the deaf person than for the rest of us. A rough estimate showed that a transfer to the sense of touch of the principle used in the visible-speech instrument was possible, and this we decided should be the basis of our apparatus.

We found out very soon after starting that the investigators at the Bell Laboratories had also considered the possibility of a tactile reception of sound, and had included it in their patent application. They were kind enough to tell us that they had done no experimental work on it, and that they left us free to go ahead on our researches. Accordingly, we put the design and development of this apparatus into the hands of Mr. Leon Levine, a graduate student in the Electronics Laboratory. We foresaw that the problem of training would be a large part of the work necessary to bring our device into actual use, and here we had the benefit of the counsel of Dr. Alexander Bavelas of our Department of Psychology.

The problem of interpreting speech through another sense than that of hearing, such as the sense of touch, may be given the following interpretation from the point of view of language. As we have said, we may roughly distinguish three stages of language, and two intermediate translations, between the outside world and the subjective receipt of information. The first stage consists in the acoustic symbols taken physically as vibrations in the air; the second or phonetic stage consists in the various phenomena in the inner ear and the associated part of the nervous system; the third or semantic stage represents the transfer of these symbols into an experience of meaning.

In the case of the deaf person, the first and the third stages are still present, but the second stage is missing. However, it is perfectly conceivable that we may replace the second stage by one by-passing the sense of hearing and proceeding, for example, through the sense of touch. Here the translation between the first stage and the new second stage is performed, not by a physical-nervous apparatus which is born into us but by an artificial humanly constructed system. The translation between the new second stage and the third stage is not directly accessible to our inspection, but represents the formation of a new system of habits and responses, such as those we develop when we learn to drive a car. The present status of our apparatus is this: the transition between the first and the new second stage is well under control, although there are certain technical difficulties still to be overcome. We are making studies of the learning process; that is, of the transition between the second and third stages; and in our opinion, they seem extremely promising. The best result that we can show as yet, is that with a learned vocabulary of twelve simple words, a run of eighty random repetitions was made with only six errors.

In our work, we had to keep certain facts always in mind. First among these, as we have said, is the fact that hearing is not only a sense of communication, but a sense of communication which receives its chief use in establishing a rapport with other individuals. It is also a sense corresponding to certain communicative activities on our part: namely, those of speech. Other uses of hearing are important, such as the reception of the sounds of nature and the appreciation of music, but they are not so important that we should consider a person as socially deaf if he shared in the ordinary interpersonal communication by speech, and in no other use of hearing. In other words, hearing has the property that if we are deprived of all its uses except that of speech-communication with other people, we should still be suffering under a minimal handicap.

For the purpose of sensory prosthesis, we must consider the entire speech process as a unit. How essential this is, is immediately observed when we consider the speech of deaf-mutes. With most deaf-mutes, a training in lip-reading is neither impossible nor excessively difficult, to the extent that such persons can achieve a quite tolerable proficiency in receiving speech-messages from others. On the other hand, and with very few exceptions, and these the result of the best and most recent training, the vast majority of deaf-mutes, though they can learn how to use their lips and mouths to produce sound, do so with a grotesque and harsh intonation, which represents a highly inefficient form of sending a message.

The difficulties lie in the fact that for these people the act of conversation has been broken into two entirely separate parts. We may simulate the situation for the normal person very easily, if we give him a telephone-communication-system with another person, in which his own speech is not transmitted by the telephone to his own ears. It is very easy to construct such dead-microphone transmission systems, and they have actually been considered by the Telephone Companies, only to be rejected because of the frightful sense of frustration they cause, especially the frustration of not knowing how much of one's own voice gets onto the line. People using a system of this sort are always forced to yell at the top of their voices, to be sure that they have missed no opportunity to get the message accepted by the line.

We now come back to ordinary speech. We see that the processes of speech and hearing in the normal person have never been separated; but that the very learning of speech has been conditioned by the fact that each individual hears himself speak. For the best results it is not enough that the individual hear himself speak at widely separated occasions, and that he fill in the gaps between these by memory. A good quality of speech can only be attained when it is subject to a continuous monitoring and self-criticism. Any aid to the totally deaf must take advantage of this fact, and although it may indeed appeal to another sense, such as that of touch, rather than to the missing sense of hearing, it must resemble the electric hearing aids of the present day in being portable and continuously worn.

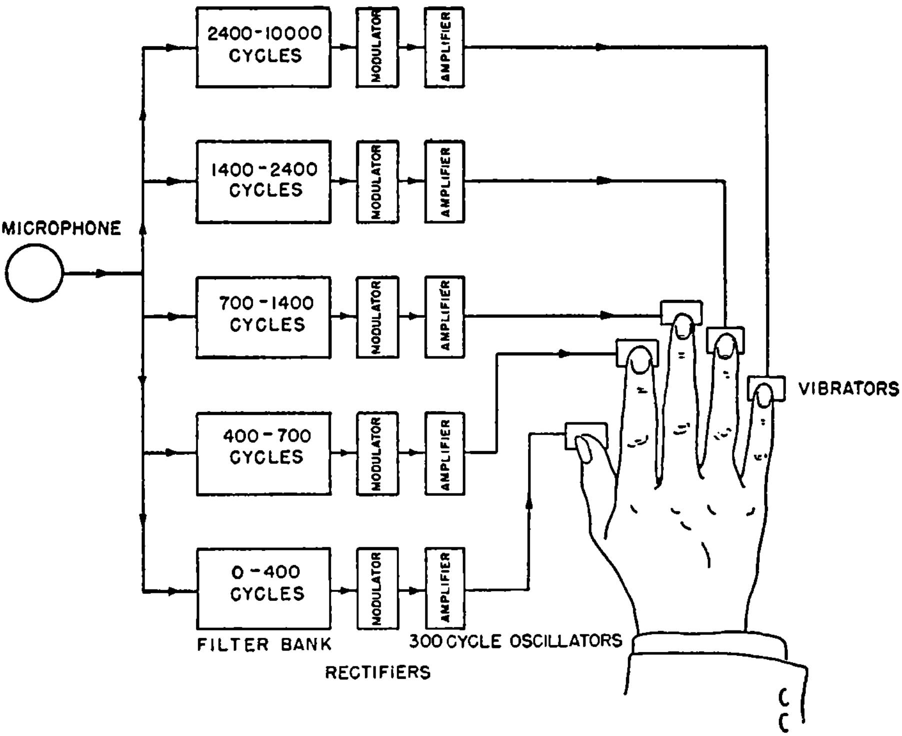
The further philosophy of prosthesis for hearing depends on the amount of information effectively used in hearing. The crudest evaluation of this amount involves the estimate of the maximum that can be communicated over a sound range of 10,000 cycles, and an amplitude range of some 80 decibels. This load of communication, however, while it marks the maximum of what the ear could conceivably do, is much too great to represent the effective information given by speech in practice. In the first place, speech of telephone quality does not involve the transmission of more than 3000 cycles; and the amplitude range is certainly not more than from 5 to 10 decibels; but even here, while we have not exaggerated what is transmitted to the ear, we are still grossly exaggerating what is used by the ear and brain to reconstitute recognizable speech.

