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CYBERNETICS AS A DISCIPLINE AND AN INTERDISCIPLINE

DEFINITIONS

There are various ways of defining cybernetics. (1) Some recognize it in the so-called problems of information, when they are concerned with the transmission, elaboration and conservation of information. (2) Some consider it as the science of command and control in machines and in animals. (3) Some refer to it in studying the two aspects of automatism. (4) Finally some see in cybernetics the study not so much of the mechanisms which provide results that were previously provided by man, but rather of the superior and intelligent activities of men themselves, in order to analyse and describe them in terms which make possible their reproduction in a mechanical model; cybernetics being in this case the study of the mind.

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THE OLD AND THE NEW THEORIES

What therefore is old and what is new in this field of science, and where does the unity in cybernetical research come from? Man has always tried to alleviate his efforts by using the strength of animals and inventing machinery. But during previous centuries the main concern was to relieve man from his meaner tasks, from physical exertion. The case of Blaise Pascal who in 1642 built the first adding-machine in order to help his father, who was a tax collector, with his accounts, is an exception. Yet in our century attempts are made to diminish length and boredom which is usually inherent in man's tasks, even if they are not strenuous, such as cooking, peeling potatoes, separating objects according to size, colour, shape, etc., washing or dishwashing, etc. People have gradually become convinced that a great part of human work, whether it be physical or mental, which is in any way regular and recurrent, can and should be done by machine. This leaves us more time to dedicate to the things that interest and appeal to us more personally, and also it ensures that we do not lose a large part of what is produced. Let us give an example. Every year tens of thousands of books and cultural magazines are published throughout the world; many of the subjects they deal with would interest us; but how can we know where to find them and understand their contents, particularly if they are written in a language unknown to us. They have to be summarized, classified, etc., and translated. Now, it is a well-known fact that the number of people who are capable of this work is decreasing considerably; and in this case the cybernetician will undertake the task of inventing a machine that will translate and summarize. Of old, the aim of cybernetics was to help man with his work; nowadays it has acquired a new meaning, in that it is not only concerned with physical work, but also with mental and intelligent work.

The common denominator between cybernetics (2) taken as the science of command and control, or (3) cybernetics as the science of automation, and the conditions necessary for the construction of a model of the mind, or (4) cybernetics as the study of the so-called superior human activities, this common denominator is easily found.

In order to do so it is only necessary to recall to mind what is usually meant by command and control. When you give an order you expect it to be carried out: (*a*) that the obstacles which may possibly occur be overcome and (*b*) the possible mistakes corrected. If for instance a man has to go somewhere and finds the usual way blocked, he will look for another and if he reaches a place other than the one he wanted he will walk on, etc. But until recently there were very few machines which had this ability. There were mechanisms built to perform such or such an operation and that was all. Thus, there was a machine which fired at enemy planes but if it missed the target, the projectile was lost. But is it not possible to give the projectile a mechanism that will direct its course towards another target? In the loom the shuttle guides the thread into the warp; when the thread runs out the machine perceives it and replaces the shuttle at the right moment.

Automation, automatic and other similar words mean simply that a certain action which was previously accomplished by man, sometimes with the help of a machine, is now accomplished by a machine alone. Thus in motorcars, the engine supplies the movement and generates a certain power, but it does not take into account the incline of the ground. This is the reason for the gearbox, which is manipulated by man. But it is possible to provide the motorcar with a device that will take into account the incline of the road and the effort necessary for the engine to overcome it; this is the automatic gearbox. Whereas one never talks of an automatic differential because, apart from a few exceptions, motorcars have always possessed one from the start of the history of the automobile, and in any case man has never himself seen to it that the rotation speed of the wheels be different in curves.

Now, the man who has a purpose, who sets himself an object and pursues it, and rectifies his conduct if he realizes that he has made a mistake, the man who regulates his behaviour on circumstances, is a man who works with his head, who thinks and is endowed with intelligence. Therefore, even if we do not quite reach the case of cybernetics No. 4, which is the deliberate study of mental activity, one can say that case No. 2, which is the study of the process of command and control and case No. 3, which

is the study of automation, have already one thing in common: the attention given either to a live being, man in particular, to observe its activity, or to a machine to make it according to its image and resemblance.

