HISTORY OF CYBERNETICS

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Summary

The most important initiator of cybernetics was Norbert Wiener (l894–1964) with his book “Cybernetics or Control and Communication in the Animal and the Machine”. The contribution of Warren S. McCulloch (1898–1969) may be compared to that of Wiener. Cybernetics has also had precursors such as A. M. Ampère who introduced the word cybernétique as well as B. Trentowski who did the same in Polish. H. Schmidt, S. Odobleja in the 1930s, and P. Postelnicu in the early 1940s recognized the general importance of the idea of negative feedback.

The basic concepts of cybernetics are negative feedback and information. A famous example of negative feedback is given by Watt’s governor, the purpose of which is to maintain the speed of the wheel of a steam engine, at a given value, despite perturbations. The theory of information, mainly due to Claude E. Shannon, gives a measure of the unexpectedness of a message carried by a signal.

Other traits of cybernetics must be noted, such as the “principle of requisite variety” introduced by W. Ross Ashby. It tells that to efficiently resist a given level of variety of aggressions it is necessary to dispose of a comparable level of variety of opposite

actions. “Second order cybernetics” emphasizes the role of observation played by a cybernetic device which has to perceive in order to adjust its behavior to its aims.

Other theories have connections with cybernetics. The most important of them are: systems theory introduced by L. von Bertalanffy, the synergetics of H. Haken, and the study of dissipative structures promoted by I. Prigogine.

The program proposed by Wiener, not yet fulfilled, concerned many fields of investigation in the worlds of the artificial, of human sciences, and in the symbiosis of man and machine. (See chapter *Cybernetics and the Theory of Knowledge*)

1. Origins of Cybernetics

1.1 Contemporary Initiators

Cybernetics began properly with the publication, in 1948, of a book by Norbert Wiener entitled “Cybernetics or Control and Communication in the Animal and the Machine”. The word cybernetics had been chosen by Wiener, in agreement with other colleagues, from the Ancient Greek *kubernetike*, or the art of steering. Another initiator, almost as important as Wiener, is Warren S. McCulloch who published, in 1943, in collaboration with N. Pitts, an article on logics and the nervous system. The directions of approach of Wiener and McCulloch were different—Wiener saw Leibniz as the historical patron of cybernetics, whereas McCulloch was inspired by Descartes. Wiener’s preference was due to Leibniz’s interest in the construction of a calculating machine, and his attempt to build up a general calculus of logics (calculus ratiocinator). Contrastingly, McCulloch observed that Descartes, in his treatise on man, had introduced negative feedback in his description of how an individual escapes the inconvenience of a fire close to his foot. Incidentally, this would seem to show that it is wrong to see Descartes as a promoter of a reductionism based upon decomposition into material parts. Here the kind of reflex arc seen by Descartes is of a holistic conception. In fact Descartes only recommends decomposition of logical difficulties into parts.

It may be of interest to note that J. von Neumann also had contact with Wiener and McCulloch, mainly in a group sponsored by the Macy Foundation called the Teleological Society, or informally the “Cybernetic Club”, to which H. von Förster also contributed. Other associations also devoted to cybernetics included the Cercle d’Etudes Cybernétiques in France, and the Ratio Club in Great Britain.

Other initiators to be covered in more detail below are Claude E. Shannon and William Ross Ashby. The importance of Shannon, for his essential contribution to communication theory, was recognized by Wiener himself. The eminent role of Ashby had more to do with control seen from the point of view of “requisite variety”. Other contemporary initiators were P. Vendryès, with his early theory of autonomy, S. Odobleja, and P. Postelnicu who understood the general role of retroaction. H. Schmidt also deserves special mention for his introduction of a “general science of regulation loops”, as does J. Lafitte who recognized the interest of what he called “reflex machines”.