We have said that the best work done on this problem of estimation is the Vocoder work of the Bell Telephone Laboratories. It may be used to show that if human speech is properly divided into not more than five bands, and if these are rectified so that only their form-envelopes or outer shapes are perceived, and are used to modulate quite arbitrary sounds within their frequency range, then if these sounds are finally added up, the original speech is recognizable as speech and almost recognizable as the speech of a particular individual. Nevertheless the amount of possible information transmitted, used or unused, has been cut to not more than a tenth or hundredth of the original potential information present.

When we distinguish between used and unused information in speech, we distinguish between the maximum coding capacity of speech as received by the ear, and the maximum capacity that penetrates through the cascade network of successive stages consisting of the ear followed by the brain. The first is only relevant to the transmission of speech through the air and through intermediate instruments like the telephone, followed by the ear itself, but not by whatever apparatus in the brain is used in the understanding of speech. The second refers to the transmitting power of the entire complex — air — telephone — ear — brain. Of course, there may be finer shades of inflection which do not get through to the over-all narrow-band transmission system of which we are speaking, and it is hard to evaluate the amount of lost information carried by these; but it seems to be relatively small. This is the idea behind the Vocoder. The earlier engineering estimates of information were defective, in that they ignored the terminating element of the chain from the air to the brain.

In appealing to the other senses of a deaf person, we must realize that apart from sight, all others are inferior to it, and transmit less information per unit time. The only way we can make an inferior sense like touch, work with maximum efficiency, is to send through it, not the full information that we get through hearing, but an edited portion of that hearing suitable for the understanding of speech. In other words, we replace part of the function that the cortex normally performs after the reception of sound, by a filtering of our information before it goes through the tactile receptors. We thus transfer part of the function of the cortex of the brain to an artificial external cortex. The precise way we do this in the apparatus we are considering is by separating the frequency bands of speech as in the Vocoder, and then by transmitting these different rectified bands to spatially distant tactile regions, after they have been used to modulate vibrations of frequencies easily perceived by the skin. For example, five bands may be sent respectively to the thumb and four fingers of one hand.

This gives us the main ideas of the apparatus needed for the reception of intelligible speech through sound vibrations transformed electrically into touch. We have gone far enough already to know that the patterns of a considerable number of words are sufficiently distinct from one another, and sufficiently consistent among a number of speakers, to be recognized without any great amount of speech training. From this point on, the chief direction of investigation must be that of the more thorough training of deaf-mutes in the recognition and the reproduction of sounds. On the engineering end, we shall have considerable problems concerning the increase of the portability of the



HEARING AID FOR THE TOTALLY DEAF

apparatus, and the reduction of its energy demands, without any substantial loss of performance. These matters are all still *sub judice.* I do not wish to establish false and in particular premature hopes on the part of the afflicted and their friends, but I think it is safe to say that the prospect of success is far from hopeless.

Up to the present, we have been discussing machines which as far as the general public is concerned either seem to have some of the moral indifference of science or to be definitely beneficent aids to the maimed. We now come to another class of machines which possess some very sinister possibilities. Curiously enough, this class contains the automatic chess-playing machine.

Sometime ago, I suggested a way in which one might make an appropriate use of the speed of a modern computing machine to play at least a passable game of chess. In this work, I am following up a line of thought which has a considerable history behind it. Poe discussed a fraudulent chess-playing machine due to Maelzel, and exposed it; showing that it was worked by a legless cripple inside. However, my machine was to be a genuine one, and was to take advantage of recent progress in computing machines. It is easy to make a machine which will play merely legal chess of a very poor brand; it is hopeless to try to make a machine to play perfect chess. For this there are too many combinations. Professor John von Neumann of the Institute for Advanced Studies at Princeton has commented on this difficulty. However, it is neither easy nor hopeless to make a machine which we can guarantee to do the best that can be done for a limited number of moves ahead, say two; and which will then leave itself in the position that is the most favorable in accordance with some more or less easy method of evaluation.

The present ultra-rapid computing machines may be set up to act as chess-playing machines, though a better machine might be made at an exorbitant price if we chose to put the work into it. The speed of these modern computing machines is enough so that they can evaluate every possibility for two moves ahead in the legal playing-time of a single move. The number of combinations goes up roughly in geometrical progression. Thus the difference between playing out all possibilities for two moves and for three moves is enormous. To play out a game – something like fifty moves – is hopeless in any reasonable time. Yet for beings living long enough, as Von Neumann has shown, it would be possible; and a game played perfectly on each side would lead, as a foregone conclusion, either always to a win for White, or always to a win for Black, or most probably always to a draw.

