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Opening Up Closure: Semiotics Across Scales

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Abstract: The dynamical emergence of new levels of organization in complex systems is related to the semiotic re-organization of discrete/continuous variety at the level below as continuous/discrete meaning for the level above. In this view both the semiotic and the dynamical closure of system levels is re-opened to allow the development and evolution of greater complexity.

Introduction: Semiotics and Dynamics

I would like to offer what I believe is an interesting hypothesis about the relationship between semiotics and the dynamics of complex self-organizing systems. It assumes that the interesting complexity of such systems arises from the emergence of new levels of organization over their history. The fundamental proposal is that each new emergent level of organization in the dynamics of the system functions to re-organize variety on the level below as meaning for the level above. In this way, both the semiotic and the dynamical closure of system levels is re-opened to allow the development and evolution of greater complexity.

In order to clarify just what this proposal means, it will be necessary first to consider a number of concepts on which it is based. I will need to specify what I mean by levels of organization in a complex system, and how they relate to one another dynamically. For this I will rely mainly on the 3-level paradigm of Salthe.[1, 2, 3] Next, I will outline the kind of semiotic relationships that I believe can exist between levels. For this I will introduce a variant of Peirce's semiotics,[4,5] in which a basic distinction will be made between categorial meanings and meanings based on continuous variation. Finally, I will propose

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that emergent levels of organization tend to re-organize continuous variation at the level below as categorial information for the level above, and vice versa, perhaps in a hierarchy of alternating transformations between these two varieties of meaning.

Hierarchies of Scale in Complex Systems

Certainly for biological systems, and probably for many others as well, the richness of their complexity derives in part from a strategy of organizing smaller units into larger ones, and these in turn into still larger ones, and so on. Such hierarchies of scale are well recognized in modern biology. The parameter which most simply defines differences in scale, usually of a quantitative order of magnitude or more, may be taken to be the mass of a unit of organization on some level, the linear distance scale of strong correlations or interactions among the constituents of a unit, the energy scale of characteristic processes in which the units participate (typical amounts of energy exchanged in such processes), or the characteristic durational times of the cycles or processes which constitute the unit. As we move from level to level up the scale hierarchy, units get more massive, bigger, more energetic in aggregate (but with less energy used per interaction on the relevant scale), and slower in operation.

The dynamical relations among adjacent levels are what most concern us here. If we designate a level-in-focus, on which there is some emergent phenomenon constituting some units-of-interaction on a characteristic scale (level N), then in the 3-level paradigm of Salthe (see Figure 1) we assume that units on level N are constituted by interactions at level (N-1) among the units at that lower level, but that of all the possible configurations which such interactions might produce at level N, only those actually occur which are allowed by boundary conditions set at level (N+1). The logic of this dynamically is that the stability of a configuration of level (N-1) units at level N depends on the putative interactions among these new units at level N. Such higher-order interactions do not generally occur in an infinite and empty vacuum, but rather in some context (a container, a medium, an environment) some of whose properties (e.g. temperature, pressure, ambient energy flows) are specified by still larger-scale dynamics (e.g. solar insolation, atmospheric pressure, salinity). Only those configurations at level N will be even meta-stable on the appropriate time-scale which are consistent with the constraints imposed from level (N+1). The properties of units and interactions at level (N-1) are *constitutive* for level N phenomena; those at level (N+1) are *constraining* for level N phenomena. (Salthe refers to 'initiating conditions' from N-1 and 'boundary conditions' from N+1.)

This is still a synchronic, or steady-state view of hierachically organized systems. More truly dynamically, the model assumes that new levels of organization always emerge *between* previously existing levels. New complexity arises in systems because the new level N re-organizes the relationship between level (N-1) and level (N+1). Level N units and their interactions now *mediate* between the levels above and below: not all variety at level (N-1) remains available for re-organization at level (N+1), there is a *filtering* performed by level N. Conversely, we may say that level (N+1) is *buffered* against variations at level (N-1) by the stabilizing mediations at level N. This principle is closely related to the model of Ehresmann and VanBremeersch,[6,7] in which each level of organization can be realized by a variety of combinations at the level below; thus changes at that lower level do not result in qualitative differences at level N, and may not produce any effects at level (N+1). This is also qualititatively similar to Thom's principle of structural stability.[8]