1.2 Past Contributors

The importance of older influences must not be overestimated, but Plato, A. M. Ampère, S. Trentowski, and C. Bernard should definitely be mentioned. Plato, in “The Republic” and “Gorgias”, used the metaphor of steering (*kubernetike*) to present the art of government. A. M. Ampère, in the second volume of his essay on the philosophy of science, introduced the word *cybernétique* with the same purpose as Plato. S. Trentowski, in a book on a management, proposed *kibernetiki* as a new Polish word. C. Bernard, in his introduction to experimental medicine, emphasized the role of regulations in the equilibrium of the body, an idea which W. B. Cannon made famous with the concept of homeostasis, also used by P. Vendryès. More precisely, Bernard emphasized the importance of the constancy of the “milieu intérieur” defined by parameters such as blood pressure, temperature, concentration of glucose in blood, and so on, achieved by physiological processes.

2. Basic Concepts

2.1 Foundations

2.1.1 Retroaction

According to the title of Wiener’s most famous book, control and communication play a fundamental role in cybernetics. In this context, control is to be understood mainly as retroactive control, more precisely as negative feedback. As a concept, negative feedback belongs to the twentieth century, but the phenomenon itself can be traced back into antiquity—for example, in the clepsydra water supply, or the regulation of the speed of a mill. In more modern times, Watt’s governor gives an excellent illustration that was carefully studied, from the mathematical point of view, by J.C. Maxwell.

In these regulation problems the purpose is to maintain an essential parameter of a dynamical system at a chosen value. It is a level of water for the clepsydra, a rotation speed for a mill or a steam engine, and a temperature for a thermostat. In the case of the steam engine, when speed rises too high the steam supply is reduced through the classical device of a flywheel acted upon by centrifugal forces. In the general case a comparison is made between the value of the considered parameter and its desired level. The observed gap generates a countermeasure tending to modify the parameter in the desired direction: when the difference is positive it must be decreased, when it is negative it must be increased. The fact that the actual value (output) is compared to the desired value (input) justifies the word feedback, or retroaction. This is said to be negative as it acts to decrease difference between input and output.

In more general cases the purpose of negative feedback is not to maintain (as closely as is possible) the value of a parameter at a chosen level, but to make it follow a given law of evolution despite unforeseen perturbations. In these cases, scalar differential equations give excellent representations of the systems for which criteria of stability have been given. The above considerations may be extended (by generalized negative feedback) to the control of not only a single parameter of a system, but of all the parameters defining its state (see Appendix 1). Results obtained by R. G. Bellman, R. E. Kálmán, and L. S. Pontryagin suggest that perhaps even optimal control (for a given criterion) should be considered.

2.1.2 Information

Aside from control, the other fundamental concept of cybernetics is communication. Communication is closely connected with signal theory—a domain which interested Wiener even before cybernetics. Wiener presented his work in this field in his book on time series, in which he utilizes his previous results on Brownian motion and generalized harmonic analysis. The problem he solves is that of the elimination of noise interfering with a signal, and also of the prediction of future values of this signal. Both elimination and prediction are achieved by the use of a frequency filter set to a given criterion—a solution already foreseen independently by V.A. Kolmogoroff.

Wiener's interest in the study of signals corrupted by noise is justified by the role they play in transmission of data—and more generally, information—from one part of a cybernetic system to another. Claude E. Shannon made a very important advance in this field, considering (as Wiener did) that his purpose should be to study the capacity of a channel to transmit a signal without degradation from noise. The meaning of the signal should not be taken into account—an axiom on which Shannon insisted that, in fact, has not always been heeded.

What Shannon considered was what he called the "quantity of information" attributed to a message represented by a signal. This expression, perhaps unfortunately formulated in some aspects, has no semantic connotation. It is linked to the unexpectedness of the message. More precisely the quantity of information attributed to a message telling that an event, of probability p, has occurred is $I = -\log_2 p$, where $\log_2$ means logarithm with base 2. When p tends to zero I tends to infinity, when $p = 1$ then $I = 0$. So the greater the unexpectedness, the greater of the quantity of information. If $p = 1/2$ then $I = 1$. This means that the unit of quantity of information corresponds to the circumstance where the realization and the non-realization of the event are equiprobable. This unit is called a bit (binary digit), and less frequently a Hartley, in remembrance of R. Hartley who pursued pioneering work in this field at the same time as H. Nyquist.