Mr. Claude Shannon of the Bell Telephone Laboratories has suggested a machine along the same lines as the two-move machine I had contemplated, but considerably improved. To begin with, his evaluation of the final position after two moves would make allowances for the control of the board, for the mutual protection of the pieces, etc., as well as the number of pieces, check, and checkmate. Then too, if at the end of two moves, the game should be unstable, by the existence of check, or of an important piece in a position to be taken, or of a fork, the mechanical player would automatically play a move or two ahead until stability should be reached. How much this would slow the game, lengthening each move beyond the legal limit, I do not know; although I am not convinced that we can go very far in this direction without getting into time trouble at our present speeds.

I am willing to accept Shannon's conjecture that such a machine would play chess of a high amateur level and even possibly of a master level. Its game would be stiff and rather uninteresting, but much safer than that of any human player. As Shannon points out, it is possible to put enough chance in its operation to prevent its constant defeat in a purely systematic way by a given rigid sequence of plays. This chance or uncertainty may be built into the evaluation of terminal positions after two moves.

The machine would play gambits and possibly end games like a human player from the store of standard gambits and end games. A better machine would store on a tape every game it had ever played and would supplement the processes which we have already indicated by a search through all past games to find something apropos: in short, by the power of learning. Though we have seen that machines can be built to learn, the technique of building and employing these machines is still very imperfect. The time is not yet ripe for the design of a chess-playing machine on learning principles, although it probably does not lie very far in the future.

A chess-playing machine which learns might show a great range of performance dependent on the quality of the players against whom it had been pitted. The best way to make a master machine would probably be to pit it against a wide variety of good chess players. On the other hand, a well-contrived machine might be more or less ruined by the injudicious choice of its opponents. A horse is also ruined by the injudicious choice of its riders.

In the learning machine, it is well to distinguish what the machine can learn and what it cannot. A machine either may be built with a statistical preference for a certain sort of behavior, which nevertheless admits the possibility of other behavior; or else certain features of its behavior may be rigidly and unalterably determined. We shall call the first sort of determination *preference,* and the second sort of determination *constraint.* For example, if the rules of legal chess are not built into a chess-playing machine as constraints, and if the machine is given the power to learn, it may change without notice from a chess-playing machine into a machine doing a totally different task. On the other hand, a chess-playing machine with the rules built in as constraints may still be a learning machine as to tactics and policies.

The reader may wonder why we are interested in chess-playing machines at all. Are they not merely another harmless little vanity by which experts in design seek to show off their proficiency to a world which they hope will gasp and wonder at their accomplishments? As an honest man, I cannot deny that a certain element of ostentatious narcissism is present in me, at least. However, as you will soon see, it is not the only element active here, nor is it that which is of the greatest importance to the non-professional reader.

Mr. Shannon has presented some reasons why his researches may be of more importance than the mere design of a curiosity, interesting only to those who are playing a game. Among these possibilities, he suggests that such a machine may be the first step in the construction of a machine to evaluate military situations and to determine the best move at any specific stage. Let no man think that he is talking lightly. The great book of von Neumann and Morgenstern on the Theory of Games has made a profound impression on the world, and not least in Washington. When Mr. Shannon speaks of the development of military tactics, he is not talking moonshine, but is discussing a most imminent and dangerous contingency.

In the well-known Paris journal, *Le Monde,* for December 28, 1948, a certain Dominican friar, Père Dubarle, has written a very penetrating review of my book *Cybernetics.* I shall quote a suggestion of his which goes beyond the implications of the chess-playing machine grown up and encased in a suit of armor.

One of the most fascinating prospectives thus opened is that of the rational conduct of human affairs, and in particular of those which interest communities and seem to present a certain statistical regularity, such as the human phenomena of the development of opinion. Can't one imagine a machine to collect this or that type of information, as for example information on production and the market; and then to determine as a function of the average psychology of human beings, and of the quantities which it is possible to measure in a determined instance, what the most probable development of the situation might be? Can't one even conceive a State apparatus covering all systems of political decisions, either under a régime of many states distributed over the earth, or under the apparently much more simple régime of a human government of this planet? At present nothing prevents our thinking of this. We may dream of the time when the *machine à gouverner* may come to supply — whether for good or evil — the present obvious inadequacy of the brain when the latter is concerned with the customary machinery of politics.

At all events, human realities are realities which do not admit a sharp and certain determination, as in the case for the numerical data of computation. They only admit the determination of their probable values. A machine to treat these processes, and the problems which they put, must therefore attempt the style of probabilistic thought, in place of the exact schemes of deterministic thought, as they are exhibited for example in modern computing machines. This makes it more complicated, but does not render it impossible. The prediction machine which determines the efficacy of anti-aircraft fire is an example of this. Theoretically, time prediction is not impossible; neither is the determination of the most favorable decision, at least within certain limits. The possibility of playing machines such as the chess-playing machine is considered to establish this. For the human processes which constitute the object of government may be assimilated to games in the sense in which von

Neumann has studied them mathematically. Even though these games have an incomplete set of rules, there are other games with a very large number of players, where the data are extremely complex. The *machines à gouverner* will define the State as the best-informed player at each particular level; and the State is the only supreme coordinator of all partial decisions. These are enormous privileges; if they are acquired scientifically, they will permit the State under all circumstances to beat every player of a human game other than itself by offering this dilemma: either immediate ruin, or planned coöperation. This will be the consequences of the game itself without outside violence. The lovers of the best of worlds have something indeed to dream of!

Despite all this, and perhaps fortunately, the *machine à gouverner* is not ready for a very near tomorrow. For outside of the very serious problems which the volume of information to be collected and to be treated rapidly still put, the problems of the stability of prediction remain beyond what we can seriously dream of controlling. For human processes are assimilable to games with incompletely defined rules, and above all, with the rules themselves functions of the time. The variation of the rules depends both on the effective detail of the situations engendered by the game itself, and on the system of psychological reactions of the players in the face of the results obtained at each instant.