At the same time that the emergence of stable units and processes at level N reduces the flow of information from level (N-1) to level (N+1), thus in one sense simplifying the dynamics of the system (there are fewer possible dynamical combinations allowed), and so making it more *specified* (cf. Salthe on the 'specification hierarchy',[1,3] and see also Lemke [9]), the emergent level now also means that a new *kind* of information must be given in the description of the system; in this sense it has become more 'complicated'. We need new descriptive categories to talk about the units and phenomena of level N. Insofar as the emergence of level N may occur developmentally only following the prior emergences needed to produce its immediate precursor organization (the original level N-1 units, level N+1 conditions, and their dynamic relations), the system has also now reached a new degree of 'logical depth' in the sense of Collier and Hooker.[10,11]

Furthermore, the new organization of the system now presents us with new options for its further development, specification, or evolution. Once some particular units and phenomena at level N have emerged, it is now possible for still newer levels to be interpolated between (N+1) and N, and between N and (N-1). Each new level of organization augments the evolutive potential of the system for increasing its organizational richness still further.

[Insert Figure 1 about here]

Before leaving the issue of dynamical scale, I want to add one more point that will be relevant later on. For typical biological systems, such as cells or multicellular organisms, all of the scale parameters listed above (mass, size, energy, time, etc.) tend to shift in step with one another and it does not much matter, beyond analytical convenience and the availability of data, which we use. But this is not always the case. An important critique of the application of systems theory to human communities and their technological infrastructures has been made by Latour,[12,13] who notes that our usual systems theories assume a particular topology: we assume that units closer in space are always more likely to interact than more remote units are. This leads to assuming a 'spherical' topology for system: we envision its levels of organization as nested spheres of larger and larger spatial scale. But it is perfectly possible for two distant units to interact more intensively or more frequently than two nearby units, if the distant units are connected by a stable channel of communication, while the nearby units are not. This leads to a 'network' topology in which units on the same network interact more than units that may be nearby in space but are 'off' the network

In these more general cases, what happens to the neat notion of scale levels? I believe that it can be shown that what matters in the general case is not specifically spatial scale, but time scale.[14] This is so to the extent that what makes a "level" in a system is its dynamical functions in relation to other levels, and insofar as the key dynamical function I am proposing is semiotic reorganization, what matters is the informational or communicational coherence of a level (and its relations to adjacent levels). If we think in terms of subnetworks within a network topology, then the way in which scale levels can be defined is in terms of the *adiabatic principle*, which insures that levels are relatively insulated from one another if the timescales of their characteristic and constitutive processes are sufficiently different that they cannot exchange significant amounts of energy on each other's relevant timescales.

Topological vs. Typological Semiosis

My basic proposal is going to be that each new emergent level serves to reorganize one type of semiotic information from the level below it as another type for the level above it. What are these two basic types of semiosis? I will follow the basic model of C.S. Peirce, with a few specializations of terminology, to explicate these types. Semiosis is a process of meaning-making. It is a process of construing some material entity or phenomenon as a *sign*, rather than simply interacting with it energetically. In Peirce's terms, the entity or phenomenon is called the *representamen (R)*, and what we take it to be a sign *of* is called the *object (X)*. But Peirce wisely recognized that no R directly points us to a corresponding X; there is work of interpretation to be done, there are principles or codes by which this interpreting is done, and so there must be, in my terms, a *system of interpretance (SI)*. A sign is only a sign for some SI; R is a sign of X only for some SI.

The first step in defining a role for semiotics in the dynamics of multi-level systems is to map these defining elements of semiosis onto the 3-level paradigm of scale organization, as in Figure 1. Units or phenomena on level N are representamina, R, *of* object-states, X, of the interactions of units at level N-1 which dynamically constitute the phenomena at level N, *for* processes or structures at level (N+1), which form the system of interpretance, SI, with respect to which correspondences between R's and X's are defined and computed. Note that this implies that the SI always has both a slower timescale, and usually a more global spatial-extensional scale, than the phenomena which it interprets.

