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BASES AND LINES OF FORCE IN CYBERNETICS

Cybernetics[1] has fallen prey to snobs and journalists, who, in dealing with it, tend to mix myth with science. In this study we shall try to sift out the chaff, which a regrettable sensationalism has needlessly mixed with the good grain. Concentrating our attention on the rational bases and some of the lines of force of this new field of study, we shall try to eliminate the element of fable, but we shall not prohibit ourselves from opening windows on any perspectives that seem reasonable.

I. *Information*

The notion of "information," cornerstone of cybernetics, sheds light on the theory of knowledge. What is science, indeed, but an interpretation, which tries to be objective, of the flood of signals with which the universe submerges us? A Protean notion, it permits us to discover a certain unity among the most disparate phenomena. But it is a dangerous notion, too, because of the multiplicity of senses one may give to it.

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[1] This term was invented—or rather, reinvented, for Plato and Ampere had already used it—by Norbert Wiener in 1947, as a tribute to Clerk Maxwell.

We shall not here stop to consider the various senses which this notion has in current language—every day the newspapers bring us "information" true or false, "information" against *x* or *y* is uncovered by the public prosecutor—nor its various literary nuances. But perhaps it is pertinent to recall that, taken in these familiar senses, the idea of information must have made its appearance in prehistoric times, with—and perhaps before—language; and also that, on the whole, the information of the cyberneticists represents that of the man in the street, after it has been decanted, given form and rationalized. In either case a piece of information is a signal, or a collection of signals or signs, to which a significant content is attached. The information should not be confused with the knowledge which it brings nor with the signals or signs which carry it. When I say, in French, "*Il joue aux echécs,*" in English, "He is playing chess," in German, "*Er spielt Schach,*" or when I write an equivalent sentence in Russian or in one of the languages of India, the signals or signs change every time but the information remains the same.

But in cybernetics proper, the word "information" may be taken in several senses. To enumerate, define and compare them would easily take a volume. Without going thoroughly into this very complex problem, it is well to warn against inconsiderate use of the term and at the same time to draw attention to its interest.

Nyquist, in 1924, made the first attempt to establish the notion of selective information on a scientific basis. At the international telephony and telegraphy congress of 1927, another telephone engineer, Hartley, opened the door to further progress when he showed how to measure its quantity. Reviving an idea launched in 1871 by Maxwell, the physicist Szilard opened to information an unforeseen field of action: that of thermodynamics. In 1935 the statisticians, Fisher and Wald, gave it two new senses, which permitted the theory of induction to be posed in much more precise terms. In 1948 Norbert Wiener, and (independently of him) Shannon and Weaver reviewed Hartley's work and assured the full flowering of the theory of selective information, whose statistical character was to be studied by Kolmogoroff and Blanc-Lapierre. A little later Gabor related it to quantum physics and established its discontinuity.

This list is not exhaustive. The definitions of information form a fairly heterogeneous little population; certain of its members resemble one another strongly, while others have hardly any points in common. For lack of taking suitable precautions, a number of authors have wrongly confused Fisherian and selective information; others have confused Shannon's "information cycle" with the cycles employed in the theory of measurement in physics. Properly adapted, the notion of Maxwell's demon is useful for comparing these diverse notions of information among themselves. But even here one must distinguish between the "instrumental demons" and the "selective demons." Without attempting to map this jungle, we may simplify matters and say that there are two distinctly different types of definition, each capable of being subdivided into several variants. These two types may be classed under the headings of selective information and semantic information.

II. *Definition and Measurement of Selective Information*

Selective information, or Shannon's information, is a quantity with which telecommunication operators—telegraph, telephone and radio networks—need to be familiar in order to sell their services at the fairest price. Selective information can be effectuated only by means of known symbols: letters of an alphabet, signs of a code, etc.

Like many other notions—that of mechanical force, of chemical affinity, electrification—the notion of information has progressed from the state of a confused sensation to the dignity of a scientific concept, passing from vague appreciation to the domain of measurement. The honor of having taken the first steps in this direction goes to L. V. Hartley, who suggested a process of choice by alternatives and proposed a unit of measurement to which, quite properly, his name has been given.

When he considered the problem of telegraphic communication, Hartley realized that the amount of information in a message made up of a single sign may be measured by counting the minimum number of yes-or-no answers needed to attain or define, by successive dichotomies, an element—corresponding to the signal to be transmitted—submerged in a group of other elements: for example, a word in a dictionary. The first dichotomy consists of dividing the initial group into two sub-groups and indicating in which one the sought-for element is located; the second dichotomy consists of dividing the sub-group chosen in the preceding operation into two other sub-groups and indicating in which one the element is to be found. The process is continued until a last sub-group is obtained which is made up of only two elements, for which a last dichotomy will indicate the element wanted. The number of dichotomies necessary to attain this final objective will be, by definition, the number of hartleys involved in the operation. To find a given card in a deck of thirty-two cards five alternative choices are necessary, i.e., five hartleys.

It will be seen that the number of hartleys in a collection is equal to th logarithm to the base 2 of the number of elements in the collection. A message implying n choices among K symbols will carry a quantity of information which may be expressed thus:

$$I = n \log_2 K$$

The information might have been measured in various other ways. Th use of a logarithmic expression is particularly convenient since it define an additive quantity—one that is easy to handle. Developing an idea o Wiener's, Shannon later showed that the quantity of information transmitted in a message made up of letters may be measured by multiplyin the frequency of each letter by the logarithm of this frequency and addin the products obtained.

Another measure of information which should be mentioned is th logon, a unit of structural information invented by Gabor, which is relate not to the signals transmitted or the codes adopted but to the transmissio channels utilized—somewhat in the same way as electrical resistance characterizes not the current but the conductor.

When one uses the hartley as a measure of information one is often surprised—at least in the beginning, for all surprise wears off in time—at th new insights it permits. It is edifying to familiarize oneself with this nev type of scale and to note its breadth, which recalls that of the scale o electromagnetic waves.

Many technical and industrial mechanisms are based on the use of single hartley; this is the case, for example, with the thermostat whicl regulates our gas radiators. It lights them or not, according to whether o not the critical temperature has been reached. It is also the case with man of our actions in everyday life, and with answers to administrative questions: sex (masculine or feminine), family status (single or married), etc

If one assumes that a dictionary contains one hundred thousand word its value is sixteen or seventeen hartleys. The human brain can reason a ten hartleys a second. The human ear is sensitive to a million hartleys second, the human eye to five hundred million hartleys a second.

