Computing Anticipatory Systems: A Generic Structure of Organization

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Abstract.

A theory of organization of complexity was constructed in order to create a common semiotic lineage among the diverse symbol systems used by various disciplines (Chandler, 1996, 1997). The foundations of the theory are developed from observations on the nonlinear dynamics of organisms within ecoments -- ecoments being defined as the immediate surroundings of one hierarchical degree of an emergent system. Each system (sub-system, sub-sub-system ...) is assigned four primitives attributes (closure, conformation, concatenation and cyclicity) which are subject to scaling and semiotic constraints. In principle, each of these four terms is enumerable for a local system. Degrees of organization (symbolized as O°) are composed from lesser organized systems to higher organized systems in terms of the enumeration of the four primitives. The emergent organizations are enumerated: 1, 2, 3, ... The patterns of organization at any particular level, O°, are composed from patterns at other levels. Thus, no particular science or philosophy is assigned a privileged role in the unfolding of the dynamics. Mathematically, the organized systems are composed under the scientific representations of categories as developed in Chandler, 1991, and Ehresmann and Vanbremeersch 1987, 1997. Categorical objects have the unique mathematical characteristic of creating a 'logical shell' for other classes of mathematical structures. (see S. Mac Lane, Mathematics, Form and Structure, 1986.) This 'logical shell' character of category theory is used here to construct hierarchical relationships between scientific observations and mathematical structures. This notation parallels natural history and allows the facile accounting of the molecular biological mechanisms within a living system. Implications of this theory of natural organization for the design of artificial hierarchical systems are apparent.

Keywords: Organization, complexity, hierarchy theory, category theory, dose-response.

I. Introduction.

Historically, an objective of scientific and engineering computations was to create a basis for comparison with experimental observations or to make predictions.

One outstanding computational problem is to calculate the dose - response relationships for living organisms (Chandler, 1985, 1986). For example, a common problem is to predict the effect of chemical exposures on health or disease states. This problem remains theoretically intractable, although a number of different approximations for carcinogenesis and mutagenesis are available. A generic aspect of complexity is to identify a symbolic representation of a complex system which can be formalized for biological predictions.

Rosen describes complex relations as an unspecified sort of coding problem. From natural systems to formal systems becomes a form of encoding (observations and measurements) operation and from formal systems to natural systems becomes a form of decoding (predictions). Within the formal system itself, the rules of inference are applied to the encoding (Rosen, 1985, p. 74). A mathematical relation manifested by the encodings is then imputed to the natural systems so encoded (Rosen, 1985, p. 211). An open question is whether or not the relational diagram constructed by Rosen can be extended to hierarchically organized systems.

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For example, should the Rosen "encoding" of dose - response equations for a chemical mutagen be in terms of the graph of the chemical structures or in terms of the functional behavior of the organism?

Memory Evolutive Systems (MES) were constructed by Ehresmann and Vanbremeersch (Ehresmann and Vanbremeersch, 1987, 1996, 1997) using extended hierarchical category theory. MES theory is closely related to phenomenological description of complexity. (Chandler, 1991, 1992, Chandler, Ehresmann and Vanbremeersch, 1996)

The objective of this paper is to sketch a conceptual framework, termed the C* hypothesis, for the hierarchical organization of complexity which is consistent within the natural sciences. Earlier papers provide the conceptual linkages between dose-response relationships and the present work. (Alavanja, et al, 1989, Chandler, 1985, 1995)

II. Concept Space for the C* Hypothesis.

The notation for the C* hypothesis is grounded in several disciplines. The notion of a "concept space" is used to link observations from experimentally remote disciplines. Kaplan asserts that "The function of scientific concepts is to mark the categories which will tell us more about our subject matter than any other categorical sets" [Kaplan, 1963]. In his view, "Concepts, then, mark out the paths by which we may move most freely in logical space. They identify the nodes or junctions in the network of relationships, termini at which we halt while preserving the maximum range of choice as to where to go next." Kaplan's remarks suggested to me that an abstract "concept space" of complexity could be created and then partitioned into related scientific categories in order to link the dynamical structural pathways of natural systems.

