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Cybernetics and the Theory of Knowledge

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, are 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, they 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 first order and second 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 is 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 twentieth 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 nineteenth 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 third 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, an internal condition also has to be considered, and this condition can be seen as a discrepancy relative to a "reference value". If there is no relevant discrepancy, the perception of the stimulus does not trigger action. Farmers have always known this. They say that 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 legitimization 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 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, 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: first 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 are 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.

3. Second Order Cybernetics

The difference that separates the two kinds of cybernetics was most succinctly stated by Heinz von Foerster, whose work initiated the new direction. The first order is the cybernetics of observed systems—the second, the cybernetics of observing systems.

Questions about what it means to observe and what kind of knowledge we glean from observation, were raised by the pre-Socratics at the very beginning of recorded Western philosophy. In the course of this history, innumerable theories of knowledge were proposed, ranging between two extremes. On the one side there is naive realism which is based on the assumption that what we come to know must be a more or less "true" representation of an independently existing reality. On the other side, there is the form of subjective idealism that is called solipsism and holds that there is no reality beyond the human mind. At the realist end of this axis looms the problem of how our knowledge could ever be demonstrated to be true relative to a reality posited to be independent of its observers; at the other, there is the no less daunting puzzle why so many things concocted in the domain of our ideas turn out to be patently false in the world which we actually experience.

3.1 The Epistemological Problem

Scattered throughout the history of philosophy there are thinkers who came to see that it was impossible to find a rationally tenable position anywhere on the established axis. Whatever was proposed contained one or more elements of either one of the two extremes and could therefore be demolished by well-established arguments. There seemed to be no way to counter the skeptics' solidly founded contention that true knowledge of either the world or the mind was impossible. Consequently the nature of what we consider to be justified beliefs remained a troublesome problem.

In the sciences, problems that resist solution for a long time are usually solved in the end by the drastic modification of one or more concepts that until then were unquestioningly taken for granted. The conceptual changes were sometimes dramatic and their proponents faced fierce resistance before the established leaders of their respective field gave in (or died) and a new way of thinking gradually became general. The shift from the geocentric to the heliocentric theory of the planetary system is probably the most obvious among the historical examples. In general it was either the accumulation of empirical evidence, or the wider applicability or simplicity, that gave the new conceptualization the winning edge. Suggested before the Second World War by the Polish author Ludwick Fleck, this theory of scientific procedure and change was elaborated and presented by Thomas Kuhn, in his book "The Structure of Scientific Revolutions" that became the scientific best-seller of the post-war period.

Philosophy, and epistemology in particular, do not show this pattern. The unsolved problems in these disciplines are largely the same as they were two and a half millennia ago, and so are the concepts involved in the problems' formulation. One of these is the very concept of knowledge. It has been, and generally still is, taken for granted that what we want to call knowledge must in some way correspond to a reality that lies beyond our experiential interface. Like the notion that the earth must be at the center of the universe, it is an idea that is difficult to give up. Yet no one seemed to be able either to demonstrate such correspondence with an independent reality, or alternatively, to give a convincing account of how, without it, we could come to have all the knowledge that we confidently trust when we make decisions about our actions.

3.2 A New Theory of Cognition

Some years before cybernetics was born as a discipline, Jean Piaget formulated a principle of self-organization as: "The mind organizes the world by organizing itself" in his 1937 book on the child's construction of reality. In his theory, this autonomous process of organization forms the core of the capability of producing knowledge and is the highest form of adaptation. He took the concept of adaptation out of the context of evolution, where it does not involve an activity, but concerns the biological capacity to survive within the constraints of the physical environment; and he transposed it into the cognitive domain, where it concerns the active striving for, and maintenance of, equilibrium among concepts, schemes of action, and in the generation of knowledge as a whole.

Talcott Parsons was among the first to remark on the relation between Piaget's theory, Cannon's concept of homeostasis, and the revolutionary notion of self-regulation. But it was Gregory Bateson's analysis of the process of adaptation that allowed us to see clearly the conceptual connection between Piaget's theory of cognitive equilibrium and cybernetics. (For a more extensive survey of the researchers involved in the development of the second order, see Glanville's article.)

