

## **AMPLIFYING REGULATION AND VARIETY INCREASE IN EVOLVING SYSTEMS**

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The cybernetic theory of regulation is applied to a characterization of evolution, with emphasis on an interpretation of the directional aspects of evolutionary processes. In the suggested context, evolution appears as a general type of stability, and a perception of the world as a hierarchy of structures differentiated by discontinuities and characterized by an increasing order of complexity and organization, obtains a specific functional meaning. Such a hierarchy can be regarded as a stratified organization of controllers interacting such that across its levels, regulation is amplified.

### **INTRODUCTION—THE EVOLUTIONARY PERSPECTIVE AND THE CYBERNETIC PARADIGM**

Scientific discussions of evolution since Darwin have centered around essentially biological issues related to the emergence and subsequent history of species. A broader concept of evolution as a unifying creative principle embracing all cosmic phenomena including, but not limited to, terrestrial forms of life, has been advocated by visionary thinkers and religious mystics, for example, by Teilhard de Chardin (1955), but such contributions remain alien to established scientific disciplines.

Recent developments in the physical sciences, however, made possible the articulation of principles governing the evolution of order and complexity in physico-chemical systems. These principles, formulated in the field of nonequilibrium thermodynamics, have been applied to an analysis of some biological processes (Prigogine, 1969; Katchalsky and Kadem,

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1962), and they have been used by way of speculation or analogy to discuss evolution of sociopsychological and conscious phenomena as well (Katchalsky, 1971; Jansch, 1975).

The formulation offered by nonequilibrium thermodynamics holds that the increase of organization and complexity in physical systems is a consequence of specific kinetic principles and that the concept of evolution in physics and biology are reconcilable under a single physical law (Glandsdorf and Prigogine, 1971). This formulation can be interpreted as reaffirming the intuitive concept of the unity underlying natural phenomena, but since it involves mathematical concepts describing the dynamics of energy flows subject to strictly defined constraints, its "extrapolated" projection to the domains of social and psychological systems may be questionable.

An approach suggested by the cybernetic theory of regulation, on the other hand, offers a different perspective which, by emphasizing organizational aspects that are independent of specific material considerations, is free of similar limitations. The cybernetic approach assumes that realizable configurations (identities) imply the fulfillment of thermodynamic and energetic requirements. It involves the formulation of a general concept of regulation linking the notion of survival, in the broad sense of "viability," or "stable identity," to concepts of information communication and control. In this context, evolution can be regarded as an outcome of a particular "survival strategy," applicable to a specific constellation of dynamic circumstances and subject to the laws of regulation. These laws are conceived on a level of abstraction that makes their transfer across systemic boundaries particularly convenient. The cybernetic paradigm can, therefore, contribute significantly to a unified view of evolution and to a characterization of evolution as a general phenomenon. It provides for a consistent interpretation of both the dynamics of specific evolutionary processes and the persistent, overall evolutionary tendency of forming organizations of ever increasing complexity.

One important consequence of the cybernetic perspective is a view of evolution as being characteristic of a particular kind of dynamic behavior in systems, reflecting a particular aspect of the logic of mechanisms (in the sense suggested by Ashby, 1958b). From this viewpoint, evolution corresponds to a specific type of regulation and, as a process, it is embodied in a particular type of organization of which Pask's iconic representation of learning processes (Pask, Scott, and Kallikourdis, 1973) is an example. This broad statement is significant insofar as it stresses the concept that

evolution is a general type of stability (steady state being a special case) and that as such it is a general condition typical to environments that are subject to the operation of a particular set of constraints.

On this level of abstraction at which evolution is regarded as a general process, the essential features of reproduction, variation, and selection appear as generalizable unifying principles. Generalizable, in that they can be synthesized and become subject to simulations (Ben-Eli and Tountas, 1977). The specific mechanisms through which evolution is mediated will vary, however, with specific identifications. It is when we focus on an actual "real world" organization that such mechanisms will assume specific identities, coinciding with specific embodiments.