The logical starting point for this taxonomy is taken from von Bertalanffy's general theory of systems [von Bertalanffy, 1950], [von Bertalanffy, 1975]. von Bertalanffy's definition of a system as "a set of elements standing in interrelationship among themselves and with their environment" serves as a common thread of logic among physical, biological, and higher order systems. In terms of category theory, the von Bertalanffy definition can be more precisely rephrased by replacing the term 'element' with the term 'mathematical objects' and the term 'interrelationships' with the term 'morphisms.' Eventually, a common transcendental view of complexification could emerge; it may even become conceivable to future generations to unify physical, biological, and higher order knowledge. These possibilities, however remote, will require a robust taxonomy consistent with the natural sciences.

III. Proposal for a Notation for Organized Systems.

Traditionally, communications about natural systems use symbolizations and descriptions to relate scientific observations. To observe, to describe and to symbolize are taken as the basis of individual scientific activity. How can these activities be related to computations of complex behaviors? A robust notation for complexity is needed in order to bridge the logical gap between local scientific activities and global mathematical assertions.

Historically, a symbol can be used to denote, among the many other possibilities, a category or object or concept or belief or a class of categories, objects, concepts or beliefs. Symbols may also be used to connote a generalized class without specifying the attributes of individual members of the class.

Let O° be a degree of organization of an object. Here, the symbol of the form O° is used to denote one degree of organization from the general class of hierarchical organized structures.

It is convenient to assign a natural number to each degree of organization. Thus the sequence of natural numbers can be assigned to a sequence of degrees of organization. One potential sequence is $O^{\circ 1}$, $O^{\circ 2}$, $O^{\circ 3}$. Another potential sequence is $O^{\circ 4}$, $O^{\circ 6}$, $O^{\circ 8}$. Yet another potential sequence is $O^{\circ 1}$, $O^{\circ 5}$, $O^{\circ 9}$. In these examples, the ordering relationship within the sequence is generated without any scientific justification; the pre-existing ordering relationship among the natural numbers creates the ordering relationships assigned in the examples. In order to construct a useful scientific notation, an explicit justification of an ordering relationship among the degrees of organization is necessary. Since science has a substantial number of organizational principles, a value-laden selection is necessary to construct an ordering relationship for transdisciplinary systems. Intuitively, I wish to start simply and increase to the more complex.

A simple question now arises: How can one create a procedure for assigning scientific meaning to the natural sequence of symbols? The objective of the procedure is to construct a notation such that a one to one correspondence between the languages of scientific observations and the symbolic representation of the degree of organization creates a conceptual basis for the enumeration of complexity. Therefore, I choose to select the meaning of the symbols O°1, O°2, O°3,... such that a construction of one to one correspondences between natural numbers and material objects of increasing complexity is feasible. I have selected the following specific semantic ordering for material objects of a simple bacterial cell:

$O^{\circ 1}$ subatomic particles
$O^{\circ 2}$ atoms
$O^{\circ 3}$ molecules
$O^{\circ 4}$ biomacromolecules
$O^{\circ 5}$ cells
$O^{\circ 6}$ ecoment
$O^{\circ 7}$ environment

This ordering relationship was generated for a relatively simple biological system, such as E. coli. A higher degree of organization is composed from a lower degree of organization by a many to one mapping. This ordering is grounded in the table of chemical elements, thus analogous hierarchical ordering relationships can be composed for any material system. The meanings assigned to each of these symbols is as follows:

$O^{\circ 1}$, subatomic particles, consist of three material objects: protons (+), electrons (-) and neutrons. Lower degrees of organization could be introduced for specific physical systems composed from even smaller sub-atomic particles; however, lesser particles are not known to play a significant role in cellular systems.

$O^{\circ 2}$, atoms, composed from the three subatomic particles, consists of somewhat over one hundred unique objects (elements.) The composition of atoms from particles can be enumerated systematically in terms of the natural numbers, preserving the one to one correspondence between particles and particles bound into atoms. The binding operations which creates atoms from subatomic particles are described by specific patterns. Patterns are formed from the principle quantum numbers (p) which designates the number of protons (+) in the nucleus and the other quantum numbers (l,m,s) which designate the patterns of the electrons (-). The non-primary quantum numbers assign a unique role to each and every electron (-) of the atom. Ions are composed from atoms by adding or subtracting charged particles -- either positive (+) or negative (-).