In his seminal article on biological evolution, Bateson wrote that:

> "Causal explanation is usually positive. We say that billiard ball B moved in such and such a direction because billiard ball A hit it at such and such an angle. In contrast to this, cybernetic explanation is always negative. We consider what alternative possibilities could conceivably have occurred and then ask why many of the alternatives were not followed, so that the particular event was one of those few which could in fact occur. The classical example of this type of explanation is the theory of evolution under natural selection. According to this theory, those organisms which were not both physiologically and environmentally viable could not possibly have lived to reproduce. Therefore, evolution always followed the pathways of viability. As Lewis Carroll has pointed out, the theory explains quite satisfactorily why there are no bread-and-butter-flies today. In cybernetic

language, the course of events is said to be subject to *restraints*, and it is assumed that, apart from such restraints, the pathways of change would be governed only by equality of probability. In fact, the "restraints" upon which cybernetic explanation depends can in all cases be regarded as factors which determine inequality of probability."

In the theory of evolution, the biological living space of each organism is hemmed in by the limits entailed by its physiological make-up and by the obstacles presented by its environment. Both these are given conditions over which neither the individual nor the species has control. In contrast, in Piaget's theory of cognition, a relative, labile equilibrium is possible only in the space generated by the active avoidance of, or continual compensation for, perturbations. The conceptual difference between the two essentially parallel theories resides in the source of the restraints. On the biological level the factors that limit survival are in no way determined by the organism itself. On the cognitive level, however, perturbations that impede equilibrium spring from the mutual incompatibility of goals the organism has chosen and/or of the means used to attain them.

3.3 The Construction of Knowledge

In this view, cognitive agents themselves are clearly determining factors in the generation of knowledge. For if the goal is conceptual equilibrium, only the conceivers themselves can determine when it is reached and when not.

There is yet another, quite different consideration that has brought the role of the cognitive agent to the fore. In his book, "Cybernetics—or control and communication in the animal and the machine", Norbert Wiener wrote: "All the great successes in precise science have been made in fields where there is a certain high degree of isolation of the phenomenon from the observer." In Astronomy, he goes on to explain, the scale is "enormous", in atomic physics "unspeakably minute" compared to the scale on which we live. In both cases, he says, "we achieve a sufficiently loose coupling with the phenomena we are studying to give a massive total account". At the end of the passage, however, he warns that "the coupling may not be loose enough for us to be able to ignore it altogether".

Second order cybernetics could be characterized partially by saying that it originated from the doubt expressed in Wiener's warning. The relationship between observers and what they observe became its primary object of study. This study, clearly, did not have to begin from scratch. Beginning with the famous statement "Man is the measure of all things", made by Protagoras in the fifth century BC, there is a chain of records indicating that some thinkers had come to realize that the observer plays an active part in the process of observation, and that anything he observes bears his mark. But they have had relatively little influence on the philosophical tradition.

Even the clear statement that Immanuel Kant made in the introduction to his "Critique of Pure Reason", namely that "reason can understand only what she herself has brought forth according to her design" did not greatly shake the general belief that scientists succeed in unveiling the mysteries of the universe.

3.4 Rational Models and the Role of the Observer

Second-order cybernetics is the only Western discipline that has fully accepted this view and subscribes without reservation to the general description of the scientist which Albert Einstein and Leopold Infeld provided by means of the famous metaphor of the man and the watch in their "Introduction to relativity:.

> "Physical concepts are free creations of the human mind, and are not, however it may seem, uniquely determined by the external world. In our endeavor to understand reality we are somewhat like a man trying to understand the mechanism of a closed watch. He sees the face and the moving hands, even hears its ticking, but he has no way of opening the case. If he is ingenious he may form some picture of a mechanism which could be responsible for all the things he observes, but he may never be quite sure his picture is the only one which could explain his observations. He will never be able to compare his picture with the real mechanism and he cannot even imagine the possibility or the meaning of such a comparison."

This metaphor brings home the fact that the real world is unknowable or, as cyberneticists came to say, a "black box" (for a full explanation of this term, see Vladimirski's article). The twentieth century revolutions in physics, especially that provoked by quantum theory, prompted all their foremost exponents to declare, in one way or another, that the knowledge they had gathered concerns the organization of experience rather than the objective structure of an independent reality. But the attitude in most physics departments and of the writers of textbooks still tends to be that of realists. (See *Second-order Cybernetics.*)

3.5 Operational Definitions

Another development that, in retrospect, could have accentuated the role of the observer, was that of "operational definitions" by the physicist Percy Bridgman. He succinctly characterized the ideal attitude of the researcher in his 1936 treatise on "The structure of physical theory":

> "It is the task of theoretical physics to compress all experimental knowledge into an understandable point of view; the theorist can never foresee what the experimenter will find when his range is extended to include fields at present inaccessible, so that he must always regard his last and most successful theory as a structure of limited validity, always subject to the necessity for radical alteration when extended to include such new experimental facts as may be later discovered."