It may even be more rapid than these. A very good example of this seems to be given by what happened to the Gallup Poll in the recent election of Mr. Truman. All this not only tends to complicate the degree of the factors which influence prediction, but perhaps to make radically sterile the mechanical manipulation of human situations. As far as one can judge, only two conditions here can guarantee stabilization in the mathematical sense of the term. These are, on the one hand, a sufficient ignorance on the part of the mass of the players exploited by a skilled player, who moreover may plan a method of paralyzing the consciousness of the masses; or on the other, sufficient good-will to allow one, for the sake of the stability of the game, to refer one's decisions to one or a few players of the game, who have arbitrary privileges. This is a hard lesson of cold mathematics, but it throws a certain light on the adventure of our century: hesitation between an indefinite turbulence of human affairs and the rise of a prodigious Leviathan. In comparison with this, Hobbs' Leviathan was nothing but a pleasant joke. We are running the risk nowadays of a great World State, where deliberate and conscious primitive injustice may be the only possible condition for the statistical happiness of the masses: a world worse than hell for every clear mind. Perhaps it would not be a bad idea for the teams at present creating cybernetics to add to their *cadre* of technicians, who have come from all horizons of science, some serious anthropologists, and perhaps a philosopher who has some curiosity as to world matters.

The steps between my original suggestion of the chess-playing machine, Mr. Shannon's move to realize it in the metal, the use of computing machines to plan the necessities of war, and the colossal state machine of Père Dubarle, are in short clear and terrifying. Even at this moment, the concept of war which lies behind some of our new government agencies, which are developing the consequences of von Neumann's theory of games, is sufficiently extensive to include all civilian activities during war, before war, and possibly even between wars. The state of affairs contemplated by Père Dubarle as one to be carried out by a beneficent bureaucracy for the sake of humanity at large, is quite possibly being planned by a secret military project for the purposes of combat and domination. Père Dubarle is right – many times more than right – in his emphasis on the need for the anthropologist and the philosopher. In other words, the mechanical control of man cannot succeed unless we know man's built-in purposes, and why we want to control him.

Our papers have been making a great deal of American "know-how" ever since we had the misfortune to discover the atomic bomb. There is one quality more important than know-how and we cannot accuse the United States of any undue amount of it. This is "know-what": by which we determine not only how to accomplish our purposes, but what our purposes are to be. I can distinguish between the two by an example. Some years ago, a prominent American engineer bought an expensive player-piano. It became clear after a week or two that this purchase did not correspond to any particular interest in the music played by the piano. It corresponded rather to an overwhelming interest in the piano mechanism. For this gentleman, the player-piano was not a means of producing music, but a means of giving some inventor the chance of showing how skillful he was at overcoming certain difficulties in the production of music. This is an estimable attitude in a second-year high-school student. How estimable it is in one of those on whom the whole cultural future of the country depends, I leave to the reader.

I do not know what the youth of this country reads. I am not an expert in the funnies; and while I must pay my respects to Al Capp and Little Abner, I scarcely believe that the trade in general rises to the level of Mr. Capp's salty thoughtfulness. To some extent he is fulfilling a part of the function which fairy tales and mythology fulfilled in my day, of carrying to the young some of the gnomic wisdom of the ages.

There we learned a few of the simpler and more obvious truths of life, such as that when a djinnee is found in a bottle, it had better be left there; that the fisherman who craves a boon from heaven too many times on behalf of his wife will end up exactly where he started; that if you are given three wishes, you must be very careful what you wish for. These simple and obvious truths represent the childish and adolescent equivalent of the sense of tragedy which the Greeks and many modern Europeans possess, and which is somehow missing in this land of plenty.

The Greeks regarded the act of discovering fire with very split emotions. On the one hand, fire was for them as for us a great benefit to all humanity. On the other, the carrying down of fire from heaven to earth was a defiance of the Gods of Olympus, and could not but be punished by them as a piece of insolence towards their prerogatives. Thus we see the great figure of Prometheus, the fire-bearer, the prototype of the scientist; a hero but a hero damned, chained on the Caucasus with vultures gnawing at his liver. We read the ringing lines of Aeschylus in which the bound god calls on the whole world under the sun to bear witness to what things he suffers at the hands of the gods.

The sense of tragedy is the sense that the world is not a pleasant little nest made for our protection, but a vast and largely hostile environment, in which we can achieve great things only by defying the gods; and in which this defiance inevitably brings its own punishment. It is a dangerous world, in which there is no security, save the somewhat negative one of humility and restrained ambitions. It is a world in which there is a condign punishment, not only for him who sins in conscious arrogance, but for him whose sole crime is ignorance of the gods and the world around him.

If a man with this tragic consciousness of fate approaches, not fire, but another manifestation of original power, like the splitting of the atom, he will do so with fear and trembling. He will not leap in where angels fear to tread, unless he is prepared to accept the punishment of the fallen angels. Neither will he calmly transfer to the machine made in his own image the responsibility for his choice of good and evil, without continuing to accept a full responsibility for that choice.

I have said that the modern man, and especially the modern American, however much "know-how" he may have, has very little "know-what." He will accept the superior dexterity of the machine-made decisions without too much inquiry as to the motives and principles behind these. In doing so, he will put himself sooner or later in the position of the father in W. W. Jacobs' *The Monkey's Paw*, who has wished for a hundred pounds, only to find at his door the agent of the company for which his son works, tendering him one hundred pounds as a consolation for his son's death at the factory. Or again, he may do it in the way of the Arab fisherman in the *One Thousand and One Nights*, when he broke the Seal of Solomon on the lid of the bottle which contained the angry djinnee.