To place cybernetics in the range of a human-mechanical science when it is taken as the study of transmission, elaboration and conservation of information, would seem slightly exaggerated. One could in fact merely consider the field and interests it covers as a part of accoustics and study for instance the fact that the alteration in sound which is perceptible at a certain place is not felt at a certain distance, in this case losing its use as a symbol, signal or word. This concerns in fact the linguistic aspect of this science, not the one we are dealing with at present. This may not have been clear enough from the start to pause on the linguistic aspect in our physical and mathematical investigations. What is more one should remember that often the bond between man and machine, which makes them complementary, is secured by the reading of an indication made by man on the dial of the machine, that is to a relationship between the sign perceived and the action performed which is therefore determined by convention, the basis of semantics. Thus, even when a purely mechanical connection replaces man's, there remains the trace of the first one. This does not however explain the fact that so many of the connections between organs, whether of a machine or of a live being, are regarded and described in terms of information. I think that it is not difficult to interpret this labelling as a weakness, a very human weakness indeed, on the part of cyberneticians, who attribute to their constructions an intelligence which sets off their own and which would not appear if they confined themselves to speaking of mechanical connections or relationships of cause and effect, of very general application.

SUBSTANTIAL ANALOGIES

After this brief investigation we have a definition of cybernetics which draws a close connection between man and machine or between machine and man, either in view of relieving him from his most arduous tasks, including mental ones, or else thanks to analogies of "functioning" which have been discovered in

living beings and transferred to machines, analogies which cyberneticians do not hesitate to consider substantial. Well, as regards the first aspect of cybernetics, the economic and practical aspect, I entirely agree with the definition and I hope that machines will always be there, faithful, industrious and in increasing number, to lighten the burden of our most monotonous and degrading tasks. But as regards the second aspect, which theoretically applies to man, I think one should be extremely careful, in order not to impair this new science and the study of man itself, by mistaking "substantial analogies" with "substantial confusions."

I will explain this point. Human beings are continually using mental "categories," such as finality, regulation or semantics. At all moments they determine to do something and act consequently. For instance one says: "I am going out to buy some cigarettes" or "to have a drink." We regulate our actions and say for instance "I would like to eat more but I must refrain otherwise I shall put on weight" etc... The fact of going out is not a means in itself; buying cigarettes or having a drink are not an end in themselves; and eating a certain number of calories is not in itself a regulatory or regulated process. These actions become so because we establish this particular relationship between them. This is true in the case of actions as in the case of non-actions. By employing the category of finality we transform legs from simple anatomical parts into a "means" of walking; with the category of regulation we transform simple pieces of metal, such as balls, levers, valves, into a "regulator" and "regulated organ;" with the category of semantics or information a whistle, which is a simple acoustical phenomenon, becomes a "signal" and the approach of a train becomes, from a simple optical phenomenon, a significant event.

Precisely because mental categories are means of considering things and of establishing a connection between them, one cannot find in them the properties which can be found in things, such as colour, consistence, flavour, etc., even after the most subtle chemical or physical analysis. They can indeed be observed, but only as functions in the brain of the person who uses them, provided that he uses an appropriate technique, which at the moment does not exist. And they can be discovered if one looks

on them as operations carried out by ourselves and keeps one's attention on them while carrying them out, by singling them out and analysing them.

The knowledge of these operations has always been rather restricted, even among those who should have been interested in them by their profession, namely philosophers. The latter either considered them as "properties" which could be deduced from existing beings by abstraction, or attributed them indiscriminately to a spiritual Maker, like everything else; or, like Kant for instance, they ascribed to some of them a special state, but as entities and not as operations. It is not surprising, therefore, if the cybernetician is convinced of finding them, where he in fact places them, whether it is in living beings or in machines, convinced even that the finality with which he has built his machine has become the finality of the machine itself. As long as the mechanism is so simple that it can hardly be considered a mechanism, it is difficult to be misled, for the deception is obvious; but as soon as it becomes more complicated the temptation becomes greater. Thus one talks about an "intelligent" machine in the case of a projectile which, if it first misses the target "perceives the error and alters its course so as to hit a second time," whereas up to now I do not think that anybody, among us at any rate, has ever talked in such a way about the boomerang, which faithfully and economically comes back to the hunter who threw it, if it has not hit its target. Even the most fervent believers in this form of cybernetics and "intelligent" machines would smile at that.