A great deal could be said on this essential notion of the measure of information. We shall limit ourselves here to a few remarks.

The first is that the fact that all information can be coded with a minimum of two symbols—with an alphabet of two letters, so to speak—constitutes the very principle of the Morse code.

The second is that this principle is utilized by very primitive people like the Congo tribes, who transmit complicated messages with long and short beats on tom-toms.

The third is that this dichotomous process forecasts the role of binary enumeration in big modern electronic machines. It is indeed perfectly adapted to "all or none" functioning.[2] Nervous action also operates through the "all or none" principle. From neuron to neuron, it is transmitted by the essential organs to the brain or by the latter to the motor organs, by means of signals in binary code.

III. *Information, Entropy, Energy*

Thus we know how to measure information, or more exactly, selective information. This is a prime factor for the guidance of research, since it gives us an unexpected lead into one of the best-developed disciplines of modern physics. Knowledge of how to measure selective information helped clear up the thermodynamic aspect of the theory of information—in particular, it established the fact that a piece of information can be assimilated to a negative entropy.

Along with energy, entropy is one of the two fundamental quantities of energetics. It is a simple entity, which certainly corresponds to something very concrete in reality. Unfortunately, it is not perceptible to our senses, so that one can familiarize oneself with its use only through an initiation and exercises which go beyond the framework of this study. We may say in general, avoiding the use of the mathematical notations of integral calculus, that an entropy (in Clausius's sense) corresponds to the quotient of a quantity of heat divided by a temperature; it is measured by dividing calories by degrees. Boltzmann showed that this quotient is equivalent to the logarithm of a probability—the probability that a process will end in one configuration rather than another. Thus entropy would be nothing more than the measure of the disorder in a system.

This comparison may seem surprising to the layman, but a little reflection will help to explain it. Heat is the cause of the agitation of molecules, and the temperature of a body represents the greater or lesser agitation of these molecules under the influence of a given quantity of heat. This molecular agitation tends to modify the structure of the body, and entropy represents the probability that this agitation will determine one or another more or less regular structure. Entropy is thus related to heat and temperature on the one hand and to structural order on the other.

It is also easy to understand that the notions of entropy and information

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[2] An electric or electronic current passes, or does not pass, through a conductor or a tube.

are related. Imagine a collection of elements in a disorderly mixture. This disorder would only be apparent if we had a means of locating at will, and without ambiguity, any one of the elements in the mixture. The collection would then be, if not orderly, at least capable of being ordered.[3] Ordering will be possible if we possess a sufficient amount of information about the collection, whether this information is measured in hartleys or in any other scientifically equivalent way. As an instrument for putting collections in order, information is then, like entropy, a measure of order.

It was Szilard who established the connection between information and entropy. In demonstrating it, he turned to the celebrated parable of Maxwell's demon. This parable deals with an imaginary experiment whose aim would be to separate a certain mass of gas, of uniform average temperature, into two portions having different temperatures.

Suppose that the gas is held in a closed container divided in half by a partition pierced with tiny holes. Each hole has a stopper. Each hole is also guarded by a "demon" who keeps watch over what goes on around him. The demon is able to follow the erratic gyrations of each molecule, to gauge its speed and foresee whether or not it will come toward the hole he is guarding, and to open or close the stopper before the molecule reaches the hole. Thus he can bar the way to the slower molecules and open it, or leave it open, to the more rapid. If he carries out these instructions for a certain length of time—without himself intervening to change the direction or speed of any molecule, except when he bars the way to the slower ones—the faster molecules will all eventually be on one side of the partition and the slower ones on the other. The gas will thus have been divided into two portions of unequal temperature—or, what amounts to the same thing, a beginning of order will have been substituted for the initial disorder.

Szilard showed that it is possible to preserve the validity of the Second Law of Thermodynamics (Carnot, 1824) by admitting that the entropy lost during the separation of the low-energy and high-energy molecules constitutes the price paid by Maxwell's demon for obtaining information and transmitting it to the observer of the experiment. Szilard's argument goes far beyond discussion of the parable of Maxwell's demon. It shows us that every experiment which permits us to obtain information from a physical system is paid for by an increase in entropy—that is, by a decrease

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[3] Certain intellectuals will not permit the "disorder" of their papers to be regulated, because they know how to find their way through it; what appears to the layman to be disorder is, for them, order.

of structural order—in this system or in its environment. To observe a phenomenon is to change its order.

Selective information is thus assimilated to an entropy. Only—unlike all the phenomena to which physicists were previously accustomed and which have as their basis a positive entropy, that is to say, a tendency to disorder—information presents itself as a negative entropy, that is to say, a generator of order. Wiener and Schrödinger, working independently of each other, both noted this. Instead of saying "negative entropy," some people adopt Léon Brillouin's term, "negentropy."[4]

Is information identical with a negative entropy? It would be more exact to say that these two quantities are in any case of the same nature, homogeneous and exchangeable one for the other, as are mechanical work and heat or mass and energy.[5] This means that the real second law of energetics should be expressed thus: "The sum of the negative entropy and the information in a closed system can never increase."

What should be remembered, in any case, is that information is not energy, but that it cannot be physically separated from energy. No matter what the adepts of telepathy may think, thought cannot be transmitted through space at a speed faster than that of light. But, of course, the necessity for an energetic support does not mean that this support is considerable. As is well known, the phenomena with which neurophysiologists or linguists are concerned involve energies which are ridiculously weak. What is interesting in these phenomena is not their consumption of energy but their production of negentropy—that is, their aptitude for ordering structures.

Forgetfulness of the fact that all information is accompanied by an expenditure of energy and entropy, which may be very small but is never nonexistent, may result in sophisms or errors, of the sort which would lead one to believe that the total quantity of information may be multiplied freely—and thus indefinitely—because the same book or the same phonograph record is sold to a larger and larger number of readers or auditors or because the same radio or television program is picked up by a larger and larger number of people. The dissociation of information and negentropy which seems to characterize these examples is only an apparent contradiction of Carnot's "generalized principle."

When one reads a written text or listens to a record, one needs a source

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[4] Sometimes, but much more rarely, with other authors: "ectropy."