Specific identifications should not obscure the general validity of evolutionary principles which are not restricted to the biological domain alone. The uniqueness of biological evolution is limited to the fabric of its particular mechanisms but not to the principles underlying their operations. On the level of underlying principles, there exists a definite correspondence, for example, between biological evolution and "symbolic evolution" where the latter is viewed as the domain of cognitive processes in which concepts, or procedures for control and computation, evolve (Pask, 1970). The claim for generality which underscores such a correspondence is particularly significant since it provides a logical link between the processes of biology and the cultural, symbolic domain in which much that is relevant to psychological and social evolution takes place.

### **REGULATION FOR EFFECTIVE VIABILITY— THE CYBERNETIC FORMULATION**

Before moving on to explore in further detail the implications of extending some of the fundamental ideas of cybernetics and using aspects of the theory of regulation as an interpretative tool for examining the concept of evolution, a brief review of the now classical formulation may be appropriate.

The central idea is that regulation achieves a goal (brings about a particular outcome) in the face of some set of perturbations. The approach is due to Sommerhoff and Ashby (Sommerhoff, 1950; Ashby, 1956) who defined the process of regulation as a function of five key variables and the manner in which these variables interact. These variables include a regulator, a regulated system, a source of disturbance, a set of all possible outcomes, and a set defining desired outcomes. While the differentiation

between these variables implies a sharp distinction, the latter may not be always actually possible. For example, when control is distributed throughout a system the distinction between "system" and "regulator" is blurred. Similarly the actual boundary between "a system" and "an environment" is not universally clear cut. Often such a boundary is imposed by an observer subject to his particular interest and point of view. Nevertheless, a conceptual differentiation is useful for the purpose of description and analysis.

The role played by the five key variables in the process of regulation is specified as follows (Ashby, 1962a): for a given situation, there is a set  $Z$  of all possible events that may occur whether regulation is applied or not. Of these, a subset  $G$  defines desired outcomes—those that correspond to a condition of stability for the system under regulation. In addition, there is a set  $R$  of events in the regulator, a set  $S$  of events in the system which is being regulated, and a set  $D$  of disturbances. Events in  $D$  produce conditions in  $S$  that cause outcomes to be driven out of  $G$ . Effective regulation is achieved if for a given value of  $D$ , events in  $R$  and  $S$  relate such that the outcome is bounded by  $G$ .

The relations between disturbances and the actions taken by a regulator can be formalized in terms of game theoretic concepts (Ashby, 1958a). From this viewpoint, a set  $D$  of disturbances  $d_i$  is countered by a set  $R$  of responses  $r_j$  producing a matrix of outcomes  $z_{ij}$  from a set  $Z$  of possibilities. The values taken by  $D$  and  $R$  correspond to a pair of moves selected by each of two players and the table of outcomes is identical with the pay-off matrix of game theory which specifies values of some desired commodity that are assigned to each move.

As before, of all the possible events in  $Z$ , obtained by the interaction of  $D$  and  $R$ , only a subset  $G$  contains acceptable outcomes representing values which are compatible with a system's "essential variables."  $R$  is considered an effective regulator if it can produce a counter action  $r_j$  for each  $d_i$  in  $D$  keeping the outcome within  $G$ .

The nature of the relation between  $D$ ,  $R$ ,  $Z$ , and  $G$  is such that the concept of regulation implies selecting from a number of possible actions the one most likely to achieve a goal. This selective aspect is a dominant feature of regulation especially in complex dynamic systems where regulation takes its more interesting and active form. Since effective selection depends on the availability and processing capacity of information, there is an obvious sense in which communication and information play a central role in regulatory processes. Ashby has stressed the intimate relation

between regulation and information (Ashby, 1956) and he has shown how regulation depends upon information transfer between pertinent system's components. From a qualitative viewpoint, regulatory actions are subject to information about specific disturbances, about the state of the system which is being regulated, and about the outcome. This relation can be given a precise quantitative expression using information theoretic concepts (Conant, 1968) and various regulatory schemes can be reduced to the characteristic structure of their respective information processes. For example, error-controlled regulation can be regarded as a special case of regulation in which  $R$  receives its information from variations in the outcome. It can thus react only after the effect of a disturbance has been manifest. In other types of regulatory schemes,  $R$  is provided with an information channel directly from the disturbance, making "anticipatory" strategies possible. In such cases, the regulator is activated before the actual effects of a disturbance have been registered and its counter actions are directed at the source of disturbance itself.

