CYBERNETICS: CYBERNETICS AND THE THEORY OF KNOWLEDGE

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Keywords: Autopoiesis, Cognition, Constructivism, Epistemology, Feedback Mechanisms, Goal-Directed Behavior, Homeostasis, Observation, Operationism, Scientific Models, Self-Regulation, Teleology.

Contents

Summary

After a brief review of the seven articles included under this topic, my own contribution begins with an exposition of salient features of First-Order Cybernetics that opened the way to the development of the Second Order. This is followed by an explanation of the notion of self-regulation and its implications for epistemology in general, for the philosophy of science, and for the common sense view of the world. It will be shown that the idea has historical precedents, but has only recently begun to seep into contemporary disciplines such as anthropology, sociology, psychotherapy, and education.

1. Review of Subject Articles

The seven articles which, with the present one, were collected under the topic 'Cybernetics' reflect the views and interests of individual authors in the field. From its very beginning, this field was developed by the spontaneous collaboration of unconventional thinkers who broke through the established boundaries of their respective disciplines of physics, electrical engineering, neurophysiology, psychology, anthropology, and mathematics. The analyses of phenomena and the novel relations and concepts they came up with were far from uniform, but the collaboration flourished because there was an underlying compatibility of ideas. The individual endeavors were essentially parallel and thus paved a relatively broad pathway into a hitherto untrodden area.

Written half a century after the birth of the discipline, these articles reflect a variety of personal positions and while they duplicate the definitions of some key concepts, the diverge on others. The reader will find a mosaic of ideas, theoretical considerations, and opinions pertaining to areas of the contemporary scene, as diverse as the natural sciences, economy, ecology, business management, social organization, politics, and philosophy. The articles vary in style, but the use of mathematical formalization is rare and none of them require a great deal of scholarly preparation.

1.1. History of Cybernetics

R. Vallée presents a number of historical precursors of cybernetics and discusses some of the founders of the contemporary discipline. He defines special terms, such as 'feedback', 'requisite variety', and the theory of communication. Finally, the article provides a short survey of the influence of cybernetics on other areas and a few projections concerning its future development.

1.2. Existing Cybernetics Foundations

B.M.Vladimirski characterizes cybernetic research as relying on the principles of complex system organization, information transfer, and goal-directed control in the study of living organisms and automatic systems. He provides extensive explanations of all the key concepts of the discipline, including the widely misunderstood concept of 'black box', a rationale for the contention that in a system "the whole is more than the sum of its components", the relativity of explanatory models, the mathematical theory of communication, and he ends with a fervent encouragement for cybernetic research to continue tackling the unwieldy problems human society is running into.

1.3. Second-Order Cybernetics

R. Glanville lays out the differences between 1st-order and 2nd-order cybernetics and gives a lucid account of the conceptual relation that connects them. He compares the step to that from Newton's physics to Einstein's and describes it as the becoming conscious of the discipline. The article also gives a brief account of the personal and intellectual relationships among the scientists who were responsible for the major developments in the field.

1.4. Knowledge and Self-Production Processes in Social Systems

M. Zeleny explores differences between natural and engineering systems. His focus is predominantly on social systems and in particular on free-market economy, kinship networks, and the organization of user networks on the Internet. In all these he examines the application of the concept of autopoiesis and emphasizes the advantages its deliberate practical implementation would bring. He concludes the article by giving several examples of industrial ventures that actually adopted principles of self-generation in their management.

1.5. Cybernetics and the Integration of Knowledge

B. Scott considers cybernetics as a meta-discipline able to inspire scientific research of all kinds and to foster interdisciplinary cooperation and the mutual adaptation of basic conceptual frames, methods of research, and communicatory practices. Beginning with the study of natural systems and observers' initial assumptions, the author distinguishes the classical description of social systems from the approaches that try to understand social phenomena as the manifestations of systems seen as autonomous wholes.

1.6. Cybernetics and Communication

V.U. Degtiar specifies a division between technical and biological objects and, further, between social and non-social systems. He distinguishes man-machine communication from communication among living organisms. Focusing on the second, the author unravels the complexity of communicatory interactions, pointing out the pervasiveness of unconscious aspects that have so far not been taken into account by theoreticians. Stressing the role of the individual and its cognitive resources, he shows some of the obstacles that encumber the discussion of complex problems (also on the Internet). The author comes to several conclusions among which the observation that "the purpose of Homo sapiens is not the quality of its economy but the quality of itself".