[5] Information may be measured in units defined as above, or in thermodynamic units of entropy. Each unit of information is equivalent to an entropy equal to K ln 2—that is, about 10^{-16} thermodynamic units.

of light to illumine the text or a phonograph motor to turn the record What is furnished by these means is not only energy, but negentropy. Thi circumstance limits the possibility of an indefinite multiplication of information, but it often goes unrecognized because of the small quantitie of energy and entropy involved. "All machines for printing, reproducin or reading information," writes Léon Brillouin,[6] "have such a small output of entropy that this essential fact has always passed unnoticed. All o modern life is based on the possibility of multiplying information at minimum cost"—but not for nothing. This discussion may lead us to distinguish two new types of information: "absolute information" and "distributed information."

There is another error which must be avoided when applying this notion of negative entropy to biological, psychological or social phenomena Entropy is a statistical notion. To speak of the entropy of a living being—insofar as he constitutes a living unity, and consequently an isolated an elementary system—makes no more sense than to speak of the average o a single experiment. On the other hand, it is legitimate and useful to speak of the entropy of a living being insofar as he is made up of a population o cells, molecules, atoms, etc.

After matter, electricity, light and energy, or, rather, action, entrop and information have come within that field of measurement which corresponds, indubitably, to a universal and profound reality, and whose consequences are manifest even in the problems of living tissue and those o heredity and thought.

The smallest quantity of negentropy necessary to obtain an "atom" o information[7] is 0.7 *k*. The letter *k* represents Boltzmann's constant and i equivalent to 1.38×10^{-16} thermodynamic units. Thus, outside of the limitations which Heisenberg's Principle of Uncertainty—related to Planck's quantum of action, *h*—brings to our knowledge of the outside world, there exists another limitation to our capacity for experimenting: it is related this time to Boltzmann's *k* constant.

Dennis Gabor has done penetrating work on this discontinuity of information and on its interpretation in terms of wave mechanics. Like

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[6] "Principe de Néguentropie pour l'Information," in *Louis de Broglie, Physicien et Penseu* (Paris, Michel, 1953), p. 368.
See also the same author's article in the *Journal of Applied Physics* for May, 1954.

[7] Sometimes the term "bit" is used—an abbreviation of "binary digits."

Jean Ville, he replaces the representation of signals through real numbers by a representation through complex numbers. He has also shown the complementary character of temporal and frequential analysis of signals.

IV. *The Theory of Communications*

From the notion of selective information we pass quite naturally to that of communications. Historically, the theory of communications is prior to the idea of information; the latter was conceived, indeed, to give a solid foundation to the technique of telecommunications. A communication is a transfer of information. A communications system is a circuit, or a network formed of several circuits, which permits information to be transported over a distance. This information is coded, that is, transformed into signals (electrical, acoustic, optical or other kinds) which can be physically transmitted over the circuits of the networks. By communications systems I do not mean only telephone networks[8]—whose structures have been studied, but which do not pretend to be absolutely universal models—but the most diverse forms of networks: mechanical machines, administrative structures, and nervous systems.[9] When a storm damages a telephone line, when the police disrupt a resistance "network," communications are cut. In the same way, cerebral communications are permanently cut by the psychosurgeon when he performs a lobotomy, or temporarily cut by the psychiatrist when he has recourse to electrical or chemical shocks.

It should be noted at this point that there are enormous differences between the brain and the systems of communications created by technicians. The brain is not so much like a single circuit—extremely complicated, well defined, and consequently rigid—as it is like an immense and partly undifferentiated network in which the available circuits may be rapidly grouped and devoted for a limited time to definite tasks.

The possibility of measuring selective information and expressing it in terms of entropy permitted a mathematical theory of communications to be developed. Its mathematical character may be a serious obstacle to its use by physiologists or specialists in the human sciences, but the obstacle is not insurmountable. A part of these mathematical theories, and often the most modern part—like Boole's algebra, which Shannon applies to

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[8] Telecommunications networks use a special method of transmitting messages. Signals circulate as modulations (amplitude, frequency, etc.) of a sinusoidal current.

[9] Attempts have even been made—without great practical success so far, it must be said—to consider the propagation of such a slow geological phenomenon as the formation of a mountain chain as a kind of transmission of information.

the communication of electric circuits, or like the "Markoff chains," which relate to the calculation of probabilities—is relatively easy.

The notion of noise plays an important part in the theory of communications in generalizing and formalizing the ordinary phenomenon of background noise which may interfere with the audibility in a lecture hall or of a telephone conversation.

Noise is any alteration which comes from the superposition, on a message, of signals which are foreign to that message. A noise is a positive entropy which may be algebraically added to the negative entropy of the information; it is disorder superimposed on order. Noise is usually a regrettable natural phenomenon, but it may also be emitted intentionally, as is the case with the "jamming" of a hostile radio or the misleading of a secret service through false news. At a theoretical limit—and, in most practical cases, long before this limit was reached—an infinite noise would make it impossible for the communication to be realized. The problem of restoring information lost by distortion or drowned in a noise—a problem which has been studied particularly by Wiener and Kolmogoroff—seems to me likewise deserving of attention, because of the biological and psychological phenomena in which it appears.

As has just been pointed out, information cannot be created out of nothing; it can be created only on the basis of earlier information which permits us to foresee the structure of the message. A flow of pieces of information which arrive one after the other may be stored in a memory (animal or mechanical) without producing any result, until another piece of information, which plays the role of a crystallizer where the preceding parts are concerned, produces an effect which may be imputed not only to the last piece of information, but to all those that have preceded it. This is the case, for example, with a mystery story, in which a revelation made on the last page explains and permits the reader to organize the incomplete information disseminated throughout the preceding chapters. The process operates as if each of these revelations were less a piece of information than a fragment, the last one giving meaning to the whole, as the last fragment of a torn-up banknote must be glued into place if the note is to be accepted at its face value. In the field of physics, these phenomena may be compared with the relaxation waves so ingeniously studied by Van der Pol.

It was Shannon who, in 1949, worked out a fundamental formula expressing the capacity of a communications line in which a noise is involved. In 1950 Gabor succeeded in accounting for the element of noise in the mathematical theory of communications which he had developed in 1946. This theory is valid in a discontinuous field and includes recourse to a function analogous to the wave function in wave mechanics.

V. *Information, Experiments, Induction*

Born out of the reflections of telephone technicians, the notion of selective information went through a brilliant metamorphosis at the hands of pure physicists and mathematicians. Two masters of the calculation of probabilities, R. A. Fisher and A. Wald, proposed two new definitions of information. Though somewhat similar, these two definitions are distinct from each other and closely connected with selective information. They deal with the possibility of systematically interpreting experiments in order to draw laws therefrom, and thus permit the theory of induction to be related to the theory of information. Fisher's information deals with the limit of precision of an experiment whose aim is to estimate an unknown quantity. Wald's information is associated with the number of observations which an experimenter would have to make in order to decide between two hypotheses.[10] The relation is clear between these two types of information and selective information.