It is useful here to note the precise sense in which semiotic interpretation differs from simple physical interaction. When an organism encounters some photons or some molecules of a particular chemical species, there is a physical interaction of these entities with the organism's sensors on the corresponding scale (e.g. molecular). That is interaction. But if the organism as a whole, mediating and buffering the molecular-scale consequences of this interaction through the dynamics of other higher-scale levels of its internal organization, reacts in a way that is adaptive to the presence of food, or predators, in its environment, then it is reacting on a higher scale level than the purely physical, initial molecular-scale interaction, and it is thus acting as a *system of interpretance*, as if it were interpreting the encounter with the molecules or photons as a *sign* of the presence of food or predators (in Peirce's terms, an 'indexical' sign). The organism reacts to the molecules not just as molecules, but also as telltales of and cues for response at a higher-scale level. The extension of the anthropomorphic metaphors of 'interpretation' to simpler biological and even non-biological material systems are carefully considered by Anderson et al. and in the work of Hoffmeyer and Emmeche.[15,16,17]

In order to continue my larger argument, I need now to distinguish two broad classes of semiosis: (a) those cases in which the features of a representamen which are criterial for some SI to interpret it as a sign of some X may vary continuously, so that quantitative differences of degree in a feature of R normally lead to differences of degree or kind in the interpretant, *vs*. (b) those in which all representamina are classified by the SI into a discrete spectrum of types, and each R-type is interpreted as a distinct X. I will call the first case 'topological semiosis'; it is a generalization of the notion of analogue signaling. By 'topological' here I really mean to invoke the topology of the continuum of the real numbers: it is continuous variation, quantitative differences of degree that matter. I will call the second case 'typological semiosis'; it is a generalization of the principle of digital signaling.

[Insert Figure 2 about here]

The complications here arise from the fact that although we may normally map continuous variation in X onto continuous variation in R (the usual 'topological' case) or discrete variants of X onto discrete variants of R (the usual 'typological' case), as in Table 1), nonetheless we may also have *mixed modes* of semiosis in which the continuous is mapped onto the discrete and vice versa. The mixed modes are relatively rare in human cultural conventions for symbolism and representation, but I believe they are fundamental to the inter-level relations of dynamical systems.

[Insert Table 1 about here]

We often adopt the typological principle also for our mathematical and scientific symbol systems. A chemical element may be Carbon or Nitrogen; there is no continuum of elements (so far as we know) between them, and we represent them by discrete symbols: there is "C" and there is "N", we do not adopt the real number line to represent atomic species, as we do, for example, for atomic weights. But we do indeed need and use the topological mode of semiosis as well. In the pure case, this means representing a continuously variable X by a continuously variable R, or equivalently, interpreting continuously variable R as continuously variable X. Thus we typically represent continuously variable dynamical parameters of a system by real numbers, or by positions on a line or in a 2- or 3-dimensional space (e.g. Cartesian graphs). We could, and with the new methods of computerized scientific visualization increasingly do, represent them by the continuous visible color spectrum, or by degrees of brightness, or by acoustic pitch or loudness. Topological semiosis is at least as important and general as typological semiosis in the representation of nature and its dynamical systems.

If 'information' is, in Bateson's famous phrase 'a difference that makes a difference',[18] then it is clear that both *difference of kind*, and *difference of degree* can make a difference. Each can be the basis of semiosis, each can be interpreted as representing a difference in the object X for which some representamen R stands for a particular system of interpretance, SI.

Consider an example at a molecular level. When proteins fold up into their complex 3-dimensional spatial conformations, then at the scale of an amino acid what we see is discrete typological variation: each constituent unit is either this amino acid or that one, there is no continuous variation among kinds of amino acids. At the scale of the protein as a whole, interacting with something else at the same scale, what matters is the continuously variable distances and angles of its local conformational shape and electromagnetic fields. But at the still higher scale of a membrane with binding sites composed of many interlocking proteins, the complex spatial configuration of a ligand matters only insofar as it does or does not occupy a site and produce some triggering effect. The membrane reads only discrete ligand classes in many cases, and is blind to the details of the conformation, so long as they are within certain parameters. Many of our successful medical drugs are simply 'imposters' which fool the membrane, or some other complex larger-scale structure, because they are indistinguishable as members of the ligand equivalence class defined by the membrane, which is thus operatingas a higher-scale system-of-interpretance (or part of such a system).