1.7. Bipolar Feedback

H. Sabelli presents his concept of bipolar feedback and the application of its mathematical formulation in a variety of areas from physiology to the stock exchange and psychotherapy. The author sees the combination of positive and negative feedback as a source of 'information' that leads to the formation of novel structures. The thesis is presented with a number of mathematical formulations derived from communication theory and complemented by computer simulations that are intended to support its main claim.

2. First-Order Cybernetics

2.1. Historical Roots

The term 'cybernetics' was introduced in the 20th century by Norbert Wiener as the title of his 1948 book. In the subtitle he presented his definition: "Control and communication in the animal and the machine". The word was derived from the Greek 'Kybernetes' which referred to the steersman of a ship and is the etymological root of our word 'governor'. Historians have found prior use of the term in the writings of the French scientist Ampère; and suggestions of control functions similar to those intended by cybernetics could be seen in a paper the famous British scientist Clerk Maxwell wrote in the 19th century.

On the practical side, control devices had been invented long before any cybernetic theory or mathematics was formulated. James Watt's *governor* which, by shutting a valve at a certain rate of revolutions, prevents steam engines from running faster than they should, is the best-known example. In its ingenious design, the rotational speed of the engine itself provides the 'feedback' that reduces the intake of steam. Very much simpler systems, based on a float that 'governs' the level of liquid in a container, have existed ever since the water clocks and the self-filling oil lamps of the 3rd century BC. (For a more detailed history of the discipline-(See *History of Cybernetics*)

2.2. The Notion of Feedback

The basic meaning of 'feedback' is simply this: something that is produced by a machine or organism is led back to modify the process of production. If it increases the output of that process, it is called 'positive feedback'. It is implemented, for example, in the amplifiers of electronic sound technology. If feedback is used to regulate or limit the process that generates it, it is called 'negative'. This second kind if feedback constitutes the core of the control mechanisms that first-order cybernetics is primarily concerned with (see Sabelli's article for elaborations on positive feedback). In the examples mentioned above, negative feedback originates from an inherent physical force. In Watt's governor, for instance, it is a set of rotating weights driven outward by the centrifugal force, that 'sense' the speed of the engine; in oil lamps or water closets there are floats that sink with the consumption of a liquid and 'sense' the near emptiness of a container. Their 'sensing' is of course purely metaphorical. They have no sense organs, but are constructed in such a way that, on reaching a certain position, they respectively close or open a valve by means of a physical connection of levers or chains. (An excellent review of mechanical feedback devices can be found in Otto Mayr's book *The origin of feedback control*.).

In all these gadgets, the feedback is mechanical and does not involve signals or symbolic communication. Nevertheless the more sophisticated among them have features that manifest important theoretical characteristics of cybernetics. For this reason the thermostat was used as the prime explanatory example by the early cyberneticians. In the case of an air conditioning system, the role of the thermostat is to keep the temperature in an enclosed space at the desired level. A human agent sets a specific temperature as reference value, and the thermostat 'senses' the actual temperature by means of a thermometer and has the ability to compare it to the set value. If what it registers is lower than the reference, it activates the heater, if it is higher, it activates the cooling system. Inherent in this function are two principles.

2.3. The Function of Difference

The first of these principles is that whatever action the thermostat initiates, it is not caused by the sensed temperature as such, but by its *difference* relative to the reference value. Consequently any of these actions may cease for two reasons: either because the relevant space has reached a temperature equal to the reference value, or because the reference value has been changed and now equals the temperature the thermostat senses.

It is intuitively convincing that this pattern of acting and reacting provides a useful theoretical model to explain behaviors of living organisms (many instances of it are given in Stanley-Jones' *The kybernetics of natural systems*). The notion of feedback resolves a major problem of stimulus-response theory, namely that whatever is categorized as a stimulus does not always elicit a response. As a rule, also an internal condition has to be considered, and this condition can be seen as discrepancy relative to a 'reference value'. If there is no relevant discrepancy, the perception of the stimulus does not trigger action. Farmers have known this for ever. They say: you can take horses to the well, but you cannot make them drink.