According to Wald's theory, a certain "weight" may be given to any observation. This is what the layman tends to neglect. And thus it happens that victims of the "flying saucer" myth believe in all good faith that they are taking a scientific and progressive attitude when they point out that there exist a certain number of observations relating to unidentified objects or lights, and that the honesty of experimental rationalism demands that these cases be discussed. In reality the opposite is true. Observations which were not made in a scientific manner, and which, in particular, were not recorded with precision, do not merit being taken into account. Each of them has a "weight" of zero, in Wald's sense, and no matter how many zeros are added together, the sum is still zero.

VI. *Towards Subjectivity*

The different types of information which we have just sketched may be defined by a series of choices in a finished collection of symbols or experiences. Through this fact, all subjectivity is ruled out. Information may lead to knowledge, but it is not knowledge.

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[10] For example, to find in three weighings—without the use of weights or tares—a counterfeit coin mixed with twelve good ones.

A second type of information, semantic information or meaning, brings us considerably closer to subjectivity, if it does not immediately plunge us into it.

This higher level of information corresponds—in the case of human communications—to the moment when signals leave the acoustical, electrical or nerve circuits in which they have been circulating, and reach a mental receiver, where they acquire a meaning.

Selective information became measurable because the point of view of understanding was replaced by that of extension. Instead of analyzing the content of a message, the observer was interested in the manner of distinguishing this message in the ensemble of all possible messages. In semantic information it is the point of view of understanding which takes the guiding role. This point of view gives semantic information its particular savor as well as its weakness.

Semantic information, or meaning, has already been the object of serious studies and discussions, but up to now it has never lent itself to measurement. There is no mathematical theory which applies to it, nor, except as a hypothesis, which is quite valid, any energetic interpretation. What can be said, then, of the "personal information" which Charles Morris[11] prefers to call "pragmatic information"—which is situated beyond semantic information and penetrates, or claims to penetrate—into subjectivity?

In semantic information, the recipient of a message understands the same thing as the sender of the message and the other recipients. What characterizes personal information, on the contrary, is the special content which the recipient adds to the semantic information by virtue of his personal mental structure, his own experience, etc. Personal information is certainly linked closely with this "evocative function of language" which must be distinguished—as is pointed out by A. Sauvageot, to whom we owe this latter notion—from its "code function."

Psychologists, sociologists and linguists are doubtless more attracted by personal and semantic information than by selective information. They would probably be delighted to abandon this last field to the telephonists in exchange for a coherent theory of the first two, which they could apply to their own research. The unfortunate thing is that when we leave the solid ground of measure, and also that of energetics, we enter, if not into

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[11] In *Foundations of the Theory of Signs* (Chicago, University of Chicago Press, 1938), p. 30.

philosophy, at least into science in its embryonic stage. The present development of our knowledge in this field does not yet include enough positive elements to give hope of fruitful harvests for a long time to come.

Does personal or pragmatic information hold enough points in common with semantic information or meaning, and the latter with selective information? If so, what are the rules of the game that is played in moving from one to the other? Are the first two measurable, like the third? Can they be considered as negentropies, or, at least, as physical quantities interchangeable with negentropy? The answers to all these questions are yet to come. "How does an idea get into our minds?" asked Voltaire. That is the whole question, indeed. When, through laboratory research, we are able to ascend the ladder which goes from acoustics and optics to the anatomy and physiology of the eye, the ear, and the other senses, to the vocal chords and muscles, continues to the motor and sensory nerves, the spinal cord, the medulla, the hypothalamus, the reticular system, the cerebral cortex, and ends in the study of psychological and social behavior, of the laws of thought and language, then we will doubtless solve these major problems and be able to say whether entropy continues to play an enlightening role at the level of subjectivity or in its immediate neighborhood.

It should also be noted that—from acoustics to linguistics—the classification we have just outlined does not necessarily correspond to the assemblage of the real circuits, to the disposal of their connections or to the order in which information circulates in them. Even if one does not take into account recent affirmations concerning the possibility of perceptions outside the brain—affirmations which are without serious foundation—the fact remains, nevertheless, that certain grafts of sense organs, like those carried out by Paul Weiss, give food for reflection. They seem to show that in the lower animals, like the batrachians, certain sensations are not constructed entirely in the brain and that, for example, the "cyclops eyes" grafted into the backs of these animals can reconnect themselves with other nerve centers. One must, however, guard against hasty generalizations. The frog's brain is not a model of its type—the animal's spinal cord and bulb are more useful to it—and the rather elementary reactions which have been noted do not suggest that the "cyclops eye" is capable of very remarkable performances. It seems difficult to explain integrations of a high level without bringing in the cerebral cortex, the hypothalamus, the reticulated system and other formations of the brain.

VII. *Adaptation to Circumstances*

To transmit information through a communications system is one thing, but is not all. There remains the problem of utilizing this information, either to undertake an action—the action of a steam engine, of a larynx, of a poet or of a labor union—or to modify this action while it is being carried out. At this point the theory of control comes into play, the study of servo-mechanisms and of such technical notions as those of feedbacks, scanning, and reverberating circuits, which are enjoying a well-deserved vogue at present, in spite of the abuses to which they lend themselves. We shall not concern ourselves here with elementary controls, which—as in the servo-motor constructed more than a century ago by Léon Farcot—consist of transmitting through a powerful motor a directive conceived by a man.

Let us imagine a machine equipped with organs capable of detecting the differences (or errors) with relation to a goal which has been assigned in advance, and capable also of sending this information to the motor organs (generally known as "effectors"); let us imagine, too, that these effectors are capable of taking this information into account and setting the machine in the right direction once more. Such a machine is a servo-mechanism, a term which means that the machine has a motor organ subordinated to an organ of control. The apparatus which can measure the lack of adaptation during an operation, and inform the effectors of it in a way from which they can profit, is known as a feedback. Positive or negative, according to whether it contributes to increasing or diminishing the motive energy called upon, it is necessarily constituted by a reactive circuit grafted onto the principal circuit. It should be noted that this reactive circuit will not be advantageous unless it consumes very little energy as compared with the energy sent into the principal circuit.[12] The elements capable of detecting the differences may be the balls of Watt's regulator, photoelectric cells or radars, our eyes or ears, a military espionage group, an institute of economic analysis—in all these cases the process of regulation is based on the same principle. And, as Pierre Auger has remarked, the chief advantage of oral teaching over the reading of a manual—no matter how well the manual may be written—is in the feedback which links the professor with his audience and permits him to adjust the schedule of his course. O'Connor, who in 1953 tried to define "linguistic units," analyzed the importance of the audience in the clarity of spoken language.

