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Levels of Control and Closure in Complex Semiotic Systems

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ABSTRACT: It is natural to advance closures as *atomic* processes of universal evolution, and to analyze this concept specifically. Real complex systems like organisms and complex mechanisms cannot exist at either extreme of complete closure or lack of closure, nevertheless we should consider the properties of closures in general, the introduction of boundaries, a corresponding stability, the establishment of system autonomy and identity, and thereby the introduction of emergent new systems of potentially new types. Our focus should move from simple physical closure of common objects and classical self-organizing systems to *semiotically* closed systems that maintain cyclic relations of perception, interpretation, decision, and action with their environments. Thus, issues arise concerning the use and interpretation of symbols, representations, and/or internal models (whether explicit or implicit) by the system; and the syntactic, semantic, and pragmatic relations among the sign tokens, their interpretations, and their use or function for the systems in question. Primitive semiotic closures are hypothesized as equivalent to simple control systems, and in turn equivalent to simple organisms. This leads us directly to the grand hierarchical control theories of Turchin, Powers, and Albus, which provide an explicit mechanism for the formation of new levels within complex semiotically closed systems.

INTRODUCTION

In evolved systems we recognize spatial scaling from subatomic particles through astronomical objects, and complexity scaling from subatomic particles through chemical systems to social organizations. Each of these threads is dominated by the same concepts: wholes and parts, insides and outsides, and alternating levels of variation and constraint.

It is natural to seek, if not a general evolutionary mechanism, at least a general descriptive language for these phenomena. The concept of *closure* takes an important role in this discourse. The resulting scientific program involves questions concerning the typology of closures, and how closures of all kinds are expressed in terms of more basic concepts. Two crucial questions relate to the extent, if any, that closures can be considered distinct from systems in general, and the role that closure concepts play in the great distinction between living and nonliving, semiotic and nonsemiotic, systems.

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CLOSURES, BOUNDARIES, AND SYSTEM IDENTITY

First, we must consider closure concepts in general and how they relate to boundaries, hierarchy, and system identity.

Special and Synthetic Senses of System

Within the systems literature we can recognize two broad families of systems definitions.[1] The standard view, which we will call structural, is perhaps best exemplified by Webster's definition of "a group of units so combined as to form a whole and to operate in unison."[2] This has been adopted in the systems literature in many forms. In mathematical systems theory this view is best expressed by the Mesarovic school,[3] which sees systems as mathematical relations (subsets of the cross-product of the constituent state spaces).

We call this view structural because it focuses on the specific given types of relations among specific types of entities. It entails entering into a relation among multiple entities, called parts, to form a new whole entity with new properties at a level hierarchically distinct from those parts. These new properties do not follow from considering the parts simply together as a collection, rather they must enter into a particular relation so that the whole is formed, resulting both from the parts as entities *and* from the particular way in which they are arranged, that is from their mutual interrelation and organization.

The other view of systems, which we call *constructivist*, is more recent. Consrtuctivism avoids concepts of existing entities with objective attributes, instead defining a system as a bounded region of some (perhaps abstract) space that functionally and uniquely distinguishes it. Thus, it emphasizes the perceptions, and most significantly the *distinctions,* drawn by people. "Certainly, [the making of distinctions] is the most fundamental act of systems theory, the very act of defining the system presently of interest, of distinguishing it from its environment."[4] Although this sense can be traced in the systems theory literature to Ashby[5] and Spencer-Brown,[6,7] and it resonates with postmodernism, constructivist epistemology, and "second order cybernetics",[8] it should be noted that it is also used in much of classical physics, beginning with thermodynamics, where a system is "any quantity of matter, any region of space, etc., which is selected for study and set apart (mentally) from everything else, which then becomes the surroundings" (Ref. 9 p1).

Recent *physical constructivists* such as Kampis[10] and Rosen[11] have emphasized that the natural world of evolving, emergent systems can never be sufficiently represented by formal systems with fixed, finite, universes of discourse that have been determined *a priori*. Instead they suggest open-ended systems that define or construct their own elements and universes of discourse through the emergent processes of their own self-creation and self-modification.

These systems are not *composed of* things, but are rather *defined on* things, and there is a clear distinction between their physical, "thinghood", and logical, "systemhood", properties. Gaines reaches the *solipsistic* limit of this trend, defining a system as "[that which] is distinguished as a system."[12]

Movement toward a synthetic sense of system, capturing both the structural and constructivist traditions, is both possible and desirable. Previously we have approached this within a more fundamental language of distinction, variety, and constraint, and on the distinction between cardinal (token) and dimensional (type) distinctions and variety.[1] It is sufficient here to note that both special senses and our synthetic sense entail the presence of a distinction, or boundary, between any system and its environment.

Boundaries, Closures, Throughputs, and Systems

In considering closures, then, it is crucial to more explicitly express this concept of the boundary between system and environment. This was first expressed by von Bertalanffy in his discussion of closed and open systems.[13] Perhaps the clearest formulation of this idea was due to Bunge,[14] who provided a pseudo-topological definition later corrected and deepened by Marquis.[15] To paraphrase in our language, Bunge considered a system in the structural sense, and defined a boundary element as a system element that, although contained within the system, also received influence from the environment. The boundary proper is then the collection of boundary elements, and the interior the remaining elements, which are not boundary elements.