Bridgman formed the operationist idea in the context of Einstein's theory of relativity by an examination of the concept of simultaneity. He explained that the germ of the theory had been the examination of what we do when we compare the times indicated by clocks in different places. Einstein's revolutionary recognition was that the property of two events which hitherto had been unthinkingly called simultaneity involves a complicated sequence of physical operations which cannot be uniquely specified unless we specify who it is that is reading the clocks.

Every observer, be he or she reading a clock, looking through a telescope, or simply watching an event, has a specific position, not only in the spatial sense. Like the optical instruments scientists use, all observers have their own observational characteristics and their specific way of seeing. They also have a "point of view" that determines the concepts with which they grasp what they observe and how they formulate it when they want to communicate it to others. The "coupling" Wiener spoke of, between the agent and the object of observation, cannot therefore be disregarded.

3.6 Several Parallel Developments

Once interest was focused on the cognitive processes involved in observation, cyberneticians found themselves facing the problems that had bedeviled epistemologists during the entire course of history. The protagonists of the new discipline, however, had the advantage of a highly technical background. The successful engineering of purposive devices that manifested a practical solution of the puzzle of teleology helped to generate the confidence to break with other traditional philosophical assumptions. The most fundamental of these dogmatic fixtures was the belief that human knowledge ought to mirror a timeless, independent reality.

If the Piagetian principle that the mind organizes itself is taken as a working hypothesis, it becomes very clear that the primary purpose of knowledge is not the representation of an external world but rather the establishment of ways of thinking and ways of acting that serve the purposes the knower has formed in the world of his or her experience. This realization led to different but essentially parallel developments within the framework of second order cybernetics.

For some of the pioneers, George Spencer Brown's book "Laws of form" provided additional conceptual foundation. The "calculus of distinctions" presented in this book can be seen as the most elementary basis of all logical thinking. According to Spencer Brown, the act of making a distinction is the first step in any sequence of rational thoughts. This offers an ideally simple starting-point for conceptual construction and, indeed, led the author himself to the striking statement: "Our understanding of... a universe comes not from discovering its present appearance, but in remembering what we originally did to bring it about."

Linked by the common goal of a constructivist epistemology, individual cyberneticians went their own way in their struggle with the problems of cognition. In the narrow frame of this survey only the three relatively complete theoretical models can be acknowledged.

3.6.1 Radical Constructivism

Heinz von Foerster started from the fundamental insight that there can be no observation without an observer. What we call "real", therefore, is always rooted in an observer. In his seminal 1973 article "On constructing a reality", Heinz von Foerster explained his use of "a" in "a reality":

The indefinite article, he said, implies the ridiculous notion of other realities besides "the" only one that we cherished as our Environment.

> "There is a deep hiatus that separates the "The" school of thought from the "A" school of thought in which respectively the distinct concepts of "confirmation" and "correlation" are taken as explanatory paradigms for perception. The "The-School": My sensation of touch is *confirmation* for my visual sensation that there is a table. The "A-School": My sensation of touch in *correlation* with my visual sensation generate an experience which I may describe by "here is a table" I reject the The-position on epistemological grounds, for in this way the whole Problem of Cognition is safely put away in one's own cognitive blind spot and its absence can no longer be seen."

The statement that it is the cognitive agent's active correlation of sensory impressions that creates the notion of objects would be somewhat dubious if it were taken by itself. But von Foerster supports it by citing the "Principle of undifferentiated coding", formulated by Johannes Mueller before the middle of the nineteenth century and confirmed by neurophysiologists ever since. The principle summarizes the finding that the neural signals sent from an organism's sensory "receptors" to the brain are qualitatively all the same and differ only in intensity. In von Foerster's formulation, "the response of a nerve cell does *not* encode the physical nature of the agents that causes its responses. Encoded is only *how much* at this point of the body, but not *what*". This well-established empirical finding presents a serious stumbling block for all realist theories of knowledge.