2.4. Self-Regulation and Equilibrium

Besides, the feedback model makes conceptually explicit what Walter Cannon, an important forerunner of cybernetics, called 'self-regulation'. His book, *The wisdom of the body*, is still one of the pillars of biological cybernetics. Indeed, the various types of homeostasis Cannon studied mainly in mammals, all demonstrate the ability to compensate for an environmental perturbation by an internal modification rather than by an action on the environment.

A second principle is not quite so obvious. In order to be a satisfactory regulator, a thermostat must not be too sensitive. It must allow for a reasonable space around the set temperature, so that it does not switch on the heater the moment it senses a temperature just below the set value, and then switch on the cooling system as soon as the temperature has risen above it. In other words, there has to be a range of equilibrium in order to avoid unbearable oscillation.

The realization of this requirement leads to an important shift of focus. Interest is no longer concentrated on isolating *one* external cause of an organism's perturbation, but rather on the conditions that limit its equilibrium, i.e., the constraints within which equilibrium can be maintained. Gregory Bateson applied this idea to the theory of evolution and thus opened a highly productive perspective on the processes of adaptation. As this constituted one of the steps towards second-order cybernetics, we shall return to it in the later context.

2.5. The Domestication of Teleology

Historically, the most important effect of the study of such control mechanisms was the legitimation of the concept of purpose in the domain of science. Notions such as intention and purpose had been declared out of bounds for explanations that wanted to be considered scientific. These notions, it was held, involved something that was logically impossible because they suggested that a goal that lay in the future could influence the course of events in the present. Positing such a paradoxical influence was branded as 'teleology', a pattern of thought invariably associated with the metaphysics of Aristotle. A closer examination shows that this proscription was mistaken on two counts. Re-reading Aristotle, it becomes clear that he separated two kinds of teleology. On the one hand, his metaphysics did, indeed, contain the idea that all development would eventually lead to perfection because it was guided by the blueprint of an ideal world. On the other hand, however, he left no doubt that he saw goal-directed behavior as something eminently practical that involved no mystical assumptions whatever. See *Existing Cybernetics Foundations.*

Aristotle left no doubt about this when, in Book II of his *Physics*, he discussed the fourth of his explanatory principles that translators later termed 'causes'. He called the fourth principle 'final' - not because it was the last, but because it involved the desired end of the activity in question and not, as do the other three, only the initiation or the stuff acted upon. Aristotle's defined the *final* cause by giving the example of someone walking 'for the sake' of his health, and he added the explanation that, in this case, health is the cause of the person's walking about.

He did not think it necessary to state in so many words how people had acquired the belief that walking would be good for them. It was common knowledge that exercise loosens the joints, reduces fat, stimulates the heart and other functions, and could therefore be considered beneficial to one's health. This had long been established by inductive inference from the domain of common experience. It was no different from the knowledge that food will alleviate hunger and that water will quench thirst. It was one of the countless rules of thumb that have proved to be quite reliable and that we use to get rid of discomforts or to attain pleasures. All of them are based on the implementation of an *efficient cause* that has regularly produced the specific desired effect in the past and is therefore expected to produce it in the future. But it is we, who project this effect into the future, not something that exists in the future and affects the present.

2.6. Purpose and Goal-Directed Behavior

Once the analysis of feedback mechanisms presented a model showing how goal-directed behavior could actually work and attain specified goals, the inadequacy of the behaviorist's stimulus-response theory became quite obvious. Although B.F. Skinner in 1977 still persisted in stating that: "The variables of which human behavior is a function lie in the environment", it was apparent that the relation between a thinking organism and its environment was only very rarely explicable in terms of direct causal links. The inner state of the organism, its particular cognitive structures, its individual mental focus and interests, including its goals, had to be taken into account, and the notion of reference values and feedback provided powerful tools in the articulation of this new view.

In retrospect, it becomes apparent that not all the ideas that played a part in the development of the cybernetic paradigm were as new as they seemed. In 1921, Ralph Barton Perry, a philosopher of admirable erudition, published a sequence of articles in an attempt to reconcile the behaviorist approach with the notion of purpose. They are documents of a heroic struggle, and it is fascinating to see how close Perry came at times to the cybernetic concepts of goal-reference and negative feedback. In one of his papers, he said, for example, that an act is performed because its implicit sequel coincides with the incomplete part of some course of action that is at the time dominating the organism. What he did not mention (and presumably did not see) was that the assessment that something is 'incomplete' requires a mental representation of the item in its state of completeness.