$O^{\circ 3}$, molecules, consists of a very large number of different material objects composed from atoms or ions. The binding operations which form neutral molecules from atoms preserve one to one correspondences between atoms and atoms bound into molecules. These binding operations also form patterns. The patterns formed in molecules are created from the organization of the quantum numbers. In contrast to the neutral molecules, the binding operations which form electrically charged (either positive(+) or negatively (-)) molecules to not preserve the one to one correspondence between atoms and atoms bound into molecules. Charged particles are either added to or subtract from the neutral molecule. Since the number of charged particles can be counted, non-neutral molecules can be enumerated in terms of number of subatomic particles and the organization of these particles into atoms and atoms bound into non-neutral molecules.

$O°^4$, biomacromolecules, consists of many material objects (not an infinite number), composed from specific classes of molecules. Biomacromolecules are composed from specific monomers into specific sequences via Boolean operations. The binding operations preserve one to one correspondences between subgraphs the molecules and the bound subgraphs within the macromolecules.

$O°^5$, cells, consists of living objects which can be represented as have a boundary sustained by a genetic system. The genetic system is composed of components of a consisting of $O°^1$, subatomic particles, $O°^2$ atoms, $O°^3$ molecules, and $O°^4$ biomacromolecules. (In some special cases another (smaller) cell or portion of a cell may be embedded within a (larger) cell.). The ordering relationships among the components of a cell are not completely specified by internal relationships. In general, no one-to-one correspondence exists between a cell and the internal components of a cell; this absence of a simple one to one correspondence is often referred to as the adaptability or plasticity of a living organism. Nonetheless, ordering relations exist among all the essential components of a cell.

$O°^6$, ecoment, consists of the surrounds of the cell. In natural systems, the surround may include $O°^1$, subatomic particles, $O°^2$ atoms, $O°^3$ molecules, $O°^4$ biomacromolecules, O°5 other cells and potentially more highly organized systems. The ordering relationships among the components of an ecoment are not readily specified for natural systems. However, the minimal essential components of an ecoment are known for many cells and higher organisms - they are named essential nutrients.

$O°^7$, environment, embedding system of the ecoment ($O°^6$) surrounding an organism ($O°^5$).

As indicated by the notation, the term *ecoment* is introduced to describe the immediate surrounding of the living organism. It is this immediate surroundings which provides the nutrients (the necessary and sufficient conditions) for sustaining life. The term ecoment implies a specific subset of the environment which is experienced by the organism.

A sequence of degrees of organization can be designed for less complex or more complex relationships. Such designs may require either a smaller number or a larger number of degrees of organization. For example, less complex mechanical and / or electrical systems would not require as many degrees of organization as a living organism. Higher degrees of organization can be assigned for more highly organized systems by composing cells into higher structures, that is, organs, mammals, humans, and so forth. (see Miller, Living Systems, 1978)

The conceptual basis of this proposal for a scientific notation is the recognition that three degrees of organization are essential to predicting the complete behavior of any cybernetic system and these three O° must form an ordering relationship. (Chandler, 1995) Philosophically, these three degrees of organization can be expressed in common language as the parts, the whole and the surroundings of the whole. Co-extensive with this language and these symbols are the scaling factors -- the parts are smaller than whole, the whole is smaller than it's embedding surroundings.

The transition from a lower degree of organization to a higher degree of organization is defined as a "unionization" -- a genesis of a new unity. By definition, a unionization implies the formation of a new degree of organization and the emergence of new vertical attributes. Such emergent unionizations lie at the heart of complexification. Logically, a unionization includes emergent cycles which sustain the existence of the emergent attributes of the new degree of organization. The composition of a new natural degree of organization is usually accompanied by an increasing the attributes described by closure, conformational, and concatenation. Analogously, genesis of a simpler system, the 'de-unionization' of a higher degree of organization, is accompanied by loss of the stabilizing cycles. Within this context, de-unionization is comparable to the much simpler notion of reductionism.

IV. Selection of Mathematical Frameworks for Organizations.

Selection of an appropriate mathematical framework for logical operations on the complex notation is a challenging task. Material objects can be represented from either a structural or functional perspective. Descriptions of living systems tend toward a functional perspective toward the ecoment but acknowledge the internal structural diversity [Lambert and Hughes, 1988]. Just as a diverse range of natural structures exist, so does a diverse range of mathematical structures exist. Miller, who analyzed the structure and function of living systems from a hierarchical perspective, assumed that linear information theory was capable of describing hierarchical organizations [Miller, 1978]. I believe that Shannon information theory is insufficient to describe evolutionary complexity because it is based on an a priori distribution of symbols. I believe that the pattern generating behaviors of natural objects and processes within natural systems should find their parallels in the objects and processes of mathematical systems. How else can potential dynamics of complexity be captured in the symbols? Within a limited domain, for example, within one discipline such as computer science, the utility of information theory is unquestionable. Within the scope of applied mathematics, it is easy to postulate that any mathematical structure which 'fits the data' is the correct explanation for the local data set. Often, this is the case. If the data and the system are constrained to a small region of space or time, then identifying such local structures may be sufficient for local explanations.