THE MOST IMPORTANT CHAPTER OF CYBERNETICS

It follows that the most important chapter of cybernetics, if the latter really aims at approximating the machine to man and obtaining from the machine what is obtainable from man, is the study of man, of his superior and intelligent activities of thought, in order that the label of intelligent might be attributed to machines without making an error of vocabulary.

However, as I have pointed out, one could not turn to the people who one could have supposed would have a ready answer, that is philosophers or psychologists; one must find it for oneself

and prepare oneself to study this problem as if it were a new one. Even those who are not particularly familiar with the traditional researches on the human mind, on the problems of thought and language, of perception and representation, of memory and others, know that the descriptions they contain are always full of irreducibly metaphorical and useless expressions which are the basis of their construction and recognition, but are utterly unnecessary. To seek a definition of thought or language in Plato, in Aristotle, in Berkeley or in Kant, in Hegel or in Croce, which would give an idea of what a thinking and talking machine could be, or of how and where one should study the human brain, would be a waste of time. I think it is possible to state the reasons for the inconclusiveness of philosophy in regard to a technique of observation and construction; actually philosophers and psychologists are the first to admit it although they try to defend and justify themselves.

Why not then turn to the anatomists and physiologists of the nervous system? Unfortunately the situation on this point is not any better in these fields of science, even if it is somewhat more clear. In fact although neurophysiology has recently been boasting of great progress in this direction, one knows practically nothing of the relationship between the brain and intellectual activities.

The cybernetician must therefore do everything alone, or almost, even though in order to do that he will have to use all that can offer him knowledge, collaboration and criticism of former mistakes. However he possesses something important, the requirements of a constructor of models, which are the requirements of the machines themselves so to speak. This is an utterly new dimension compared with the philosophical view, and with these requirements he carries the possibility of testing his assertions, which is the sign of integrity in any technique.

Let us see what these requirements are. A monument is built with physical materials, stone, bronze, etc. But it would be a mistake to restrict a machine to these. A machine is also made of physical components, copper, glass, etc., but in a machine these components function, they become organs and unfold such or such an activity. Although they are physical in that they are made of copper or glass, their activity is not physical for an activity does not take up room, does not weigh anything, does not have

a colour, and so on. Without going as far as thinking, let us take the example of eating: the plate, the mouthful, the fork, the mouth, the throat, are all physical, but not the act of eating. On investigating however what can be expected from a machine, and what operations it can perform with its various organs, one finds that in all cases there is a change of position or condition or shape in the physical components which form these organs. In a motor car's engine, a lighter, a sewing-machine, a model of the brain and even the human organism, nothing can be seen of the functioning or the various organs, apart from one of these alterations of the physical components.

This gives us a clearer idea of the task of cybernetics. If the aim is only to copy the heart or the lungs one can find a description of them with their various components and transformations in books on anatomy and physiology, and thus artificial hearts, artificial lungs, etc., are already accomplished work; but if one intends to copy the brain and its activity of thought, the first step to take is to obtain such a description of thought and its contents, of language, perception, representation and categories of the mind. Only then can the physician, the chemist, the mathematician and in the end the engineer, the metal founder, etc., play their part.

These studies of the mind are the testing field of the new science, before any intervention of the engineer.

RESULT MISTAKEN FOR OPERATION

These studies will enable the cybernetician to beware of one of the mistakes which is most commonly made today: that is the confusion between the operation due to which the required result is obtained and the human activity which provides not only this particular result itself but the whole chain of results connected with it.