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[12] The word "circuit" is obviously borrowed from electrical terminology. But it remains valid when one is speaking of the nervous system or of social arrangements.

The success of Grey Walter's electronic "tortoises"[13] is due to feedbacks. So is that of Shannon's "mouse" with conditioned reflexes (1952), which, after it has once made its way out of a labyrinth by the trial-and-error system, can get out of the same labyrinth a second time without hesitation. The same thing is true of the machine which A. E. Oettinger constructed in 1952 and which, besides having a capacity for "learning" and "remembering," is also endowed with a sort of "curiosity." Another case is Fromme's "bee," which can imitate the behavior studied by von Frisch. At a higher level, a combination of several feedbacks makes it possible to assure the homeostasy[14] of a system, that is, its ability to recover its equilibrium when this equilibrium is lost as a result of outside causes. Although the epithet, "plan for a brain," used by its author seems somewhat excessive, Ashby's first homeostat, with its four electro-mechanical servo-mechanisms, was already capable of avoiding simple traps. Still more impressive results may be expected from his super-homeostat, the dams (Dispensative and Multiple System), an electronic device which will interconnect one hundred elements and be capable of recovering its stability within a reasonable time. We are still far from the approximately 10^{10} neurons of the human brain. But science sometimes progresses very fast. A few years ago MacCullough remarked that if a calculating machine had as many electronic tubes as our brain has neurons, it would occupy a volume comparable to that of the Empire State building and could consume all the energy produced by Niagara Falls. With transistors, the same machine could be comfortably installed in a house a few stories high and consume only a few hundred kilowatts.

One can see how much the process of adaptation through the feedback has added to the potentialities of the old machines, as H. S. Black, in 1924, and Nyquist, in 1932, first pointed out.

We must not, however, fall into the error of seeing feedbacks everywhere by confusing them with simple reactions. The feedback, essentially, characterizes living beings or machines made by man. It very rarely appears in natural phenomena, which, on the contrary, are generally governed by reaction. When an oceanographer, M. J. Dunbar, shows us that the Gulf Stream turns in its course as it passes near coasts which direct it to the open sea; when organic chemistry reveals the equilibriums that operate between opposing causes (as, for example, between etherification and

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[13] It should be clearly understood that all the words in this paragraph which are placed between quotation marks are to be taken only as images.

[14] Walter B. Cannon is responsible both for defining the notion and applying the term.

hydrolysis); when physical chemists refer to Guldberg and Waage's law of action of mass; or when city transport technicians study the rate of delay of buses at rush hours, it is not feedbacks which are involved, but ordinary reactions.

Furthermore, valuable as it may be, the notion of the feedback is not the only one which explains the success of servo-mechanisms. It is obviously enormously useful to be able to note the discrepancy between the goal desired and the effect obtained, and to transmit this information to the effectors so that they can make use of it. But that alone would not be sufficient to solve all the problems. In particular, the machine may need to consult a store of information in order to find among a number of useless items the one which is necessary to solve the partial problem posed at that particular moment, thus permitting further progress toward the desired goal. This may be achieved through use of the scanning process, which is a perfect tool for applying Descartes's fourth rule of method.

In this process, an instrument of detection—an electronic brush, a photoelectric cell, a blade of metal, or the eyes of an archivist in a library—makes a complete survey, once or several times over, of all the elements within a certain field of realities. When the detector passes by the element which is sought, it informs the effectors, which turn this information to their own use. Through neglect of the scanning process, we may when absent-minded stumble in the street. On the other hand, the chess champion who successfully plays a hundred games simultaneously obtains good results only because, as he reaches each position, he is capable of exploring it completely and rapidly: this aptitude for scanning is a necessary, but insufficient, condition for the formation of an accurate idea and a winning decision.

In certain cases it may also be indispensable to lay aside this information for a certain length of time (not only because it could not be used during that time, but also because its intrusion might confuse the decisions of the effectors), and then to call on the information at the opportune moment. A really perfected machine should be something like a meeting. In a meeting it would be inconvenient if everybody talked at once, but it would be regrettable if any participant desiring to present interesting observations could not get the floor at the opportune moment. But how is a spatial structure to be transformed into a temporal succession of signals? How can information be stocked by transcribing time into space?

Such services cannot be performed by "static memories." Whether they take the form of dictionaries, files, weaving looms or mechanical pianos, there are many cases where these "passive" memories could not be used. They can, at most, be used as bases for processes like scanning. Recently "dynamic memories" have been brought into play. They are usually made up of reverberating circuits capable of registering an impulse which goes around them indefinitely, without changing, until such time as the command organs of the machine decide to interrogate them.

These circuits are generally made up of an emitter, E; a tube, AB; a receiver, R; and another tube, CD. The emittor, E, transforms into Hertzian waves of the same frequency the oscillatory phenomenon whose rhythm is to be conserved for a certain time. This wave goes from A to B at the speed of light, which may be considered as practically infinite. As it leaves the first tube, at B, the electromagnetic wave is transformed by the receiver, R, into a supersonic wave which enters the second tube at C. It goes from C to D at the speed of sound, which is considerably less than its earlier speed, so that the signal arrives at D in a time which is no longer negligible. On leaving D the supersonic wave is picked up by the emitter, E, and induces the same Hertzian wave which left E at the beginning. The same phenomenon may be reproduced indefinitely as long as energy is supplied to the circuit. Thus we have an impulse which goes round and round, sometimes in an electromagnetic form, sometimes in an acoustical form, until some outside agent comes to "consult" it, and, if indicated, frees the circuit.

In servo-mechanisms, adaptation to the goals to be achieved is usually made by respecting simple principles. This does not prevent processes like feedbacks, scanning, and reverberating circuits from constituting very ingenious means of realization. Feedbacks can do no more than raise or lower a level, add or subtract speed, increase or decrease an angle, a voltage or an amperage. No more than this is needed to permit a "proximity fuse" airplane to follow the zigzags of another airplane and overtake it, or to permit "Joe," the automatic pilot, to keep his plane on its course despite the caprices of the wind; to equip a radio receiving set with an anti-fading device; to control the pressure or the carbonic acid content of the blood; to regulate the necessary and sufficient dosage of anaesthetic according to the encephalogram of a patient on the operating table; or to assure the functioning of the automatic assembly plants designed by W. Leaver and J. J. Brown or of the completely automatic factories already functioning in the U.S.S.R. The achievements of the feedback are impressive, and new ones are being added almost every day. Let us not ask it to produce miracles which transcend its nature and go beyond its possibilities.