#### LIMITS ON REGULATION, AMPLIFYING REGULATION, AND VARIETY INCREASE IN EVOLVING SYSTEMS

According to the formulation given above, the process of regulation can be regarded as a sequence of events in which  $R$  selects a move  $r_j$  from a finite repertoire for each value  $d_i$  taken by a disturbance from the set  $D$ . The variety in  $R$ 's repertoire of actions puts a limit on its capacity as a controller since in order to regulate effectively, the variety of actions available to  $R$  must be at least equal to the variety in the disturbance. This concept, which is fundamental to the theory of regulation, is expressed in Ashby's "law of requisite variety." Ashby's law puts an absolute limit on the amount of regulation which can be achieved by a regulator of a finite capacity. It states that for a given variety in the disturbance only variety in  $R$  can force down the variety in the outcome.

The need for a particular amount of variety in a regulator is greatly reduced if its environment is characterized by fundamental regularities such as a continuity or a repetitive pattern of events. Thus, when a regulator "faces" a complex, dynamic world, a situation that is common in biology as it is in social and economic affairs, there are circumstances that make effective regulation actually possible even with a relatively low variety. Nevertheless, a system may be exposed to patterns of disturbances requiring an augmented regulation capacity. In such a case, an extension in

regulation potential will be essential, and if systemic disintegration is to be avoided, the regulatory capacity will have to be increased until it becomes adequate.

The limitation specified by the law of requisite variety prohibits any direct increase in the capacity of a regulator but it does not rule out supplementation. As Ashby has shown, if there is a continuity in an environment, a number of regulators can be linked in stages to form a more potent regulator with an increased overall capacity. When regulation is applied in stages, for example when a regulator  $R_1$  uses its selective power to form another regulator  $R_2$ , the capacity of the latter need not be bounded by that of the former. The possibility thus exists that a small amount of regulation, properly exercised at one stage, will make available a higher regulation potential at the next stage. The procedure can be repeated over a number of steps with the result that a significant increase in regulation capacity is achieved, the process as a whole showing an amplification.

Conceivable means for maintaining viability relate directly to the law of requisite variety and to the possibility in principle of amplifying regulation. The latter, in particular, makes possible an extension of the classical concepts of steady state and ultrastability to account for evolution. This extension goes beyond but is fully compatible with the original formulation. The basic argument proceeds as follows.

Depending on underlying conditions, various methods for achieving stability are possible. For example, if the environment is simple, in the sense that the pattern of its characteristic events is predictable, a regulator can be constructed as a physical barrier for blocking the effects of disturbances, or it can be made to embody a set of decision rules specifying an appropriate counter-action for each disturbance. Both cases require an ability to specify all disturbances in advance and they imply building into the regulator a variety which would exactly match all contingencies. This regulation strategy is manifest in special cases of adaptation where the range and magnitude of environmental variations is sufficiently consistent to make it adequate.

When the pattern of disturbances is particularly complex, or when it is constant for too short a time, specification of all possible configurations may be impractical. In such a case, an advantage can be gained if the regulator is made to incorporate a relatively large amount of variety, and if instead of a fixed set of rules it will contain an underspecified provision for

modifying internal states in a search for a match with specific conditions as they occur. This is the more general method of adaptation by ultrastability.