For Shannon, a communication system may be represented by a source of information providing an input message that is then changed by a transmitter into a signal suitable for transmission over a channel. The output signal results from the addition of noise to the input signal. The output signal enters a receiver, delivering the output message to its destination. For the sake of simplicity we shall now consider the case of a discrete source of information generating an input message constituted by a sequence of symbols that occur according to certain probabilities. The input message is encoded into an input signal—a sequence of other symbols that also occur according to probabilities. This signal is disrupted by discrete noise that is also probabilistic. Shannon has shown that if the average quantity of information produced by the source, per symbol and unit of time, is less than or equal to a certain number C, there is a coding of the input message into the input signal such that the transmission, up to the output message, is realized with a frequency of errors arbitrarily small. Shannon calls C the channel capacity. The average quantity of information considered above needs a precise definition. Let $\{s_1, s_2, \ldots s_n\}$ be the set of symbols from which the source chooses. If p_i is the probability of occurrence of symbol s_i, the quantity of information associated to this occurrence is $-\log_2 p_i$, and the average quantity of information per symbol is

$$J = -\sum_i p_i \log_2 p_i$$

So the average quantity of information considered by Shannon is J/d if d is the mean duration of the emission of a symbol. We may remark that J = 0 when one p_i equals 1 (the others equaling 0), and that J = $\log_2$n when all p_i are equal to 1/n, these values being the extremes of J.
If we consider a thermodynamical system whose possible n states have probabilities $p_1, p_2, \ldots, p_n$, its entropy is, by definition,

$$E = -k\sum_i p_i \log_e p_i$$

where $\log_e$ means natural logarithm (base e) and K is Boltzmann's constant. Shannon was of course aware of the formal analogy between J and E—which is why he also called the average quantity of information per symbol "entropy". This analogy has been considered significant by L. Szílard, B. Mandelbrot, L. Brillouin, and L. de Broglie. The three first authors proposed explanations of the Maxwell demon paradox (supposed to prove that the second law of thermodynamics, concerning the increase in entropy of a closed system, may be inexact in microscopic physics) based upon a kind of equivalence between J and E which has not yet been properly clarified.

L. de Broglie's interest in cybernetics was mainly due to information theory and its possible implications in theoretical physics. At a time when cybernetics was not accepted by mainstream thinkers in the USA, Europe, or the USSR, he expressed his sympathy for it. It may be remarked that after the death of Stalin, cybernetics—which had previously been considered a bourgeois theory aimed at enslaving the people—became very popular in Russian academic circles.

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Biographical Sketch

Vallée (Robert) was born in 1922 in Poitiers (France). His father and mother were professors. He studied at the Lycée d'Angoulême, Ecole polytechnique (Paris), and the Université de Paris. During the course of his career, he has been Associate Director of Institut Blaise Pascal (1956-1958)., Maître de conférences at Ecole nationale supérieure de l'aéronautique (1958-1962) and at Ecole polytechnique (1961-1971), Professor at Université de Besançon (1962-1971), Professor (1971-1987) then Professor emeritus (1987) at Université Paris-Nord., Professor at Université Paris I (1975-1987) and at Université Paris II (1988-1989), Director-General of the Institut de Sciences Mathématiques et Economiques Appliquées (1980-1982)., Editor in Chief of Revue Internationale de Systémique (1986-88), And Director-General and Honorary Fellow of the World Organisation of Systems and Cybernetics (1987–). He is a Member of Société Mathématique de France (member of the council, 1964-1967), Member of the Board of Administration of Association Internationale de Cybernétique, Member of the International Society for the Systems Sciences, Honorary President of the Collège de Systémique de l'AFCET, Vice-President of Cybernetics Academy Odobleja, Member of Académie Francophone d'Ingénieurs, and Member of the Council of AFSCET.

Dr. Vallée has published over 120 articles in international scientific journals on mathematics, cybernetics, and systems. He is the author of *Cognition et Système, essai d'épistémo-praxéologie*, and editor of two books on systems and information applied to economics. He was awarded the Medal of Collège de Systémique de l'AFCET in 1984, the Norbert Wiener Memorial Gold Medal, and the distinction of Dr Honoris Causa of Universitatea din Petrosani in 2000.