Let us now simplify things somewhat and consider only a frame of reference fixed to a particular given system–environment distinction. Logically, we can then recognize only two forms of relations (entailments, forces, influences, etc.) that flow through a system–environment boundary. First, input–output relations are those that flow through the boundary in one direction or the other. These we call *linear*, and the resulting subsystems *throughputs.* By contrast, those influences that flow reciprocally in both directions simultaneously across the boundary we call *circular,* and identify *closures* as the corresponding subsystems.

Of course, we could also consider influences completely contained within either the environment or the system, but we do not do so here. We also recognize the circular relations as composed of two linear relations, in tandem, in opposite directions. Furthermore, we use the terms *linear* and *circular* generally, to indicate only that these relations flow through the boundary in either a one-way or reciprocal manner, respectively. Nothing is implied about other senses of the term, for example linear equations or linear systems theory.

If the circular relations linking system to environment are strong, then those aspects of the environment and of the system, respectively, that participate in those relations become very tightly linked. By contrast, those aspects of the environment and system that participate in the linear relations are segregated into distinct regions. The resulting process actually creates a *new* system: the closure of the old system–environment coupling becomes the interior of a new system, with those aspects that do integrate with the linear relations forming the new boundary (see FIGURE 1).

Conversely, we recognize the interior of the original system as a closure of some (yet undetermined) interior elements, whereas the original boundary is participating in linear relations with the original environment. In this (so far abstract) argument, we have demonstrated that closures are, in fact, the most general mechanism for system formation.

Properties of Closure

Each form of closure introduces a form of hierarchical scaling. In particular, *boundaries* (as we have seen) distinguish those processes that are included in the

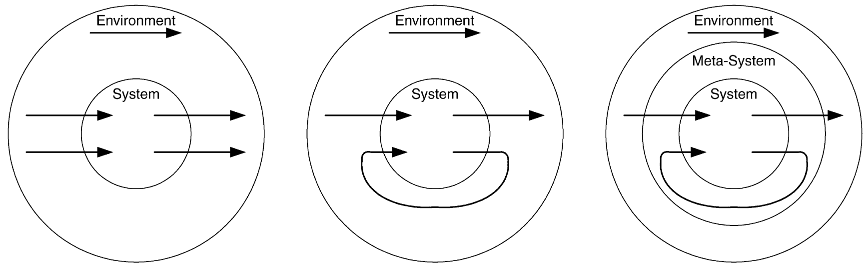

FIGURE 1. A possible mechanism for emergence: **left**, linear relations across a system boundary; **center**, a cyclic closure develops across the system boundary; **right**, which results in a new boundary.

closure (and are, therefore, inside the closure), from those that are excluded from the closure (and thus outside). There is a corresponding *stability,* in that processes involved in the closure generally exist at a relatively smaller spatial scaling, and both faster and more permanent temporal scaling, than those outside. It is through this hierarchy that system *identity* itself is established in terms of those boundaries and stabilities. Finally, each closure can be recognized as imparting a form of *autonomy*[16] in terms of the circular relations in the interior.

Types of Closure

Generally, we recognize a continuum of classes of systems in terms of closures and throughputs. One extreme is when the system is totally closed: the boundary is empty, and all elements are in the interior. This corresponds to an idealized adiabatic isolation: no energy or information can flow across that barrier. No processes of organization or development can occur, but rather there is only an inexorable collapse to thermodynamic equilibrium.

The other extreme is when the system is totally open, totally throughput—all elements are in the boundary, and none are in the interior. This extreme is also an idealization—as a system becomes less closed from its environment, it becomes more involved in linear flows, and has weaker boundaries. In the limit, it actually loses all identity and ceases to exist as a distinct system.

Thus, it is clear that real, complex systems (the systems that are of most interest to us, like organisms, complex mechanisms, and distributed information systems), cannot exist at either extreme of autonomy. Rather, they are all both autonomous in certain modes with respect to their environments and simultaneously involved, in other modes, in throughput relations with their environments. Thus, closure is not an unequivocal concept, but rather admits to degrees as the balance between linear and circular processes changes, possibly from one extreme to the other.

Many particular types of closures are also recognized in systems science, including:

- *Self-Reference:* Closure of reference within a system, for example within a formal language or natural linguistic community, reflected in the *referential autonomy* of these systems.

- *Self-Organization:* The concepts we have identified above are readily apparent in classical self-organizing systems, for example, closures in autocatalytic cycles and attractors of dynamical systems.
- *Autopoeisis:* Where organizational closures result in stability and creation of self-producing systems.
- *Control Systems:* Where causal closures result in stability of controlled variables.