Let us suppose that we have drawn up a list containing a certain number of results obtained by performing operations on certain data. A simple process of substitution will enable the machine to give out those results, once it has been supplied with the data. For instance, if the list contains among a certain number of multiplications the figures $3 \times 5 = 15$, the machine will

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substitute the figure 15 for 3×5. But is it right to consider and designate the action of the machine as a multiplication, and to believe that a multiplicating machine has been invented? The faultiness of this belief immediately appears if one asks a similar machine to multiply something which the person who drew up the chart has already multiplied. Fortunately computers are not built like that!

This is however the method of the machine which calculates chess moves by repeating such and such a move which has been previously carried out in a famous tournament and had been registered by its memory. Do not the chess players also play thus, by repeating unknowingly the moves of former players?

This mistake has proved to be the source of unfortunate consequences in two of the fields recently explored by cybernetics: mechanical translation and summarizing. This should not come as a surprise since in this case no less than thought and language come into play for the understanding of a text, that is to say precisely the human activities which, according to philosophers, psychologists, physiologists and anatomists bring us into the realm of mystery. To image the mechanization of a bi-lingual dictionary is indeed easy, but it is not at all easy to construct it in actual fact. In the case of a mechanized "Italian-English" dictionary, when faced with sign "cane" the machine will replace it with the sign "dog," thus producing the same result as the most perfect translator. But can one say for all that that a translating machine has been constructed? Of course, as long as one does not know how a translator operates, this is possible; and it has happened even in the most cultured nations. The situation becomes even more confusing when the traditional bi-lingual dictionary is replaced by another which contains eiter additions in both languages already translated, such as forms of verbs, nouns and adjectives, or a certain number of expressions. The result can be correct, with forms not only such as "il," "cane," but also "corre" which the machine replaces by "the," "dog," "runs," and not only such as "il cane corre," but also such as "il cane nero corre," if the inverted form of the words "black dog" has already been supplied to the machine for the sign "cane nero." But does man translate in this way? Does he not first translate thanks to a general idea suggested to him by

the text, a general understanding of the text? The faultiness of this theory clearly appears moreover when the machine is requested to translate a succession of signs which have not previously been translated by man, or for which the two languages do not have the same solution in the organisation and number of words used. Indeed some more complicated solutions have been propounded recently, with classifications of words, in nouns and verbs, articles, adjectives, abstract and concrete adjective, live and inanimate beings, etc. But the principle remains unchanged and this substitution process on given data has very little to do with the action of the person who reads or listens, understands and then only translates. In these conditions it would have been better to talk of a mechanization of dictionaries rather than a mechanization of translating. But then what would have become of the constructor's prestige and the excitement and magic of cybernetics?

Of course, however short the history of cybernetics may be, it is not reduced to that; and even when it is, it has the merit of having promoted a series of researches, such as those on "intelligent" chess-playing machines, which would have otherwise been quite unthinkable; they were certainly unthinkable as long as research could be content with the drafting of a beautiful book.

To the people to whom Norbert Wiener gave the name of cyberneticians in 1947 we are indebted for some designs, interesting works and above all suggestions which are worthy of note. In the years just before the war the mathematician Wiener met the neurophysiologist Rosenblueth and another mathematician called Begelow: they had the task of supplying anti-aircraft artillery with an automatic system of firing, taking into account the possibilities of the marksmen as well as the pilot and their reactions. Their plan was never carried out but they published several documents.

In 1943 the mathematician Pitts and the psychiatrist McCulloch resolved to start a biological, physical and mathematical study on the neurons. In 1949 they also put forward a project aiming at translating the written alphabet into sounds for blind people. They had to find the varying and unvarying elements of the various typographical elements. The biologist von Bunin is not far

from their work. In 1948 Malvoisin studied the same problem. Since that time there have been dozens of projects for an "automatic reader," and although somewhat limited, some are already in use.