[Insert Figure 3 about here]

Considering both the logic of the 3-level paradigm, in terms of how semiotic functions are mapped onto dynamical scale levels, and many examples such as those just given of the reorganization of continuous variation into discrete variants (Figure 3, upper), and of discrete variants into continuous variation (Figure 3, lower), has led me to what seems at least heuristically an interesting conjecture:

The Principle of Alternation:
Each new, emergent intermediate level N in a complex, hierarchical, self-organizing system functions semiotically to re-organize the continous quantitative (topological) variety of units and interactions at level (N-1) as discrete, categorial (typological) meaning for level (N+1), and/or to re-organize the discrete, categorial (typological) variety of level (N-1) as continuously variable (topological) meaning for level (N+1).

In each case, level (N+1) functions as the system of interpretance which construes entities and phenomena at level N as signs of microstates of the system at level (N-1). By extension, where these level (N-1) states correspond to the effects of interaction with the environment at level (N-1), higher levels of the system respond to them as signs at level N of phenomena in the environment at level (N+1), which may have only a very indirect causal-material relationship to the actual interactions at level (N-1) or none at all.

Dynamics and the Principle of Alternation

The basic mapping of semiotic functions onto organizational scales in Figure 1 has a dynamical implication, if we interpret it in terms of the evolution or development of the system:

Principle of Emergence:
A new level in the scale hierarchy of dynamical organization emerges if and only if a new level in the hierarchy of semiotic interpretance emerges.

This is in some sense a logical precondition for the Principle of Alternation. The exact connection between the two becomes clear if we ask ourselves whether the semiotic relationship between adjacent levels of the dynamical scale hierarchy could be a simple mapping of continuous variation at the level below to continuous variation at the next level up? Or of discrete variants at the level below to discrete variants at the next level? This is logically possible, but would we then consider that there was any point in saying that a qualitatively new level had emerged? And if it had, what would its functional advantages be? In a mapping of continuous variation onto continuous variation, there is very little room for novelty or innovation; there is only re-description. Similarly for mapping one discrete set onto another; what else is this but re-naming, especially if it is one-to-one? As Ehresmann and vanBremeersch argue in the case of a logical model of hierarchical multi-scale systems,[6,7] the novelty of new levels arises in part because each higher level has many possible realizations at lower levels. It is only a many-to-one mapping that provides for classification, and filtering and buffering (from level N-1 to level N), as the 3-level dynamical scale model expects. The 3-level model of course also expects that as we go up one more level, a categorial element (at level N) can be interpreted (at level N+1) to have many possible meanings, or system responses, depending on contextual constraints from 'elsewhere' (at level N) that are integrated by the higher-scale (more global, longer timescale, N+1) level.

I believe that this dynamical logic appears to us users of human categorization as an alternation between topological and typological semiotic relationships of adjacent levels, taken in (possibly overlapping) groups of three. This is clearest in the cases where quantitative variability is reduced to discrete categorial variants. We know of many applicable mathematical models in which continuum dynamics produces discrete states, when subject to higher-scale boundary constraints: discrete spectrum eigenvalue solutions, bifurcations, discrete attractors and their (classificatory) basins, threshhold effects of all kinds. What is a bit less obvious is how the complementary half of the cycle of alternation proceeds. How do systems interpret discrete variants as continuous variation?