Physical Closures and Hierarchy

As mentioned above, one crucial property entailed by closure is hierarchy, or the recognition of discrete levels in complex systems. Thus, the results of our discussion can be seen in the work of the hierarchy theorists. In particular, Salthe recognizes these as *scalar hierarchies* in physical systems.[17]

A number of systems theorists[18–23] have advanced theories that recognize distinct hierarchical levels over vast ranges of physical space. Each of these levels can, in fact, be related to a level of physical closure in our sense; that is, circularly-flowing forces among a set of entities, for example among particles, cells, or galaxies. In one sense the advances of these scientists are modest, dealing only with physical systems, and usually with gravitational interactions in astronomical systems. Nevertheless, in their work we can see some form of vindication for the grand unified scientific view propounded by early systems scientists, such as von Bertalanffy and Boulding.

The overall issue of levels in systems has been treated very well by Havel,[24] who casts scale as a dimensional unit similar to space, time, or mass. From this perspective, discrete levels of hierarchy are represented as discrete entities along this *scalar dimension.* Such discrete layers are absent, for example, with fractal structures, which, by virtue of their self-similarity, are actually *smeared* to different extents vaguely across a wide range of scalar values. It can be hypothesized that the emergence of such distinct scale-thin regions would indicate the presence of circular, closed forces and, thereby, closures in our sense.

One last thought here is that we traditionally think of hierarchies using the mathematical metaphor of a tree, or a branching structure where each upper level is composed of a distinct set of constituents or parts, each of which belongs to only one such whole. In fact, mathematically, any partially ordered structure, for example one in which parts can exist in multiple wholes, can be represented as being decomposed into distinct levels.[25,26] As we have considered it here, this would result again from components participating in multiple kinds of relations and, thus, possibly existing in multiple closures simultaneously.

SEMIOTIC SYSTEMS

So far we have considered the typologies of closures that include physical objects and classical self-organization as closures of flows and structures. These systems are, of course, sufficiently interesting in their own right, and bring many important questions about the measurability of emergent properties.[27] However, our focus should move from these relatively simple and well understood cases to the kinds of systems that really interest cyberneticians; machines and organisms. In particular, these systems admit to the kinds of *specification hierarchies* discussed by Salthe.[17]

Semiotic Relations

What characterizes these systems is that they involve processes of perception, interpretation, decision, and action with their environments. These semiotic processes involve the reference and interpretation of sign tokens maintained in coding relations with their interpretants. Thus, issues arise here concerning the use and interpretation of symbols, representations, and/or internal models (whether explicit or implicit) by the system; and the syntactic, semantic, and pragmatic relations among the sign tokens, their interpretations, and their use or function for the systems in question.

Semiotic relations are characterized by being *contingent functional entailments*. In particular, they are entailments, meaning regularities of constraints in system relations; which are functional, meaning deterministic (equivalent to a mathematical function); and which are contingent, namely that other such functional entailments (coding relations) could have been possible. This concept captures the arbitrary coding nature of symbol systems—the symbol and its referent share no properties in common except that the symbol refers to its referent when interpreted by an agent acting within the constraints of the symbol system. These are contrasted with purely physical systems, which are characterized by necessary functional entailments.

Simple Semiotic Systems

Again, drawing from the systems literature and our prior work,[28] we recognize two canonical classes of semiotic systems corresponding to our two classes of overall system relations across boundaries, as shown in FIGURE 2.

- *Control Systems as Semiotic Closures:* Primitive semiotic closures are hypothesized as equivalent to simple control systems, and in turn equivalent to simple organisms.[29] Such systems form semiotic closures with their environments, and entrain cyclic processes of measurement, interpretation, decision, and action. Such semiotic closure was first introduced by Pattee in the form of statistical closure[30] and then semantic closure.[31]

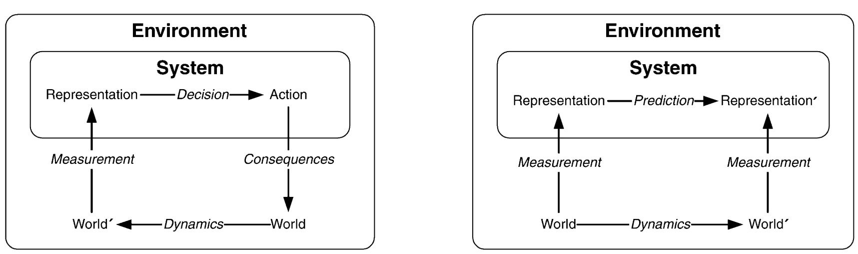

FIGURE 2. **Left**, a primitive control system (semiotic closure). **Right**, a primitive model (semiotic throughput).

- *Models as Semiotic Throughputs*: In primitive semiotic throughput systems are hypothesized as being equivalent to simple models. Here the measurement process produces internal representations of environmental states, but there is no reciprocal action back into the environment to complete a closure.

Complex Semiotic Systems

We conclude by pointing to where a more detailed continuation of this discussion leads. In particular, organisms and mechanisms clearly involve multiple, hierarchically nested levels of both models and control relations. In general, we are interested in *anticipatory control systems*, where an internal model of the environment is used by a control system to make predictions as to which actions to take to maintain good control. Consideration of the origins and operations of such systems lead directly to the grand hierarchical control theories of Turchin,[32] Powers,[33] and Albus that provide an explicit mechanism for the formation of new levels within complex semiotically closed systems.

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