Since then the number of publications, books and congress reports can no longer be counted. The most important aspect of this production is the manifold competence it requires, the at least twofold interest present in the single investigator, and in all cases the meeting of specialists belonging to various disciplines: experts on computers and neurophysiologists, psychiatrists and biologists, mathematicians and linguists and so on. If there is one "interdisciplinary discipline," it is cybernetics.

All this does not however, in the light of our previous discussions, prevent the mechanisms which have been constructed or planned up to now and above all the labels that have been given them from being extremely questionable. G. Walter's famous "tortoises" which reacted to external stimulations such as light, or internal ones such as the auto-charge and discharge of their batteries, were supposed to solve the problem of free will; Ashby's homeostat, which maintaned a predetermined balance notwithstanding a change of both external and internal conditions, was for that reason called a "brain." Dubrocq's apparatus which aligns words according to "hazard cells" is presented as an electronic poet, and so forth; these cannot fail to rouse suspicion unless they simply make one smile.

But it can also happen that the allusive label brings harm to a research which tries to progress against great difficulties by giving the impression that some problems have been solved which in actual fact have not even yet been set in terms of solvability. This can have unpleasant economic consequences, since it can lead to important investments on projects which are destined to abort very quickly, without any prospect of renewal or continuation. Lastly, after the initial surprise, it brings discredit and judgments of superficiality, amateurism and ignorance on the cyberneticians, and consequently on cybernetics itself.

I should like to illustrate this criticism with an example taken from cybernetics. There is nothing to prevent one from imagining a solution for the construction of an automatic reading machine,

that is to say a machine which recognizes signs notwithstanding their typographical variations and which when in front of a sign such as the letter "el" for instance, which is always an "el" whether it is written "l" or "L," whether it is written in point eight or in point ten, recognizes it as such. The problem is precisely to find the characteristic elements of the signs which we call "el" from all the other letters of the alphabet and which are common to all "els." Whoever succeeds in obtaining this result from a mechanism combining security, speed and economy, is very welcome. But what should one think of an investigator who presents his research as the solution to the metaphysical problem of abstraction, that of Socrates and Plato, and who after identifying this abstraction with human intelligence, goes as far as to call his machine an "intelligence machine"? One would say that this investigator has never read Plato's Dialogues, for otherwise he would know that the problem of ideas, concepts and universality, does not consist, for the philosopher, in finding himself from the start in front of a certain number of things which our human understanding recognizes as belonging to a certain category but, first of all, in explaining this recognition and this designation. One can of course discuss the philosophical problem, its conjecture, its formulation and its various solutions, but one cannot assert triumphantly that it has been solved after having in fact dealt with another. As for human intelligence, although it can be defined as the capacity of establishing relationships, it is in fact more inclined to establish new ones rather than to repeat relationships which have already been established.

PRESENT RESEARCH AT THE CENTER OF CYBERNETICS AND LINGUISTIC ACTIVITIES OF MILAN UNIVERSITY AND THE NATIONAL RESEARCH COUNCIL

Eight years ago Professor E. Maretti and I constructed a mechanical models showing the mental processes. This model was known originally as "Adam II." This experience together with my membership in the Center of Cybernetics and Linguistic Activities, established six years ago at Milan University, and above all as director of a research group in cybernetics working for the

National Research Council, qualifies me, I believe, to speak as a cybernetician and to make a few specific suggestions.

The criticisms set forth until now call for a statement: each time we talk of models and each time we use labels taken from any human activity to designate our projects and achievements, we do so because these results were obtained thanks to our utmost efforts to understand the processes of these activities. The isolation, the analysis and the description of the activity can be mistaken and indeed at present they are still insufficient, but one never starts from the process discovered for a particular result, to call into cause one of our so-called superior or intelligent activities. This is what happened in the case of mental categories, of observation, perception, or representation, of thought and language, of behavior, etc.

I will not here give an exhaustive account of these studies, I will only touch on them as concisely as possible.

The line followed was mainly that of language. We wondered which operations correspond, as named objects, to linguistic expressions, single words, parts of words or groups of words. This investigation, which has been going on for twenty years, has had the result of enabling us to find an operative counterpart to speech, to which there can correspond in a machine the changes of position, state and shape which we have previously seen.