The epistemological position of radical constructivism is primarily based on the logical consideration that observers necessarily conceptualize what they observe in terms of concepts that are of their own making (as Kant said, according to reason's own design); but the fact that the "data" of vision, hearing, touch, smell, and taste are (from the neurophysiologist's point of view) all indistinguishable is a welcome empirical corroboration of the perceiver's autonomous constructive activity.

The constructivist theory of knowing, one of the cornerstones of second order cybernetics, can be briefly summarized in the principles:

- Knowledge is the result of a cognitive agent's active construction.
- Its purpose is not the representation of an external reality, but the generation and maintenance of the organism's equilibrium.
- The value of knowledge cannot be tested by comparison with such an independent reality but must be established by its viability in the world of experience.

3.6.2 The Theory of Autopoiesis

Humberto Maturana developed his theory of cognition as a biologist involved in the study of perception. Investigating vision in frogs and color vision in pigeons and primates, he came to the conclusion that responses in these organisms were not triggered by specific external stimuli but by the co-occurrence of neural events that showed no one-to-one relation with conditions or events in their environment. In experiments done by Lettvin, Maturana, McCulloch, and Pitts in 1959, a frog, for instance, would respond with its "bug-catching" behavior whenever three or four neural signals created a specific pattern in its brain, irrespective of the fact that, from an observer's point of view, what caused the individual signals in the frog's visual organ may have nothing to do with a bug that could be eaten by the frog. The “what” that caused the response was far from fully determined, and this finding required a radical revision of the generally accepted theory of more or less direct perception.

A partial conceptual skeleton of the “autopoietic” model of cognition, which Maturana worked out during the subsequent decade, can be summarized by the following statements:

(a) Whatever is said, is said by an observer to another observer who may be the speaker himself.

(c) Cognition as a process is constitutively linked to the organization and structure of the cognizing agent.

(d) Autopoietic systems are closed homeostatic systems without input or output.

(e) The changes of state through which an autopoietic system goes while compensating for perturbations can be seen by an observer, for whom the system is in the context of an environment, as the system’s actions upon the environment.

From this perspective, it becomes clear that the observer should remain aware of the fact that the observed organism, and the environment in which it is being seen, are parts of the observer’s experiential field and therefore not an objective reality.

When Maturana published statement (a) for the first time in 1970, it immediately seemed to be a perfectly obvious statement to his readers; but a look at the histories of philosophy and science shows that the quest for descriptions of the world that could be considered “objective”, in the sense that they are not dependent on the characteristics of the observer, was never given up.

Statement (b) can easily be translated into Piagetian terms by saying that what a cognitive organism comes to know is necessarily shaped by the concepts it has constructed.

The term “closure” in statement (c) is intended to indicate that the equilibrium of the autopoietic system may be perturbed from the outside, but there is no input or output of “information”; its actions are in the service of its homeostasis.

Statement (d) speaks for itself. It is an application of statement (a) in that it makes explicit that whatever is conceptualized and said about an observed system is an observer’s description of something within that observer’s experiential field, not a description of a world as such.

Maturana’s autopoietic model is a highly complex and comprehensive theoretical edifice. The four points listed here may serve to render an idea of its general direction but they cannot convey the variety of original ideas that the edifice contains. The many applications that have been developed from it in areas as diverse as family therapy, immunology, and management science are testimony to its inherent richness. (The article by Zeleny is a good example of an independent application.) (See also *The Dynamics of Social and Cultural Change.*)

3.6.3 The Italian Operational School

One of the first centers of cybernetics in Europe focused, from the very beginning, on the problems of conceptualization and its role in the semantics of linguistic communication.

Traditional semantics has always been limited to using words in order to define the meaning of words. For the rest, it relied on the theory of reference, based on the belief that words refer to things in an external, speaker-independent world. Ferdinand de Saussure, the Swiss founder of modern linguistics, had already shown at the beginning of the twentieth century that the semantic linkage was not between words and things, but between the concepts of words and the concepts of things. Both the signs and what they signified were wholly within the experiential world. The illusion of external reference sprang from the fact that meaning could to a large extent be considered intersubjective. Concepts were explained as abstractions the speakers of a language learned to make in the course of their common experience (see 1.7 above). Piaget called this process "empirical abstraction" where it could be shown to originate from sensory experiences; and he added the level of "reflective abstractions" which derive from mental operations. The idea that mental operations are a source of knowledge goes back to John Locke. But neither Locke nor Piaget nor Guy Cellérier, who wrote about the connection between Piaget's theory and cybernetics, further analyzed the mechanisms of abstraction that might yield results that could then be named by words. This analysis was undertaken by Silvio Ceccato but has remained virtually unknown because it was published only in Italian.