The answer in all cases is the same as for the continuum-to-discrete part of the cycle: by going up one level in scale. We have already seen one example of this: protein polymerization. At the small-molecule scale, the protein and its interactions in vitro are defined by the discrete typology of the constituent amino acids (level N-1). But when we consider the protein molecule as a whole, and interactions at a higher scale level (level N) that depend on, say large-molecule to large-molecule interactions, then it is the continuously variable conformational shape of the folded protein that matters. A shape which is co-determined both by the amino acid sequence (from level N-1), and by contextual-environmental constraints (level N+1) of the overall global cell chemistry (which determines, for example, the cytoplasmic pH, temperature, or similar global conditions). We should not be surprised that what at the more micro- scale look like discrete units, appears from a more macroscale perspective as continuous variation. This is the basic molecular-to-molar logic of chemistry. At the pauci-molecular scale (Halling 1989, Kawade 1996) reaction pathways depend on discrete, non-stochastic interactions of specific molecular species; but when we proceed to larger scales, such as global cellular chemistry, then we are closer to the regime of concentration-dependent effects where the Law of Mass Action applies. Concentration-dependent effects and chemical gradients are large-spacescale, long-timescale averages over discrete molecular interactions.

If we consider neurocortical activity in the brain, even in a simple model in which neural 'firing' is all or nothing (discrete variants), as we move up in scale we eventually find that there are global coherent phenomena that average over many individual 'firings' to produce the alpha and other well known EEG rhythms of continuous variation. Karl Pribram's (1991) famous 'hologram hypothesis' also posits that functionally meaningful patterns are construed more globally across neurological activity. We also know that individual firings of nerves that activate bundles of muscle fibers are globally coordinated at a higher scale (and a longer timescale) to produce smooth motor action of an entire muscle or muscle group.

Thus discrete items may be averaged to net densities and concentrations, discrete units organized into polymers and lattices (which have global coherent effects such as elastic propagation modes, which are again quasi-continuously variable phenomena), and discrete events globally coordinated to produce smooth, continuous higher-scale actions.

What the Principle of Alternation proposes is that the transformations of discrete to continuous and continuous to discrete *alternate* as we move from level to level of the dynamical hierarchy, and that in doing so they represent a *semiotic transformation* of the information content of lower levels as *signs* for higher levels, allowing *many-to-one* classifications and *one-to-many* context-dependent reinterpretations. A scale of dynamical processes in a system, at which such transformations occur, meets the logical conditions for novelty that define for us a genuinely *emergent* level of organization.

Table 2 illustrates a possible sequence of such alternations from level to level, though clearly our, or at least my, knowledge of all the intermediate scales is too limited to present it as more than a suggestion of the plausibility, or at least the heuristic value, of looking at the dynamics of multi-scale systems from this perspective.

[Insert Table 2 about here]

Alternation and the Re-opening of Closure

Let us return, finally, to the theme of closure. In what sense are self-organizing systems closed? And what is the relevance of closure to the evolution of complexity? S*emiotic closure* entails that in some sense the system's dynamics depends on exhaustive sets of classificatory alternatives, but it is saying something different from the well-known *semantic closure* thesis of Pattee,[19] which posits that the semantics of classificatory symbols completes the dynamical description of such systems by specifying initial conditions on general dynamical laws.

Pattee's thesis has much in common with the argument being presented here. He emphasizes what I have been calling typological semiosis, and speaks of the type categories as 'symbols' which have both a local material structural instantiation and a function in relation to a more global system organization that 'interprets' them. His concern is not explicitly with levels of scale in this process, but he does follow von Neumann's arguments to posit "multiple-level descriptions when we need to relate structure to function." It is not clear if these are only distinct logical levels, or also scale levels, as proposed here. Pattee's very general notion of semantic closure is thus already an integral part of the proposals here. (I might, however, differ with his conclusion that only natural selection can explain the symbolic dimension; across levels there is an intimate dialectic between physiological process and already-semanticized structures, leading to new symbolic functions that depend as much on material self-organization as on selectional accumulation of stored information.)