I would like to point out that at the basis of this operative counterpart is a process of differentiation, which we call primary differentiation, since this process does not need anything, nor the help of any other activity, to work in the machine, that is to say, to be among the activities which constitute thought and its components. From this differentiation spring attention and its opposite, inattention, consciousness and unconsciousness, and generally presence and absence.

This of course concerns the attention before it has been focalized, the state brought on in someone by saying, for instance, "be careful," "look out" and so on.

There is a difference between this and the other differentiating organs of machines or animals, such as, for instance, the small metal plate inside a machine which by vibrating or not vibrating allows it to express "noise" or "silence;" the difference is this:

in the first case the attentional organ is sufficient for the attention or inattention, whereas in the others the functioning of the former has to be coupled with that of the latter.

Attention can combine in two ways, either with itself, that is to say with other attentional states, or as we previously said, with other functions.

When it combines with itself, the operation produces mental categories; for instance a first attentional state combined with a second attentional state has given the category "thing" (in German "Etwas"); an attentional state combined with the category "thing" and the two of them combined in turn with an attentional state produce the notion of "singular;" the category "thing" combined with an attentional state, and the two of them combined in turn with the category "thing" produce the notion of "plural," and so on. In this chain one can find subject and object, cause and effect, numeration and numbers, the words "and," "or," and "but," the notions of space and time, of dot, line, surface, volume, etc., that is to say the whole world, always perceived as the "logos."

When combining with something else, attention takes on among other things a selective function, by specific or appointed differentiation or by both, and as such it has an isolating function; this allows for the differentiated parts to be combined, with various results, by order of succession and particularity of the differentiated parts, to which is added the resulting particularity of the movements between them. For instance movement between several points gives birth to figurative activity, in its proper sense, and movements between musical notes gives birth to musical figurative activity, figurative taken only partially in a metaphorical sense.

The results of the various operations, whether taken singly or altogether, do not yet constitute thought however. This is realized by a process which gives the results of the various operations a particular temporal order, characteristic of correlation; for this reason one could say that thinking is the process of opening and closing correlations. This temporal order consists in developing a mental "connecting" category in the time necessary for two other activities to succeed one another; by this relationship these two become first and second correlations, while the mental activity of

a double length of time becomes the correlator of the correlation. Through this temporal organisation, each correlation can act in turn as an element in the constitution of a larger correlation, and so on; the result is a network of dozens of correlations which correspond to the normal thinking process of an adult human being.

But in order for thought to be expressed, it has to be coupled with another activity, whose results are directly perceptible; an operation which ensures the link between the activity of thinking and that of language: for each correlation there must be in language at least five indications that can be divided into two groups: three are necessary to designate the three particular things which are in the relation (for instance, "Mario," "Luigi" and "with") and two are necessary to designate the place attributed in the relationship to at least two of these things, the place of the third one being also known thus. These five indications are supplied in all languages, either by sounds, written signs, or gestures, etc., or by the sucessive order given to these. For the most part, a correlation is indicated by two or three words (Mario with Luigi: three words; Mario runs: two words). Sometimes however one single word can convey a whole correlation: "donargli" (to give him) or a small correlational network: "donarglielo" (give it to him).

These principles and results are currently studied at the Center of Cybernetics for various purposes: (1) mechanical translation; (2) mechanical classification; (3) mechanical observation and description; (4) the exchange of information between the investigators at the Center and anatomy and physiology specialists, to control the plausibility of the solutions propounded and to employ these eventually for working purposes.

INTERDISCIPLINE AND DISCIPLINE

During the course of these studies I have become more and more convinced that team work is absolutely necessary in cybernetics. Although one can say that it has only one object, that of realizing a model of the mind, not even the great genius of Leonardo da Vinci would suffice to dominate the immensity of the task. We

must work side by side and realize that the really intelligent attitude to have is to trust the intelligence of our colleagues.

This is why I have said, and written in the title of this article, that cybernetics is an interdiscipline and more still a discipline in the strictest moral sense of the word.

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