Silvio Ceccato's main objective was "the mechanization of the mind", by which he intended the design of a model that could carry out mental operations. Early on, he had stumbled on Bridgman's idea of operational definitions and it determined the course of his work. If the meaning of words was conceptual, a valid semantic analysis required the specification of the medium out of which concepts could be made before they were associated with words. This position became the basis of several projects of language analysis by computer in the 1960s. Ceccato posited an active process of attention as material for the conceptual constructs. Unlike the general notion that attention functions as a kind of "spotlight" that illuminates objects, he saw it as an oscillatory process producing regular pulses. These pulses could either focus on other signals in the neural network or remain unfocused to mark intervals and distinctions. This attentional activity provided a mechanism for the composition of conceptual structures.

His team at the Milan Center of Cybernetics worked extensively on the minute analysis of mental operations that constitute the meaning of words. Like any effort to produce a comprehensive lexicon, it was a gigantic project. When funds dried up, the team dispersed in the mid 1960s. Giuseppe Vaccarino, who carried on single-handed for forty years, has now brought the work to a conclusion with several volumes on the conceptual foundations of the Italian language. Ceccato's theory of "operational awareness" is kept alive, applied, and further developed in the electronic age by Felice Accame and the Società di Cultura Metodologico-Operativa which he directs.

4. Applications of Cybernetic Principles

The idea that the experiencing subject shapes its experience according to its own ways of perceiving, conceiving, and feeling was implicit in the writings of many authors long before cybernetics proposed cognitive self-organization. But it remained a marginal idea and never became an insight that determined general philosophical views. Recent philosophers, such as Nelson Goodman and Richard Rorty, whose epistemological views are partially compatible with the theory of knowledge developed in second-order cybernetics, use only arguments generated within the tradition of their field and do not mention the parallels to this other contemporary area of research.

In a few disciplines the situation is different. The cybernetic theory of knowing has begun to play a noticeable role in anthropology, sociology, psychotherapy, and, most importantly, in education. What follows is no more than a sampling of conceptual parallels.

4.1 Anthropology and Sociology

Gregory Bateson began his career as an anthropologist with a thorough preparation in biology. His cybernetic analysis of the theory of evolution and his clarification of the concept of adaptation, at first a by-product of his studies of natives in New Guinea, led to the notion of self-organization and his cybernetic view of knowledge. Owing to his work and that of others such as Harold Garfinkel and Clifford Geertz, the perspective of anthropologists was slowly shifted. The earlier attitude, founded on the European notion of scientific objectivity gave way to the realization that viable knowledge of other cultures could be attained only by a participatory understanding of their conceptual and social structures. (For a somewhat different elaboration of this theme, see the article by Scott.)

This development was in keeping with the cybernetic maxims that there are no observations without an observer and that the observer's explanation of the observed is at best a model that proves viable in the experience of others. Geertz formulated the new attitude in his book "The interpretation of cultures":

> "We (anthropologists) begin with our own interpretations of what our informants are up to, or think they are up to, and then systematize those... In short, anthropological writings are themselves interpretations, and second and third order ones to boot. They are, thus, fictions; fictions, in the sense that they are "something made", "something fashioned"—not that they are false, nonfactual, or merely "as if" thought experiments. Cultural analysis is (or should be) guessing at meanings, assessing the guesses, and drawing explanatory conclusions from the better guesses, not discovering the Continent of Meaning and mapping out its bodiless landscape."

The influence of cybernetics on sociology has been far more direct. Niklas Luhmann, whose work has become quite familiar beyond the German-speaking sphere, adopted and adapted Maturana's autopoiesis and added an intricate model of communication in his construction of a complex and comprehensive theory of society and societal manifestations. His personal interactions with both Maturana and Heinz von Foerster brought out some disagreements about his use of their ideas. Maturana objected that societies could not be considered autopoietic systems because one could not ascribe to them the biological structure and organization which, from his point of view, is indispensable for autopoiesis. Von Foerster, who had contributed much to the clarification of the concept of information, could not accept the notion of communication as a reified element in Luhmann's theoretical edifice. Nevertheless

Luhmann's work on social systems constitutes a major, albeit idiosyncratic, application of second-order cybernetics.