VIII. *Choice and Decision. The Theory of Strategic Games*

There are cases where it is much more difficult to make a choice and know how to decide for the best. All the feedbacks in the world would be of little help in a bridge or canasta game or in a business or political enterprise. It is at this point that the theory of strategic games becomes useful. We should note that this new chapter of science appeared outside cybernetics and the theory of communications and pursued an independent existence before joining them. Without stopping to credit precursors[15]—historical justice has no place in this brief study—we may say that this theory began with a celebrated work by von Neumann and Morgenstern, *Theory of Games and Economic Behaviour,* which appeared in 1944.

By "strategic games" we mean games whose results are not entirely determined by chance, as in roulette, but in which the players are required to make choices and carry out reasoned decisions. Besides the element of reason, these games may also contain a greater or lesser element of chance. This is the case, for example, with many card games: bridge, poker, etc. In other cases, chess, for example, the element of chance is almost entirely eliminated.

The interest in the study of games goes far beyond their entertainment value. Strategic games give us models which we can sometimes transpose into biological or social terms. It was a problem of economic measurement which furnished von Neumann with the occasion for beginning his research. The systematic study of poker—or rather of another game which is a little simpler, but very much like it—showed that it is possible in certain cases to deduce mathematically the element of bluff. This form of behavior, by its very nature, might have seemed beyond mathematical deduction. It is quite possible that the studies undertaken with the aim of constructing a chess-playing machine are being kept secret for military reasons.

The strategic games which it is easiest to study, because they are the simplest, are two-player games, or "duels." Von Neumann and Morgenstern call them "Zero-Sum Two Persons Games," games in which the losses of one player are exactly made up by the gains of the other. If each of the two players was capable of imagining all the variants possible on the basis of his position, he might discover whether or not there existed a line

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[15] We should, however, cite Emile Borel in one field, and Bascal and Edgar Allan Poe (apropos of games) in another; and also Buffon, Condorcet, Poisson, and Cournot in connection with the probabilistic study of judicial decisions, electoral laws, commercial competition, etc. As early as 1928, von Neumann demonstrated a theorem into which enters the notion of "ruse."

which would lead him to win (or at least make the game come out in a draw), no matter how his adversary countered his plays. Such a line is called a "strategy." To play is to choose a strategy.

In a thesis presented in 1952, entitled *Theorie des Jeux alternatifs,* Claude Berge showed that the search for a strategy is closely connected with the algebraic theory of the semi-lattice.[16] The theory of alternative games may be applied to the pistol duel, in which the two adversaries walk toward each other, each having to decide at each moment whether he will fire in order to try to hit his opponent first, or whether he will wait till he comes closer in order to be surer of making a hit. The same dilemma presents itself in airplane encounters. In certain cases and within certain intervals the theory may lead a strategist to disregard the pilot's psychology and allow machines which choose at random to decide at what distance the planes should open fire on their opponents.

The case of more than two players is much more difficult to analyze, since coalitions are possible.

Without going further into the examination of the theory of strategic games, we should note that this theory has now been related to the theory of communications. In his 1952 thesis, *Theorie mathematique des Communications,* Benoît Mandelbrot had the perspicacious notion of considering the theory of communications—and in particular the theory of language—as a game with three players. These three players are the emitter, nature and the receiver. Their roles and the aims they propose to attain are not symmetrical (a situation unlike that found in many games). The emitter and the receiver form a coalition against nature. Nature seeks to falsify the messages sent between the two other players: she introduces noise. Note the complexity of this analysis. In the beginning of this study we called attention to the diversity of the definitions of the notion of information. In the case which concerns us here, nature is capable, by making noise, of altering Fisherian information; selective information, on the other hand, continues to go through. Furthermore, nature can be considered a player only within certain limits.

That is not all. Having succeeded in giving the theory of communications a place in the theory of games, Mandelbrot proposes to show how, understood in this context, the theory of communications can be broken down into three games for which there are three corresponding theories:

The game between the emitter and nature characterizes thermody-

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[16] A semi-lattice is an ordered group—that is to say, a collection of elements in which a (partial) relation of order can be defined—in which there exists an operation by which a third element can be associated with any two elements.

namics. A steam engine "plays" a game between heat and work, with nature intervening to lower the output.

The theory of decoding—which covers the deciphering of secret writing as well as that of dead languages—is a game between nature and the receiver.

The use of language is a game between the emitter and the receiver. In a well-constructed language the emitter and the receiver cooperate, so that the information is transmitted at the lowest price. Statistics applied to languages confirm this. The point is taken up in a very original work by K. Zipf, *Human Behaviour* (1949), which might well serve as an interesting basis for a further study.

Besides Mandelbrot's work, other attempts have been made to connect the theory of strategic games with that of information. A. Wald has studied a game which opposes the statistician to nature and tries to find models in it for his theory of induction.

IX. *Cybernetics and Life*

The old attempts to work out mechanico-physico-chemical explanations of life were hampered by the lack of complexity and finesse in the classical machines. The new mechanisms, with a far greater wealth of coded information in their structure, equipped with various means of control, capable even of comparing strategies, thanks to electronically computed calculations, have considerably narrowed the gap. The striking contrast between living and inanimate matter; the numerous regulating processes which maintain the internal equilibrium of organisms; the processes of perception and motor coordination which assure the extent and effectiveness of our action on the outside world; the mechanisms of consciousness, memory and reasoning which preside over the most complex operations of thought; the laws of spoken and written language which so strongly condition our social relations—all these phenomena can from now on be advantageously interpreted in terms of cybernetics. One may describe them as actions; these actions may in turn be symbolized by calculations (Ashby, 1947); these calculations may be reduced to fundamental groups of operations (Turing, 1936); and these last may all be realized by machines.[17] In this second part of our study we shall limit ourselves to four examples.