Forty years earlier, in his fundamental textbook on psychology, William James had already distinguished two kinds of teleology: that of an agent who deliberately acts to attain a goal; the other, the goal-directedness an observer attributes in order to explain the agent's behavior. This foreshadows the distinction Gordon Pask introduced into cybernetics. Applying Pask's distinction to the thermostat, we can say that its *internal* purpose is the elimination of differences between the set reference value and the temperature it senses, whereas for an *external* observer its purpose is the maintenance of a desired temperature.

To sum up this brief survey: 1st-order cybernetics was primarily concerned with the analysis and engineering implementation of goal-directed behavior. It formulated a viable theory of purposive mechanisms and provided its mathematical formalization. On the practical side, it succeeded in designing and actually constructing a great variety of mechanisms that manifested purposive behavior. The realization of automatic pilots, target-finding missiles, chess-playing computers, and robots capable of guiding their actions by their own perceptions, is ample proof of the power of the cybernetic approach. From a theoretical standpoint, however, the most significant achievement was that the practical success of cybernetic constructs brought with it the rehabilitation of the concept of purpose. This opened the path towards the study of purposive *agents*, the domain of second-order cybernetics. See *Axiological Systems Theory.*

2.7 Communication

While the analysis of feedback was being developed to account for control mechanisms, a no less important theoretical model was worked out as a technical approach to the phenomenon of communication. Communication was the second key term in the title of the book that launched cybernetics, and its problems had been tackled some years earlier by Claude Shannon with some acknowledged contributions from Norbert Wiener. The Mathematical Theory of Communication had an enormous influence in the development of communication technology (the problems of social communication are extensively treated in the article by Degtiar). Far more relevant to the present survey, however, is the conceptual clarification the theory provides for communicatory process in general.

A message can be sent from point A to point B only if there is a medium that allows such transmission. This medium has to be a 'channel' in which pulses of some form of energy can travel. In old-fashioned telegraphy, it was a wire and pulses of electrical energy; in radio and television, it is electromagnetic waves and the modulation of their frequency or amplitude; in speech, it is sound waves and their modulation; and in writing or printing, it is marks on some physical surface that can be taken from one place to another. But these pulses or marks do not carry a message, unless it has been *encoded* in them. For this to happen, three things are necessary. First, the sender must have a code, that is to say, a list that indicates what kind or combination of pulses or marks corresponds to the elements of the message that is to be sent. Second, the receiver of the message must also have such a list in order to *decode* the pulses or marks he receives. Third, if communication is to succeed, the code-lists of the sender and of the receiver must obviously be the same. (Vladimirski gives a more technical explanation of communication theory.)

This last condition was never seen as a problem in technical communication systems, because it was taken for granted that the established code would be distributed to all participants in the system. However, the technical analysis highlights a point that was rarely considered in the study of linguistic communication. Although there are lexica for natural languages, their contents is accessible only to readers who already have a basic vocabulary. Children are not handed a code that displays the connections between words and their meanings - they have to develop it for themselves, largely by trial and error. It is true that the meanings of a number of words can be conveyed to them by parents or care givers, but the bulk of their vocabulary is formed on the basis of subjective experience in the course of interactions with other speakers.

As a result of this inherent looseness in the acquisition of the linguistic code, linguistic messages and texts in general leave a great deal of space for individually divergent interpretations. The realization of this fact had a considerable influence on some of the authors of second-order cybernetics.

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Biographical Sketch

Ernst von Glasersfeld was born in Munich, 1917, of Austrian parents, and grew up in Northern Italy and Switzerland. Briefly studied mathematics in Zürich and Vienna and survived the 2nd World War as farmer in Ireland. Returned to Italy in 1946, worked as journalist, and collaborated until 1961 in Ceccato's Scuola Operativa Italiana (language analysis and machine translation). From 1962 principal investigator of US-sponsored research project in computational linguistics. From 1970, he taught cognitive psychology at the University of Georgia, USA. Professor Emeritus, 1987. - At present Research Associate at Scientific Reasoning Research Institute, University of Massachusetts.

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Honors:
University of Georgia Research Medal, 1983.

Christ Janer Award for Creative Research, 1984 (jointly with L.P.Steffe). Chairman, Third Gordon Research Conference on Cybernetics, Oxnard, CA, January 1988.
Warren McCulloch Memorial Award (American Society for Cybernetics), 1991.
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