In spite of its great generality, the concept of ultrastability cannot account for the increase in complexity that is typical to evolution. As a strategy for regulation it can be greatly enhanced, however, if it is directed not only toward "experimental" modification of internal states, but also toward forming linkages with selected parts of the environment so that new organizations incorporating a higher variety emerge. Here in particular, a significant amplification of regulation capabilities can be obtained. The increase in variety that is involved is typical to the evolutionary process. It is relatively slow in biological evolution where it depends on genetic mutations and on primitive forms of cooperation and coalition formation; it becomes more rapid with the emergence of simple forms of learning; and it is accelerated further still, becoming ever more flexible and much richer in scope, in the symbolic environment of language, culture, and ideas.

A broad distinction can be made, accordingly, between three major and basically different regulation strategies. The simplest involves a precise specification of contingencies that is manifest in a mechanical adaptation or the incorporation of a fixed decision rule in a simple homeostatic mechanism. The second involves adaptation by ultrastability where a sufficient amount of variety is "built" into a system so that, within limits, changes in its environment can be matched by appropriate internal modifications, even when a specific decision rule is not available. The third is adaptation by evolution. As a strategy for ensuring an effective viability, it involves incorporating additional variety from the "environment," forming a new and more complex "unity." The latter corresponds to a new level of systemic integration which is marked by an increase in regulating capacity, and which is subject to selection for some specific survival advantage.

### AMPLIFYING REGULATION THROUGH EVOLUTION

The possibility of amplifying regulation has played a major role in the emergence of stable organizations on earth where circumstances favor the formation of active regulators which mediate local stabilities, selecting for those that are particularly effective in their task. Two ideas emerge in this context as all-important.

First, that in any complex dynamic system subject to the operation of

consistent constraints, some properties will be more resistant to change than others. These will tend to "survive" and gradually dominate their environment appearing as being particularly well adapted to its demands. If the total system is of an exceedingly high complexity, the selective processes leading to local stabilities may involve a wide range of dynamic activities rich in a variety of intriguing manifestations. Complex as such activities may be, they are all traceable to the phenomenon of adaptation (Ashby, 1962b).

Second, the active interactions of coexisting organizations (which are only partially autonomous in any case) continuously alter the properties of the medium in which they occur (Luria, 1973). As initial constraints are modified, and with them the norms of "survival success," new needs and conditions for further evolution are being continuously established, and the whole cumulative process proceeds with new possibilities and challenges created at each evolutionary step. The mutually adaptive processes that are inherent in the interaction of evolving organizations thus generate, as they unfold, the requirement for further adaptation.

In the process of seeking for a local viability, various organizations and modes of behavior arise, subject to satisfying the condition for stability under existing constraints. Relative to such constraints, favorable organizations and modes of behavior are allowed to persist and those that entail an improvement are encouraged to develop, thus generating step by step a trend that an observer would deem "evolutionary."

The selective process that mediates evolution is subject to the laws of control, specifically to the law of requisite variety and to the possibility of amplifying regulation. It operates simultaneously on two distinct levels. On one level it operates to increase the regulation potential of specific organizations, producing a better match between such organizations and the variety of their environment. On a higher "metalevel," however, it operates not just by selecting particular organizations at random, but by systematically encouraging variability in general. The outcome, as manifest by organic evolution on earth, is a local increase in the range and variety of adaptive possibilities and a consistent general trend characterized by a succession of progressively more complex organizations.

These involve a succession of stages which mark the ascent of living organisms and the development of a hierarchy of survival-related mechanisms. The latter range from mechanisms associated with differentiation and the formation of specialized organs, to mechanisms such as those involved with sexual reproduction, the formation of nervous systems and

ever more complex brains, and the development of various modes of perception and communication. They include social organizations of increasing complexity, together with all their technological extensions. Ultimately, they involve the emergence of such properties as self-consciousness, logical reflection, and moral judgment.

From the viewpoint of cybernetics, this succession is interpretable as manifesting an expansion in regulation capabilities and living organisms, as they ascend the scale of complexity, show their ascent by a growing potency for regulating their environment under a potentially greater range of conditions.