Let us remember that there are game-playing machines both of the Monkey's Paw type and of the type of the Bottled Djinnee. Any machine constructed for the purpose of making decisions, if it does not possess the power of learning, will be completely literal-minded. Woe to us if we let it decide our conduct, unless we have previously examined the laws of its action, and know fully that its conduct will be carried out on principles acceptable to us! On the other hand, the machine like the djinnee, which can learn and can make decisions on the basis of its learning, will in no way be obliged to make such decisions as we should have made, or as will be acceptable to us. For the man who is not aware of this, to throw the problem of his responsibility on the machine, whether it can learn or not, is to cast his responsibility to the winds, and to find it coming back seated on the whirlwind.

I have spoken of machines, but not only of machines having brains of brass and thews of iron. When human atoms are knit into an organization in which they are used, not in their full right as responsible human beings, but as cogs and levers and rods, it matters little that their raw material is flesh and blood. *What is used as an element in a machine, is an element in the machine.* Whether we entrust our decisions to machines of metal, or to those machines of flesh and blood which are bureaus and vast laboratories and armies and corporations, we shall never receive the right answers to our questions unless we ask the right questions. The *Monkey's Paw* of skin and bone is quite as deadly as anything cast out of steel and iron. The djinnee which is a unifying figure of speech for a whole corporation is just as fearsome as if it were a glorified conjuring trick.

The hour is very late, and the choice of good and evil knocks at our door.

XII

VOICES OF RIGIDITY

In several places in this book I have indicated that the immediate future of society is dangerous and dark. In the first place, I have pointed out that we are proceeding on our course on the basis of charts of the idea of progress which do not mark the threatening shoals. In the second place, in a field more immediately allied to my own interest, I have had something to say of the very dangerous problems of the new machine age, both from the point of view of the economic upheaval it is likely to cause, and from that of the threatening new Fascism dependent on the *machine à gouverner*. What then are we to do?

By we, I mean both the people of the world, and the United States in general, and that particular section of the people to which I belong, consisting of the socially conscious scientists and engineers. In neither case is there a simple answer. For the people at large, the best we can hope for is a long and probably unwelcome education in science and its political background, and in the immediate dangers confronting us. For the scientists and scholars like myself, there is the task of carrying out this education. To do this, we must find some way or other to organize opinion, so as to make effective whatever insight we possess into the new problems.

In this we are very much hampered by the false position which science and the scientist hold in public opinion. Despite all the scientific education of our schools and all the scientific publicity and propaganda that have gone into our journals, the fact remains that the average man in the street, while he may have some knowledge of the results of scientific invention and discovery as they impinge on his daily life, has no idea whatever of the internal concepts of science and of the task of the scientist. For him, the scientist is exactly what the medicine-man is for the savage; namely, a mysterious ambivalent figure, who is to be worshiped as the carrier of recondite knowledge and the agent of recondite powers; and who is at the same time to be feared, even hated, and to be put in his place. The medicine-man may be a power, but he is a very acceptable sacrifice to the gods.

This situation is one of long standing, but it has been accentuated by the atomic bomb and the feelings of universal fear and of universal guilt to which this has given rise. There is scarcely anyone who does not realize that the atomic bomb threatens him with the possibility of personal extinction; and more immediately with the likelihood that he will have to change his manner of life, and even take to the caves. On the other hand, the employment of means of massacre as potent as this is a shock to the moral sense of those of us who have already been appalled by the threat of the utilization of poison gas as a means of war. The immediate reaction to the bomb of Hiroshima was one of exultation at our new show of national power. In a few days, the full horror of the act, which had already struck the more sensitive of us, reached the public at large. Men said to one another, "This is terrible! It is so terrible that I cannot have had any part in it." At the very least, they said this to their internal consciences. The natural result was that they inquired as to who did have a part in it. During the excitement of war the man in the street had identified himself too closely with the Government and with the military forces to put the guilt on them, for they had become an extension of his internal self. He sought for an unfamiliar scapegoat, outside the range of his personal knowledge. Who could serve this purpose better than the scientist?

The scientist had always been for him an incomprehensible sort of person, who talked a language not understandable by the laity, and whom he did not meet at his country club or at his bowling alley. The scientist bore a certain air of the devil about him, and above all, he was not there to talk back.

This bad press of the scientist rapidly received a serious addition from the secrecy propaganda and the current charges of espionage, whether the latter were justified or not. It is without doubt true that some espionage has taken place, as it is equally beyond doubt that we have tried to worm out the secrets of foreign countries. In any case, relatively minor situations involving a very few people have been so inflated as to give a bad character to the scientific profession as a whole; especially as it was only people of this profession who were in a position to uncover and to sell, or even to understand, the secrets of the atomic bomb.

Thus a writer like myself, who tries to urge upon the public the need for a realization of the dangers attendant on the new scientific era, is in the position of the mouse who advised the other mice to bell the cat. Personally, I am of no particular use in venturesome undertakings, such as the belling of cats; but at least I may hope that I speak to others who are willing to undergo the long course of political work and obloquy necessary if they are to make these views effective at the polls.

Let us consider then what cats there are to bell. The great arch-cat which is feared most by the American man in the street is the Government of Soviet Russia, together with its associate the Comintern. There was a time when many of us hoped that the professed pro-scientific bias of this power group as shown in the relative freedom which they gave Pavlov, and in the active pursuit of new scientific investigations in Russia, would lead to an ultimate state of affairs in which the extravagances of the Revolution and its immediate sequel might give way to a less exclusive and more universal attitude to the world in general, to other countries, and to science. Whether from the rigors of external hatred to which it has been subject, or from the internal necessity of its own development, the Soviet policy has become progressively more doctrinaire and restrictive, and less tolerant and humane. In fact, the Soviet State has become a closed and rigid institution closely resembling the historical Church, even in the minute details of its attitude and organization.