[17] In some of these problems, the penetration of biology by the exact sciences is illustrated by the complementary character of the specialists who collaborate in the same research. Thus it was a mathematician, Norbert Wiener, who first advanced the hypothesis that if the organism uses negative feedbacks we should expect to find pathological troubles with oscillat-

To begin with, the theory of information permits us to consider, from a suggestive angle, the problem of living matter, or more exactly, the problem of the way in which its functional properties are linked to its structure. The explanation of the mystery probably lies in the very great quantity of information which might be said to be inscribed—coded—in the architecture of living matter. According to this hypothesis, all living matter would contain a very elaborate "taping" (or set of prescribed regulations) which would prevent it in a great many cases from behaving with the sort of indifference which governs physico-chemical phenomena. Hence this appearance of finality which impresses so many metaphysicians. But is not a record—a simple musical record, which succeeds in inscribing in the variations of its sound-track all the magic and individuality of Vivaldi or Alban Berg—already a very impressive object? Furthermore, the fact of giving forth order, that is to say, of producing a negative entropy, would not contradict (let us avoid mystical reveries here!) the Second Law of Thermodynamics, which says that the entropy in an isolated system tends to increase. For life is not a closed system; it is open on an environment, and it remains subject to Carnot's inviolable law, by paying to the surrounding inanimate world, with which it carries on exchanges of energy, this negative entropy which, to use Schrödinger's expression, "it feeds on," and which, as we first become aware of it, strikes us with wonder.

The mere concept of a "taping" may clear up more than one enigma in biology. There would be no need, for example, to have recourse to a naïve theory of incasement of germs to explain how the development of a many-celled organism may be partly determined in advance by the genes of a single initial cell.

Not only the notion of taping, but also those of the feedback, of reverberating circuits, and of other auxiliaries of servo-mechanisms may render great services in physiology.

Neither the neurophysiologists nor even the man in the street waited for the theory of communications to speak of "blocks," or "switches" (in the case of the scientist), or of "having self-control" or "losing track" (in the

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ing structures, and who, applying Van der Pol's calculations, predicted their forms. It was a physiologist, Rosenblueth, who discovered them experimentally; they are the clonic spasms of stretched muscles or the ataxias of the cerebellum. Cooperation of the same type associates mathematician W. Pitts with the neuro-physiologist W. MacCullough. At times, a single scientist combines fields of competence that are usually separated. W. R. Ashby, a psychiatrist by profession, handles figures with talent. All those who have met Norbert Wiener have been astounded by the versatility of his culture.

case of the man in the street). On the other hand, technicians of servomechanisms or electronic calculating machines use terms like "post-mortem diagnosis" or "frog-jump test" when discussing breakdowns or characteristics of these machines. Can we find—if they exist—the mechanisms that are probably hidden behind these images? It seems likely, since N. Rashevsky—to whom we owe some original insights in mathematical biophysics—showed in 1938 that abstract models of electronic circuits can manifest certain properties of nerve circuits.[18] Furthermore, it may not be suitable to express all these problems in purely spatial terms. In 1906 Sherrington formulated the hypothesis that "Pure conjunction in time, without there being necessarily a cerebral conjunction in space, is at the base of the solution of the problem of the unity of the mind." The hypothesis is still valid and can surely be extended to other mechanisms.

Another question arises, that of memory—I mean animal and human memory. Is it static or dynamic, or does it belong to another order of things?

It is hardly probable that our memory is static. It has been calculated that if our brain had a "catalogue of perforated proteins" which it consulted by scanning, it would work 10^{13} times more slowly than it does in reality. We cannot guarantee this calculation, but it seems probable. And then there is the well-known fact that the loss of a very great quantity of brain matter does not necessarily result in a great loss of memory.

The thesis of a dynamic memory is certainly more attractive. Advanced in 1929 by Alexander Forbes and in 1930 by S. W. Ranson and J. C. Hinsey, it is defended with virtuosity by Lorente de No and von Foerster. The non-punctual *Jetzt*, or specious time of the psychologists—the time during which one retains a part of the past and considers it as the present—suggests a dynamic memory far more than a static one.[19] However, recent experiments show that the question is not yet solved. Animals have been chilled to temperatures which are considered far below those that could be withstood by neuronic reverberating circuits, and, after they are returned to normal temperature (when these circuits should have been destroyed), the memory remains. The problem of explaining the phenomenon of

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[18] These comparisons have been pursued by Warren MacCullough, who established them on probabilistic bases.

[19] According to MacKay (1950), the sensation of the passage of time may be nothing more than the appreciation of the greater or smaller flow of information that penetrates our consciousness in practically continuous fashion. As François showed in 1927, this sensation is linked with the temperature of the body; and, according to Hoagland, the latter regulates the rate of oxidation of certain glucides in the brain.

memory thus remains open, but there is no doubt that cybernetics has shed fresh light on it.

The same thing is true of the problem of form—Gestalt.

How does it happen that we recognize an object by its form, independently of its position (which alters the appearance of the form) or of its dimensions? Similarly, how do we recognize the voice of a friend? Such a phenomenon obviously depends on the comparison which we establish between the information furnished by the object at the moment we are looking at it, or by the voice at the moment we hear it, and information which has previously reached us from the same source and been stored up in reserve. But a purely analytical comparison is not enough to explain the phenomenon of recognition; to account for it one must admit that it is possible to describe a structure in terms of information.

In demonstrating the possibility of this translation—which in 1947 W. Pitts and W. MacCullough related to the invariability of the behavior of a mechanism toward a particular transformation group[20]—cybernetics has extended to machines a privilege which might have been thought to be a monopoly of life. Certainly most of the Gestalt devices, like the automatic readers (machines for reading a written text aloud) and the automatic stenographers (machines for writing a spoken text) are still in the projected stage, and it would be vain to expect that mechanical perception will quickly reach human finesse. But machines can be envisaged, even now, which would be capable of recognizing structures that man is powerless to discern—for example, spatial structures having more than three dimensions, or topological structures. These machines will be, from the very beginning, superior to man.

The apprehension of meanings—a continuation of the recognition of structures—and, beyond that, the phenomenon of consciousness, which crown the edifice of psychology[21]—are they to be considered as nervous integrations in which all the preceding notions play a role? How many of us answer this question with assurance, revealing thereby a belief in some philosophical position whose truth remains to be demonstrated! Science alone—which pronounces only on that which knows—remains mute on

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[20] "Transformation groups" are mathematical notions which play an important role in many natural phenomena.

[21] We do not assume in any way, here, a substantial existence of the consciousness. If we suppose that consciousness is only an "illusion" which should not be taken into consideration in building an objective psychology—as certain of the behaviorists believe—then this appearance nevertheless requires an explanation. Optical illusions have a real existence, as illusions, just as do erroneous beliefs.

this subject. Nevertheless, the assimilation of thought to a complex nervous phenomenon seems, without a doubt, to constitute the best working hypothesis. How, for example, can one fail to be impressed by the correlation which appears to exist between the rhythms of electrocerebral waves and the time needed for the establishment of states of consciousness?