In contrast to symbolizing local observations, finding a mathematical structure which fits the O° notation for complex biological behaviors is a different class of problem. Stolyar stated:

> *"A language is well adapted to a precise description of a certain class of objects if in that* language *two conditions are satisfied: 1. for each object, there is a name for the properties of the object and the relationships between the objects of that class; 2. different objects, their properties and their relationships have different names. If the first of these conditions is not satisfied, the language is poor and insufficient for describing the given class of objects. On the other hand, if the second condition is not met, the language is ambiguous.* [Stolyar,1971]"

Complex organization thus poses a special dilemma for symbolization and analysis precisely because it is not localizable to simple, functional explanations. Consequently, the symbols used must be scrutinized for meaningfulness at each successive degree of organization.

Modern mathematics has discovered numerous logical systems of relationships among words and symbols. These mathematical systems vary in simplicity and complexity in a way which could be viewed as similar to natural systems. One approach to classifying mathematical systems is in terms of the nouns and the verbs used to compose the logical structures. This simplistic approach to classification of mathematical systems is extraordinary primitive, but it has a singular virtue of allowing a comparison between the symbolic mathematical system and the parallel natural system. The following table selects some prominent mathematical theories and lists the nouns and processes which are used to initiate the construction. From a historical and scientific perspective, it is important to note that all of these theories are rooted in the study of differential equations and dynamical systems. The ordering of the following listing could be viewed as one of increasing structural mathematical complexity.

THEORY	NOUNS	PROCESSES
category	objects	morphisms
graph	vertices, edges	ad hoc constructions
set	element, set, null set	ad hoc constructions
lattice	sets, upper/lower bounds	ordering functions
group	elements, sets	identity, inverse, closure, associatively,
topologies	sets, neighborhood, spaces	functions

Category theory is a simple mathematical structure. Constructions proceed from only two semantic components, objects and morphisms. Set theory requires three objects (an element, a set and the null set,) according to B. Russell [Russell, 1996]. The verbs for relating one set to another set must be constructed from Boolean logic. Thus, set theory, when applied to homogeneous classes of natural objects, can be viewed as a primitive form of a hierarchy. Graph theory starts from the notion of nodes (vertices) and edges. Relations among graphs are typically constructed from set operations. Group theory, in contrast to the simpler theories, is highly constrained by four technically precise operations. Group theory is very effective for representing symmetrical objects and symmetrical processes. While natural objects must satisfy identity criteria, natural dynamical systems may fail the highly restrictive requirement for the existence of the group inverse. Continuous topological spaces are often assumed in routine mathematical analysis of scientific data and provide a rich source of dynamic and statistical behaviors for paralleling natural phenomenon with asymmetric forms and processes. For example, both catastrophe theory and chaos theory can be viewed as classes of dynamic behaviors within continuous topological spaces.

The structural simplicity of category theory lends itself to both logical and scientific applications. It has found wide application in the logical design of computer algorithms (object oriented programming) [Walters, 1991]. Rosen has used category theory to explore the mathematical character of anticipatory systems. More recently, Ehresmann and Vanbremeersch used Category theory to construct a broad class of complex dynamical systems named as "Memory Evolutive Systems". C* and Memory Evolutive Systems are closely related theories [Chandler, Ehresmann and Vanbremeersch, 1995, Vanbremeersch, Chandler and Ehresmann, 1996]. The theorem of Ehresmann and Vanbremeersch [1987] may provide a substantial basis for exploring the natural history of emergence using category theory. Enhanced graph theory is widely used in chemical computations. Thus, it is highly probably that aspects of both graph theory and category theory will play a substantial role in the analysis of complex natural systems (see Baas, 1994).

V. C* Language of Description of a Degree of Organization.

The next step in designing a scientific semiotics for accounting for complexity is to list a common set of concepts which can be applied to a specific system. Four concepts can be used to describe the behavior of any degree of organization (Chandler, 1995).