I have said before that man's future on earth will not be long unless man rises to the full level of his inborn powers. For us, to be less than a man is to be less than alive. Those who are not fully alive do not live long even in their world of shadows. I have said, moreover, that for man to be alive is for him to participate in a world-wide scheme of communication. It is to have the liberty to test new opinions and to find which of them point somewhere, and which of them simply confuse us. It is to have the variability to fit into the world in more places than one, the variability which may lead us to have soldiers when we need soldiers, but which also leads us to have saints when we need saints. It is precisely this variability and this communicative integrity of man which I find to be violated and crippled by the present tendency to huddle together according to a comprehensive prearranged plan, which is handed to us from above. We must cease to kiss the whip that lashes us.

In the great periods of intellectual development, there has been a willingness of men to stand for ideals and opinions, even when they are unpopular. In the present age, this type of intellectual courage has been conspicuously lacking. It is not only that we suffer from a fear of persecution by authority. We cringe before the even greater fear of incurring the persecution implicit in being different from other people. The schoolboy cruelty by which the dissident individual is reduced to a lifeless pattern has received the sanction of authorities who should long ago have outgrown this evil stage of adolescence. If the present age is to bear fruit, and be worthy of the dignity of history, we must resist the psychopathic compulsion to universal likeness.

I should like to comment on the difference between a love for truth and a love for consistency and logic. In the long run, either the truth must be consistent, or it must be impenetrable to us. However, a consistent view of things does not necessarily mark the first stages of our intellectual penetration into new fields, but rather their final conquest and integration into a larger world, containing in an organized form all that is valid of the different and previously unresolved alternatives. In fact, a process of this sort is consciously recognized by Marxism, in its support and incorporation of the Hegelian dialectic of thesis, antithesis, and synthesis.

This consistency of final result, which emerges as a consequence of the process of investigation and study, is not characteristic of all the steps by which we learn to know the truth. At present, the apparent contradictions between relativity and quantum theory represent a still unresolved region of physics. Intellectual honesty demands the recognition of that which is still unresolved in science, as well as the expectation that a means may be found to reconcile the opposing half-opinions and the urge to take action to fulfill this reconciliation

Whenever an intellectual movement becomes a militant religious propaganda, there is also a drive to relinquish those imperfectly defensible outposts of knowledge which have not yet been integrated into a tight and consistent line of defense, and to retreat into a ritual behind the security of an apparently impregnable logic. This should be recognized as the step backward which it actually is.

Two cases in point are those of the Jesuit Order and of the Communist Party. All of Catholicism is indeed essentially a totalitarian religion. The claim to possess the Keys of Heaven and Earth, or in other words, the claim to control the only access to Salvation, is a totalitarian claim. Such a claim is always forced to base itself on a closed logic. In the case of the Church, this is the Aristotelean logic as interpreted by St. Thomas Aquinas. Nevertheless, the Catholic Church is a house with many mansions. There are wide fields of Catholicism, and whole religious orders, in which neither the propagandist nor the totalitarian urge is explicitly to the front. However, the Jesuit Order is something like a Church within a Church, as both the larger Church and the Order have repeatedly learned to their sorrow. It is a military and militant order, founded in a Spain which was not yet completely free from the threat of the Moor, and in a spirit which had something in it of the Moorish Jehad. Indeed, even in the days of Their Most Catholic Majesties, the Catholicism of Spain, in its claims and its devotion, has been the mirror image of the martial fervor of the followers of Mohammed.

In what is the Jesuit Order to be distinguished from the other orders of the Church? In its discipline, its logic, and its use of logic to make the truth subservient to the will of the Church and of the Order. Its great service to education has largely been in the direction of an education in casuistry. I am not using this word in any invidious sense, for it is a word used by the Jesuits themselves. It means the treatment of moral problems by exemplifying them in individual cases, in the same way in which law is taught by the case system at the Harvard Law School. From a certain point of view, it means the turning of the moral law itself into a field of combat, like that which the common law has become in our courts. Its main tool is a strict logic.

Allied to this military fervor, which has produced many heroes of the Cross, such as St. Francis Xavier and Matteo Ricci, is a superb system of organization. The *relations* of the Jesuits are known as one of the great sources of history, scarcely second to the reports of the Venetian ambassadors at an earlier period. Like these, they consist in comments, not only on the internal life of their religious order, but on every phenomenon, political, military, or social, which might be of interest to the Church and to the Order. This has always been one of the duties of the Jesuit, and it is a duty leaving no corner of immunity for not reporting affairs which were as significant in their time as the discovery and the details of the atomic bomb have been in ours. For the Church and the Order, the laws of the Church are those of God, transcending and superseding all laws of temporal princes.

There is no phase of this description which is not valid with purely verbal changes when applied to the Communist Party, as it is now organized. The Communists do not consider themselves servants of God, but they do consider themselves servants of a cause to which they are completely devoted, and which they believe to contain the ultimate duty of humanity. They are a military order, hardened by years of underground revolution and of foreign wars, even as the Jesuits were hardened in the perpetual conflict with the Moor. They know no more pity in serving their ends than the Jesuit did in his work of Salvation. They do not spare themselves, and will not spare others. Their logic means to them precisely what the logic of St. Thomas means to the Church, and particularly to the Jesuits: namely, a central fortress of belief. It is, however, the logic of Hegel as interpreted through the word of Karl Marx, and not that of St. Thomas, to which they adhere. Even where this logic suggests an interplay and modification of scientific ideas in the course of their internal history, it remains itself a point of doctrine. Finally, the Communists have a system of reports and *relations* quite as detailed and rigorous as anything known to the Jesuits.

A curious example of the Soviet desire for consistency comes up in connection with the problems of espionage and of treason. The countries of the West have a very double morality in this matter. There is not a military headquarters, nor a Foreign Office, our own included, which does not make habitual use of those unsavory characters in other countries who are willing to disclose their country's secrets for pique or for money. There is no great nation which does not also maintain officers of its own, with the duty of living abroad as private citizens, and of reporting on just those things which the country of their domicile holds most secret. Those of us who have mixed freely with our military friends know only too well the details of this situation.