4.2 Psychotherapy

Considerations not unlike Wiener's admonition that the relation between observers and what they observe cannot be altogether disregarded have wrought a significant change in the theory and practice of psychotherapy. Traditionally, it was held that there is a clear, demonstrable difference between the sane and the insane, and that mental insanity could therefore be detected and objectively characterized with relative ease. Empirical studies, by Rosenhahn and others, however, have shown that an objective observation of behaviors and their categorization as "abnormal" is very often problematic. A large-scale investigation of what happened to "normal" people who were committed to psychiatric hospitals shook the discipline to its foundations. Among other things, the study made two points appallingly clear: first, the observation of behaviors always involves a particular interpretation of what are considered empirical facts; second, both the facts and their interpretation are to a large extent determined by the observer's expectations. Thus, normal reactions of a pseudopatient were interpreted as symptoms of schizophrenia by the hospital staff, for no other reason than that the person had been categorized as a schizophrenic when he or she was being admitted.

As a corollary of the realization that observations could not be considered to be independent of the observer's concepts, theories, and contextual assumptions, the conceptual fictions of patients were no longer seen as totally erratic. Instead, it was assumed that they had their own, albeit "abnormal" logic and systematicity and that at least in some cases therapy had a better chance if it explored the patient's ways of thinking. This approach, of course, contrasts sharply with the common practice of categorizing patients as mentally ill and then treating them pharmaceutically.

Gregory Bateson and Paul Watzlawick introduced the cybernetic way of thinking into Psychotherapy and the development of different therapeutic methodologies on the basis of second-order principles is still going on. To give an instance, constructivism and Maturana's autopoietic model in particular had a considerable influence in the area of family therapy. Its general approach has been guided by the notion that each member of a family constructs his or her own "reality" of the family, and that the problems of, and conflicts among, the individuals often spring from the incompatibility of their constructions.

4.3 Education

The cognitive psychology of Jean Piaget had a first bout of influence on the practice of teaching some sixty years ago. His specification of stages of development was picked up by designers of curricula, and the notion of the role of biological maturation in the ontogeny of mental development became a kind of dogma for educators and educational researchers. The epistemological core of Piaget's theory, however, was largely disregarded. Not until around 1970 did a number of researchers focus on the idea of self-regulation. By then Piaget himself had become aware of the affinity of his theory and basic concepts of second-order cybernetics. Above all, they shared the principle that whatever we call knowledge has to be actively constructed by the knowing subject.

From then on, this principle of self-organization gained some attention among educators. By now, it has a firm foothold in the areas of mathematics and science education. An extensive literature concerning the individual and social construction of knowledge has been produced and there is considerable evidence that its practical applications are successful, but it is still far from being universally accepted.

Among the points stressed by advocates of constructivism are the following:

- If knowledge consists of conceptual structures learners have to form in their own heads, verbal communication (by teachers' speech or textbooks) does not guarantee a positive result. What is required is thought, i.e. reflection on both practical experiences and whatever teachers and books try to communicate.
- Two excellent ways for teachers to foster students' reflection are the imposition of collaboration with others and the persistent demand that students verbalize their thinking in their attempts to solve a problem ("Team problem-solving").
- The implementation of the constructivist approach requires two things of teachers: they have to credit students with the ability to think and they have to provide the students with opportunities to discover that they are able to solve problems without the teacher providing a ready-made solution.
- Perhaps most importantly, the insight that linguistic communication cannot replace students' active abstraction of knowledge from their own experiences.

These four points are sufficient to indicate the need for a radical change of educational attitude: namely the concession of a great deal of autonomy to the student in order to develop their own capacity for thinking and learning.

A serious argument against such a change is that it would require tests that are very different from the ones given to students now. This is indeed a problem. Testing for understanding is far more difficult than testing for the correct repetition of verbal statements heard from the teacher or read in a textbook. On the other hand, there is sufficient evidence by now, that the motivation to learn grows by itself once students realize that learning is not a passive but an active process and that the ability to solve problems by one's own thinking yields satisfactions that are at least as enjoyable as winning a game.