Semiotically, each higher level is characterized by its own exhaustive paradigms of types, and dynamically the inter-level relations (for adjacent levels) come to be (ontogenetically, as phylogenetically) such that normal fluctuations at lower levels *do not* *matter* because they do not, by construction, alter the 'structural stability' (in the sense of Thom [8]) of the structures they constitute at the higher level. But semiotic closure as a *typological* notion can never be the whole story. We all have two eyes, but they are never the same distance apart, never the same exact shape or size. All faces look much alike at some level of typological classification, but their quantitative 'topological' differences allow us to distinguish them as individuals *and* to form, at a new intermediate level of interpretance, Gestalt patterns (again types) of recognition from many quantitative features, and then classify these patterns yet again. In development, the type-specific features are equifinal, but there is still plenty of room for quantitative individuation. *At* levels of organization where only typological difference matters, and *for* levels for which this is true, we can speak of semiotic closure *within* a level. But if the Principle of Alternation is a useful guide, then *across* semiotic triples of levels, there is always somewhere a lack of *topological-semiotic* closure, and it is this very source of *potentially* meaningful open variation which is reorganized at some higher level again into a new *typological-semiotic* closure.

We also make more sense of closure if we look at the development (in the individual instance) or evolution (of the type-class) of a hierarchy of orders of closure at various scales of organization. According to the 3-level paradigm, new emergent levels of organization come-to-be *between* always pre-existing scales. This is a dynamical hypothesis, based on semiotic motivation. It says something about how additional levels of organization get added to an initial multi-scale dynamical system (perhaps including the primordial case of a non-semiotic two-level system). The typological order at some level, with respect to the SI level above, always has some residual quantitative variability that initially is 'ignored' by the level above. But it can (and presumably must, though 'under what conditions?' remains a key question) happen that certain correlational patterns within this residual quantitative variability *become* significant for the level above. This does not add new types to the original lower level, it remains semiotically 'closed'; but the correlational patterns in quantitative relations *among* these units now constitute a *new intermediate* level just insofar as they do come to matter to the level above.

Why do these particular correlational patterns, among all the possible ones, come to be selected out as signficant at a higher scale? We can still say it is because they are 'adaptive' at the higher scale, but what we mean now is that they are the lower-scale *signs* of something that makes a difference on larger scales, particularly on longer timescales, than the ones on which they themselves exist. It may be that they are the system's way of feeling ahead into its future, or at least into the future with respect to the timescale of the level in focus. One can say, with a pointlike-present view of time, that they aid 'anticipation' at that level.[3,20] Or equally we can say that they are the means by which the temporal coherence, the organization and integration of processes across different timescales, is achieved.

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Table 1. Typological vs. Topological Semiosis

Type-X represented as: • spoken word • written word • mathematical symbol • chemical species	Quantitative-X represented as: • size, shape, position • color spectrum • visual intensity • pitch, loudness
	Iconic scale models, maps
	Indexical voltmeter, thermometer
	Symbolic cartesian graph scientific visualization

Table 2. The Principle of Alternation -- Examples

Quantum variety (typo) organized as molecular charge distributions (topo)
Biomolecule conformations (topo) organized as ligand class information (typo) by larger-scale membrane polymers
Pauci-molecular reaction pathways (typo) organized as molar concentration-dependent effects (topo) at global cell-chemistry scale
Molar chemistry (topo) organized as neuro-transmitter threshold effects (typo): “firing”
Firings in neural nets (typo) organized as coherent cortical effects (topo): “brainwaves” "holograms"
Cortical dynamics (topo) organized as limit cycles (typo): “percepts” “phonemes”
Neuronal attractor effects (typo) organized as smooth motor behavior (topo): “drawing” “gesticulating” “enunciating”
Smooth motor behavior (topo) organized as visual and verbal signs (typo): “gestures” “words” in ecosocial supersystem as meta-system of interpretance

FIGURE 3. -- SET AS TABLE??

Figure 3: ***Trans-organization across modes***

Level N-1 Topology to Level N Typology

- continuum dynamics to eigenvalue types
- bifurcations, attractors, basins
- threshhold effects
- topological variety to equivalence classes
- fuzzy sets to sharp sets ??

Level N-1 Typology to Level N Topology

- Discrete items averaged to net densities, concentrations
- Discrete units organized as polymers, lattices, networks
- Discrete lattice or network dynamics organized to coherent macro-phenomena ("propagation") and molar
- property effects ("elasticity")
- Discrete events organized as continuous action (neural firings --> smooth motor actions)

NOTE -- FIGURES 1 AND 2 ARE INCLUDED ON THE DISK AS GIF FILES.