The world being what it is, all these things are necessary. However, we speak softly of them in order not to shock the tender susceptibilities of the good citizen. There is a pretense that this espionage does not exist; or at least that it is done only by dirty foreigners and that our own skirts are clear. This is hypocrisy, but it is probably a hypocrisy which is rather necessary; as without it the citizens of every country would lose themselves in an atmosphere of intrigue and cynicism which is more than hostile to the proper execution of civilian duties. Russia rebels against this hypocrisy, and makes very few bones as to its policy of espionage. It demands that members of its Party transfer to it all the information that may be vital to its continued existence. Fundamentally and potentially, this does not differ from what occurs in the reports of some of the religious orders; but it happens in this country that we are alerted to the dangers of Communism, and that we are as yet somewhat indifferent to the political possibilities of the Church. There are important places where these latter possibilities have come to light. Let us remember what happens to a birth-control bill in Massachusetts; and let us note well the concentration of the great guns of the Church on Mrs. Roosevelt, and the cold Inquisition which resulted.

I do not wish to defend those of double allegiance, and in particular those who sell and give away our secret documents. I hate the whole atmosphere of cops and robbers, which is obliterating the decencies of our national life. I do not believe that all the attacks being made on those supposed to be spies or traitors are justified by the facts; and I am quite convinced that there is a hue and cry all over the country, which considers conviction an achievement in itself quite apart from the question of guilt. What I am trying to do in this paragraph is a very different thing: to free the situation from the atmosphere of the chase which obfuscates it.

Let us return to the more general question of the comparison between the attitudes of the Jesuits and those of the Communist Party, especially in matters concerning the position of science. In the first place, where no point of religious doctrine is concerned, the Jesuits have a long and honorable record of scientific achievement. Their study of earthquakes is of the first class, for the study of earthquakes is both important for humanitarian reasons, and not likely to lead to any debatable points of doctrine. The history of pure mathematics contains the name of more than one great Jesuit, such as that of Saccheri, as it also contains those of more than one member of the Communist Party. Here again, mathematical points of doctrine conflicting with those of the Church or the Party are few and far between; and they may easily be avoided by those who wish a flawless doctrinal record. On the other hand, I do not advise a scientist or a historian of liberal and individual views to teach at a Jesuit university, any more than at a Communist one, assuming that he could be appointed by either school in the first instance. Under both conditions, science can exist; but it is science in a strait-jacket, fearing for the conditions of its own continuation.

To speak more specifically of Communism: its policy with respect to science has not been constant, and has fluctuated with the Party Line. There was a period in which Soviet Russia was appealing to the scholars of the world for its recognition as a cultured and a learned country. In that period, the Russian journals, including the publications of the Russian Academy of Science, published after each article an abstract in English, French, or German. This epoch terminated with the times following the second World War. Now the Russian periodicals confine themselves strictly to Russian, with the possible exception of other languages spoken in different parts of the Soviet Commonwealth. At the same time, the welcome temporarily extended to visiting scholars, even as candidates for positions at Russian schools, has been considerably abridged. Foreign connections have become more dangerous than ever for the Russian professor. Worst of all, matters such as the gene theory of inheritance, the quantum theory, relativity, and various logical theories as to the nature of mathematics, have come within the cognizance of the Russian Government, as questions concerning which the State has an orthodox opinion, which the individual will fail to follow only at his own peril.

Let us now turn to the other side of the present international alignment. The attitude of Western Europe is confused, and tends to follow the lead, either of Russia on the one hand, or that of the United States on the other. There still remains a great middle group of intellectuals who accept socialistic ideas but are unwilling to align themselves completely with the Communist system. This middle group is at present fighting a losing battle on both fronts: against the antagonism of Russia, and against the American desire to discredit the slightest coloring of socialism.

It is only in America and in Vatican City that one meets the compact headquarters of the real forces antagonistic to the Soviet Union of the present day. It is only in these capitals and in their satellites that anyone considers seriously a war against the Soviet Union, whether this war be hot or cold.

As to the Church, which has come out explicitly as the chief enemy of all things Communistic, let me say again that no men can doubt its essential totalitarianism. "Quod semper, quod ubique, quod ab omnibus," are noble words, but they will only bear a totalitarian interpretation. The Church is patient. If it finds itself in a position in which it cannot get a whole loaf, it is willing to compromise for half a loaf; but this compromise is only a temporary expedient, and in the long run the Church will accept nothing less than the whole loaf. In a democratic republic like the United States, the Church's acceptance of a position as one religion among other religions is conditioned by the fact that it is still a minority, and that this is the best bargain which it can enforce. It still regards itself as the only channel of approach to Salvation, and to the Presence of God. Since it so represents itself, it can accept no permanent compromise.

The Church has never discredited the Inquisition. How can it, when it regards heresy as treason to God, and the greatest of all sins? The Inquisition remains in its quiver together with Excommunication and the Interdict. Only recently, the Church has drawn the arrow of Excommunication and has put it to the bow.

At this point, let me say that I am moved by no particular hostility to the Catholic religion. As the most powerful ecclesiastical organization in existence, with the possible exception of the Communist Party itself, the Church shows in a supreme degree the characteristics which belong to all ecclesiastical organizations with a claim to totalitarianism. There are very few Christian churches which do not put forward a claim of this sort, and which differ from the Church of Rome to any extent, except in their power. That is, there are very few Churches which do not accept in principle their universality, their incompatibility with all other religions, and the complete and unquestioned righteousness of their principles. These are not necessary concomitants of religion. They are abandoned in the religious syncretism, by which a Chinese can be a Confucian, a Buddhist, and a Taoist at the same time; and they are weakened to the vanishing point in Unitarianism and among the Society of Friends. Nevertheless, neither Calvin nor Luther is free from the conviction that outside his Church there is no way to salvation.