X. *Reasoning Machines, Playing Machines, Machines That Reproduce Themselves*

There is no space in this article to study the relations among cybernetics, phonology and linguistics. They involve the important notions of redundancy, frequency and continuity, and—though "Markhovian machines" capable of writing "mechanical novels" have not yet made their appearance—they have already led to some remarkable achievements, such as Audrey (the telephone which forms the number pronounced in front of it without the user's having to touch the call dial), the Vocoder and the Voder (which permit the reconstitution of the human voice) and the Automatic Translator (of which some, like the I.B.M. 701, have been in use for more than a year and are already much more than automatic dictionaries, since they take grammatical structure into account).

Nor shall we discuss here the modern numerical or analogical calculating machines. They belong to a specialized field, in general better known. Though based on similar principles, the reasoning machines are more interesting because their accomplishments are less specialized.

MacCallum and Smith's logical machine (1951) can combine seven different variables through the use of six logical relations: "not," "and," "or," "or else," "if, and only if," "if then"—which permits it to consider 128 possibilities. Here is an example of the type of reasoning which it can carry through:

"It is known that merchants always tell the truth and engineers always lie. G and E are merchants. E says that D is an engineer. A declares that B affirms that C states that D says that E emphasizes the fact that F denies that G is a merchant. If A is an engineer, how many engineers are there among the other persons mentioned?"

Such machines have already gone beyond the purely theoretical interest of logicians' games. They can facilitate the establishment of insurance contracts containing special clauses involving risk of litigation.

The battery of playing machines—which only a few years ago was limited to the automatic chess player invented by Torres y Quevedo and capable only of checkmating by King and Castle an opposing isolated

King—is being enlarged every year. The field of the newcomers extends from geometric or logical structures to purely psychological games.

At the British Festival of 1951, visitors to the Science Hall could—without the slightest chance of success, unless they played first—play a game of Nim against a machine called Nimrod, constructed by the Ferranti firm. Despite the simplicity of its rules, the game of Nim has close analogies with the laws governing the economy of a country which is neither entirely under the regime of monopolies nor entirely under that of free trade.

We have already mentioned chess-playing machines. Two different types may be envisioned. The first type would be capable of calculating all the possible lines of play in any position and would thus be infallible; its theory has not yet been worked out. The other would decide what plays to make after having analyzed each position with the aid of criteria representing the quintessence of principles already known; without pretending to be infallible, these machines—which would not be subject to fatigue—could obtain excellent results against very good players. This is the type to which Strachey's checker-playing machine belongs. While it is inferior to a world champion, it considerably outstrips the average player.

Independently of each other, D. W. Hagerbarger and C. E. Shannon have both built machines capable of playing a game whose content is identical to the game of "Even or Odd" which forms the subject of some penetrating pages by Edgar Allan Poe.

These machines begin by playing at random; they answer a human opponent's "questions" haphazardly, and when it is their turn to ask "questions," they ask them haphazardly, too. But at the same time that they give their random answers, they register the questions and answers of their opponent. When they have accumulated enough of these questions and answers, they analyze the group; they pick out the frequencies and the arrangements which chance could not explain and which obviously define the player's psychology. From this point on, the machine has only to extrapolate the series of preceding questions and deduce therefrom the question to put or the answer to give, with a certain probability of success.

Of course an ingenious player may try to "deceive" the machine by changing tactics from time to time. Since they are based exclusively on the tactics of the preceding plays, the machine's extrapolations will lead it into error. But it will soon take into account this new line of action and deduce therefrom its opponent's aptitude for changing tactics. This aptitude cannot be infinitely free. A moment will come when the machine, basing its calculations on a sufficient number of plays, will deduce a deep and unchangeable structure behind them and will certainly win the majority of the games. Already these machines win fifty-five or sixty per cent of the games.

The best tactics for a human player would obviously be to put his psychological tendencies aside and play at random. But such tactics can only be theoretical. It is impossible for an intelligent being, charged with negative entropy, to imitate chance perfectly.

If all the necessary materials were placed within their reach, self-reproducing machines ought to be able to sort the materials and build out of them machines like themselves, which in turn would repeat the same operation until the materials were exhausted. This is a chapter of technology which still belongs, if not to the field of science fiction, at least to that of pure speculation. But can one treat speculations lightly when they originate with a von Neumann, a Shannon or a Wiener?

In 1952 J. von Neumann imagined two different models of such machines. The first has some analogy with the mode of reproduction of crystals and genes; the second has a resemblance to the process of animal reproduction on a large scale. Von Neumann showed that such machines could not be built below a certain degree of complexity, involving a minimum of about ten thousand elements.

There is no doubt that the prospects we have just discussed are rich in promise. But we must not be dazzled by the luxury of this modern Circe or—above all—fall into the temptation of confusing analogies, or sometimes even metaphors, with real identity of form. The attitude taken toward this precaution draws the chief boundary line between positive science and occultism. We should remember in particular, as Professor Fessard cautions us, that "*the constitutive element of the nerve machine, the neuron, has a life of its own which must not be forgotten.*" Let us then avoid the exaggerations of those in whose eyes cybernetics—the "cream puff of contemporary science"—should assume the chief responsibility in the renewal of industry, biology, psychology or sociology, and maybe even of politics! Brilliant as its recent performances are, it is hard to see how they could fulfill such vast ambitions.

On the other hand, we should not go to the other extreme. If we consider only the field of physiology, such work as was done in Canada in 1953 at the symposium on "Cerebral mechanisms and phenomena of the consciousness," held under the auspices of UNESCO and the World

Health Organization, show indisputably the clarifying power of cybernetics when it is handled by real scholars. There is a reasonable course between pretension and denial.

The interest of the theory of communications—and of its interpretation in the theory of strategic games—lies in the fact that it is mathematized, formalized and related to energetics. This is largely due to its having developed out of the work of telephone and radio engineers. For biologists and psychologists it has a solid base, solid but narrow. Their problem is to broaden it without weakening it, to extend it to their own fields without a loss of validity. How far is this possible? Cybernetics is not the philosopher's stone of the alchemists. However, in the labyrinths where so many researchers wander, there are some doors that it would be highly desirable to open and to which the theory of communications and strategic games may furnish the key. The "open sesame" may be found in tomorrow's experiments and research.