The crucial point is that a viable system that is well adapted to its environment can be regarded as a successful regulator in that the repertoire of its actions matches effectively the variety of the disturbances "threatening" its stability. The concept of selection, accordingly, can be seen as entailing a process that operates to encourage an appropriate match between a regulator's variety and the variety in its environment. In a complex dynamic world it would favor the formation of high variety regulators, those effective in securing viability under a wide range of dynamic events.

In other words, variety "mismatches" between interacting controllers will tend to produce a pressure for local variety supplementation. A dynamic environment of high variety can be expected, accordingly, to put a definite premium on the possibility of local increases in the potency of regulation capabilities. This condition in itself is sufficient to explain the persistent evolutionary tendency of forming stratified organizations of increasing complexity. Only through such a stratified organization, an increasing advantage in regulating capabilities can be achieved.

Thus, a perception of the world as a hierarchy of structures, differentiated by discontinuities and characterized by an increasing order of complexity and organization (Bronowski, 1970), obtains a specific functional meaning. Such a hierarchy can be regarded as a stratified organization of controllers interacting such that across its levels regulation is amplified (Ben-Eli, 1976). Each level in this hierarchy corresponds to a class of regulators, and these become more potent as they ascend the scale of complexity. Evolution is the process through which such a complexification—qua increase in regulation potency—is achieved and in this sense it can be regarded as an essential regulation strategy for achieving stability in a dynamic environment in which the context for stability is changing.

## SUMMARY—A CHARACTERIZATION OF EVOLUTION

Evolutionary processes can be depicted by a dynamic activity in a redundant network of interacting regulators involving the selective formation of linkages between initially independent loci of control. The overall context of stability will shift, and actual realizations of stable configurations in such a network will continuously change, as linkages are formed and reformed.

While such overall shifts and local changes depend on various "chance" events, they are not entirely random. They are directionally biased by selection processes which reinforce particularly "survival worthy" patterns, thus altering the condition probabilities of their own further realizations. As a result, evolution appears to an observer as a consistent trend involving a progressive increase in organization and suggesting an in-built drive for persistent self-improvement. Both features are fundamental to a concept of evolution and to a perception of life as a process which not only maintains but also constantly improves itself (Szent-Gyorgyi, 1974).

Current thinking, whereby the concept of a "stable process," or a "stable identity," has become synonymous with the notion of "organizational closure" (Von Foerster, 1976; Goguen, 1975; Varela, 1976; Pask, 1977; but also Maturana and Varela, 1975; Varela, Maturana, and Uribe, 1974—in a characterization of life), can be seen in a particular light with respect to the characterization of evolution as a process, involving relative changes in variety, especially relative increases and local amplifications of variety among interacting organizations.

The crucial point is that instances of variety increases are interpretable as involving the expansion of closure. Across a sequence of evolutionary steps the constancy of closure is maintained. At the same time, however, closure is also being expanded and improvements on previous norms of attaining closure are obtained. While variety is locally amplified, the means of ensuring closure gain in potency, thus expanding not only the closure itself, but the boundaries of the domain within which it can be attained (Ben-Eli, 1977).

The evolutionary sequence of realizations and continuous improvements of realizations which result, appear to an observer as a coherent trend (Pask, 1961) characterized by a consistent dominant feature. We are now in a good position to characterize this dominant feature specifically. It involves the systematic production, through variety amplifications, of ever more general regulators fitted for an increasingly more comprehensive niche.

At any instant, the question of how the next amplification, how the next expansion of closure will be obtained, is left unresolved. For even as it is confined to the circumstances of a particular environment evolution is essentially an open-ended process.

Above all, evolution is regenerative and unlimited, for as long as sufficient diversity is generated locally, and sufficient distinction is maintained, among interacting viable organizations. This fact is important in biology and in the context of the dynamics of stability of an ecology. It is especially significant to the question of the long-range viability of society, and, ultimately, of life itself. The implications to problems of policy in education, social organization, and social development are enormous.

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