The tendency to claim a totalitarian basis for the Church is one that accompanies the transition from the Church of the Saints to the Church of the Bishops. So long as the Church possesses no powers except the moral power, and so long as its membership involves a very real contemplation of personal suffering and martyrdom, it need not trouble to make claims outside the group of its own members. In that moment in which the successor of Saint Peter compromises with Caesar, becomes an official of a public order which is parallel to that of the State, and shares the functions of the State by a mutual agreement, the Church becomes an organization offering advancement and a personal career. If such an organization is to survive, it must take its duty of survival very seriously, and the path to totalitarianism is short indeed.

The Church of the Bishops must assume that it is a universal organization; that there is no way to Salvation which does not go through it. For this reason, there is nothing which is more vexing to a Bishop than a Saint in his diocese. By his very nature, the saint claims a direct relation with God. This relation by-passes the authority of the Church, even when it does not contravene it. There is something in personal holiness which is akin to an act of choice, and the word *heresy* is nothing but the Greek word for choice. Thus your Bishop, however much he may respect a dead Saint, can never feel too friendly toward a living one.

This brings up a very interesting remark which Professor John von Neumann has made to me. He has said that in modern science the era of the primitive church is passing, and that the era of the Bishop is upon us. Indeed, the heads of great laboratories are very much like Bishops, with their association with the powerful in all walks of life, and the dangers they incur of the carnal sins of pride and of lust for power. On the other hand, the independent scientist who is worth the slightest consideration as a scientist, has a consecration which comes entirely from within himself: a vocation which demands the possibility of supreme self-sacrifice.

In history, the Bishop is not only the man of the Crozier; he is also the man of the Mace. He is supposed not to shed blood, but he does not interpret this injunction so strictly that he may not spill brains. In the *Chanson de Roland*, the Archbishop Turpin is as much a man of violence as any

Roland or Oliver; and at Hastings, Odo of Bayeux fights by the side of his brother, the Bastard of Normandy.

Since the Bishop is not always the man of peace, we must not be surprised if what we have said about the Church of the Saints and the Church of the Bishops applies with equal force to Communism. The men of the Russian Revolution, whatever violence they did, and whatever they intended to do in the way of upsetting existing institutions, were men of great courage and great suffering. Almost none of the old Communists survived the Revolution for more than a decade, and this was owing to the hardships they had undergone. They were often men of culture, even when they were men of a limited and bigoted standpoint. Many of us had hoped that after the Revolution and a period of reorganization, the quality of these men would come to the fore, and that some of the rigidity of Communism would dissipate itself.

There were phases of the Russian Revolution which bore out this expectation, but in the present world of conflicts and ambitions, it seems to those of us not in Russia, that the prevailing trend toward liberalism has been reversed. The new generation of Communist leaders has replaced the insurgence of the originators by the rigidity of the great administrator.

The similarity which we have noted between the Church and the Soviet is not as surprising as it might seem. A struggle exposes both sides to the same field of combat and the same hardships, and ends by making them very much alike. This similarity is more likely to appear in the vices than in the virtues of the individuals in question.

The Christianity of the Spaniard, as we have said, has much in common with the Islam of the Moor. The flames of the Inquisition burn again in the fire to which Calvin condemned Servetus. The Communist commissar and the

Jesuit superior are brothers; although one calls on Christ, and the other proclaims the new Azan, "There is no God, and Marx is His Prophet!"

I have indicated that freedom of opinion at the present time is being crushed between the two rigidities of the Church and the Communist Party. In the United States we are in the process of developing a new rigidity which combines the methods of both while partaking of the emotional fervor of neither. Our Conservatives of all shades of opinion have somehow got together to make American capitalism and the fifth freedom of the businessman supreme throughout all the world.

Our military men and our great merchant princes have looked upon the propaganda technique of the Russians, and have found that it is good. They have found a worthy counterpart for the GPU in the FBI, in its new rôle of political censor. They have not considered that these weapons form something fundamentally distasteful to humanity, and that they need the full force of an overwhelming faith and belief to make them even tolerable. This faith and belief they have nowhere striven to replace. Thus they have been false to the dearest part of our American traditions, without offering us any principles for which we may die, except a merely negative hatred of Communism. They have succeeded in being un-American without being radical. To this end we have invented a new inquisition: the Inquisition of Teachers' Oaths and of Congressional Committees. We have synthesized a new propaganda, lacking only one element which is common to the Church and to the Communist Party, and that is the element of Belief. We have accepted the methods, not the ideals of our possible antagonists, little realizing that it is the ideals which have given the methods whatever cogency they possess. Ourselves without faith, we presume to punish heresy. May the absurdity of our position soon perish amidst the Homeric laughter that it deserves.

It is this triple attack on our liberties which we must resist, if communication is to have the scope that it properly deserves as the central phenomenon of society, and if the human individual is to reach and to maintain his full stature. It is again the American worship of know-how as opposed to know-what that hampers us. We rightly see great dangers in the totalitarian system of Communism. On the one hand, we have called in to combat these the assistance of a totalitarian Church which is in no respect ready to accept, in support of its standards, milder means than those to which Communism appeals. On the other hand, we have attempted to synthesize a rigid system to fight fire by fire, and to oppose Communism by institutions which bear more than a fortuitous resemblance to Communistic institutions. In this we have failed to realize that the element in Communism which essentially deserves our respect consists in its loyalties and in its insistence on the dignity and the rights of the worker. What is bad consists chiefly in the ruthless techniques to which the present phase of the Communist revolution has resorted. Our leaders show a disquieting complacency in their acceptance of the ruthlessness and a disquieting unwillingness to refer their acts to any guiding principles. Fundamentally, behind our counter-ruthlessness there is no adequate basis of real heartfelt assent. Let us hope that it is still possible to reverse the tide of the moment and to create a future America in which man can live and can grow to be a human being in the fullest and richest sense of the word.

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