5. Conclusion

First order cybernetics originated in 1948 with Norbert Wiener's publication of his book. It was baptized as an independent discipline when the prestigious Josiah Macy Foundation decided to devote meetings to the new area of research during the years that followed. Before it was given its name it had already started, and now continued at a growing pace, to revolutionize technology by introducing self-regulating mechanisms that could fly planes, guide the actions of robots, and enable computers to prove theorems and play chess. Today nearly all the machines that serve us in the conduct of our daily lives contain cybernetic devices—from the braking systems of the cars we drive, and the traffic lights that control our driving, to the networks of electric power and the photographic cameras we use.

Two conceptual revolutions went hand in hand with the technological innovations. On the one hand, the successful analysis of feedback mechanisms made the notions of purpose and goal-directed behavior respectable elements in scientific explanation; on the other, the theory of communication substantiated the old suspicion that language by itself was not a vehicle for the transportation of knowledge—it could stimulate conceptual construction, but it could not carry concepts from one head to another. From these premises developed second order cybernetics which, by means of the concept of self-regulation, was able to propose a novel approach to the age-old problems of the theory of knowledge. From this new perspective, human knowledge is defined as the repertoire of ways of thinking and rules of action that are found to be successful in the domain of experience. So viability is put in the place of ontological truth. This momentous change is justified by the fact that we gather our rational knowledge from experience and the only way we have of testing it is again through experience. This in no way diminishes the role of that other kind of knowledge which the religious and the mystics of all ages claim to possess on the basis of revelation or intuition. That knowledge, however, owing to its origin, is beyond the purview of rational analysis.

The epistemological proposal of second order cybernetics is still viewed with suspicion by traditional philosophers, and it will take time to overcome their resistance. One reason why the notions of cognitive self-regulation and experiential viability, instead of ontological truth, are difficult to accept may be that it is easier to put up with the contention that one's solution to a problem may be wrong, than with the idea that no solution will ever be the only "true" one.

Nevertheless, the focusing on self-regulation in an area of possibilities within constraints has led to considerations that seem eminently appropriate at the present moment in human history. In one of the papers that launched his notion of a second order cybernetics, Heinz von Foerster formulated a guide-line for society by referring to the rehabilitated concept of purpose. His admonition, made a quarter of a century ago in "The cybernetics of cybernetics", seems no less pertinent today:

> "Social cybernetics must be a second-order cybernetics, in order that the observer who enters the system shall be allowed to stipulate his own purpose: he is autonomous. If we fail to do so, somebody else will determine a purpose for us. Moreover, if we fail to do so, we shall provide the excuse for those who want to transfer the responsibility for their own actions to somebody else: 'I am not responsible for my actions; I just obey orders'. Finally, if we fail to recognize autonomy of each, we may turn into a society that attempts to honor commitments and forgets about its responsibility."

Glossary

Adaptation: Serves the ability to survive, reproduce, or maintain equilibrium within limiting constraints.
Cognition: The mental faculty of generating and compiling knowledge.
Control: To keep a process or quantity within limiting bounds.
Ontology: The study of what is presumed to exist irrespective of human observers.
Perturbation: Anything that upsets an equilibrium.
Realism: The doctrine based on the belief that it is possible to obtain "objective" knowledge of a world underlying experience.
Teleology: The use of the concept of purpose in the explanation of phenomena.

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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. He briefly studied mathematics in Zürich and Vienna and survived the Second World War as farmer in Ireland. He 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 he was principal investigator of a US-sponsored research project in computational linguistics. From 1970, he taught cognitive psychology at the University of Georgia, USA. He became Professor Emeritus in 1987, and he is presently a Research Associate at the Scientific Reasoning Research Institute, University of Massachusetts.

His books include: The Construction of Knowledge; Radical Constructivism in Mathematics Education (as Editor); Radical Constructivism: A way of knowing and learning; Grenzen des Begreifens; and Wie wir uns erfinden (with H.von Foerster).

He has produced more than 240 papers since 1960, has acted as Chairman for the Third Gordon Research Conference on Cybernetics, and has received honors including the University of Georgia Research Medal, and the Warren McCulloch Memorial Award (from the American Society for Cybernetics).

He is a Trustee of the American Society for Cybernetics, an Honorary Member of the Austrian Society for Cybernetics, and a member of the International Board of Consultants for the Archives of Jean Piaget in Geneva.

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