Closure: a domain of discourse, a category, a system, an object, a unity.

Conformation: the components of the closure of a system, the internal patterns of the system, the relationship among the parts of the system, a three dimensional depiction of the internal description of a system, a specific geometric and algebraic description of components of the system.

Concatenation: binding parts together, linking changes in the conformation, changes in the internal patterns of a system, the specific linkages between parts of the whole, dynamic processes of the system linking patterns to patterns.

Cyclicity: a pattern of concatenations which sustains the system, the potential cyclic walks or pathways over the conformations of the system, the habitual behaviors of the closure.

These four concepts serve as the basis for a linguistic description of simple and complex material systems. *In principle, each concept can be applied to the enumeration of each degree of organization.* When the material state of a system is known, then these concepts provide a basis for specifying specific objects and may allow an accounting of the complexity. These four terms are interdependent with each other and must be defined sequentially. The logical necessity of these sequential definitions impose severe restrictions on the potential "encoding" operations proposed by Rosen. In technical language, the first three sequential definitions, when implemented in a suitable scientific framework, impose sets of constraints which create the initial conditions generating potentially stable behaviors (long range attractors.)

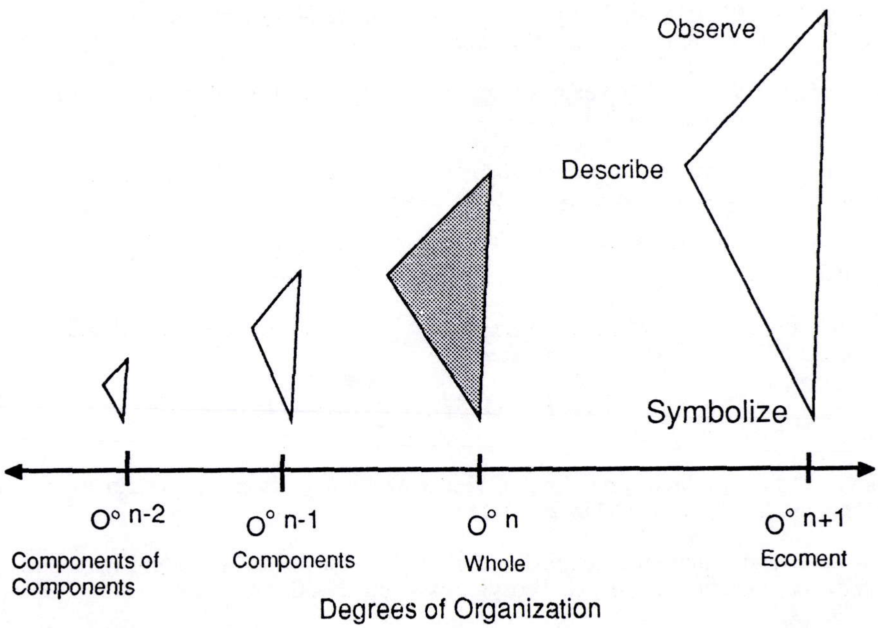
The traditional thermodynamic classification of a system as isolated, closed, and open can be smoothly embedded within this notional and semantic framework -- the thermodynamic classification places constraints on the relation between the "whole" and the ecoment (in C* terminology) as described above.

VI. Discussion.

A basic challenge is to identify methods which create a consistent view of scientific activities defined in terms of elemental scientific behaviors - to observe, to describe and to symbolize (Chandler, 1995). As part of long range effort to quantify biological phenomenon, a notation was developed. This notation creates a structure for symbolizing and describing logical relationships which allows simple autonomous parts to be composed into constituents of a more complex objects via the process of unionization. When the autonomous parts become unionized into an emergent object, they become constituents of the new whole and participate in the cyclic dynamics which stabilize the new material entity - the constituents are "glued" together by attractive forces such that a cooperative whole comes into being. As noted, the stability of the emergent object is constrained by the surrounding ecoment. (For example, an organism continue to function only within a narrowly bounded set of initial physical, chemical and biological conditions.)

This view of complexity emerged from consideration of evolutionary systems [Chaisson, 1989, 1996]. Although the role of emergent creativity has not been described in this paper, it provides one of the critical justifications for the cooperative relationships between the lesser and higher degrees of organization. This is a constructive view, relying on the binding relationships among the parts to construct a more complex whole. The complex whole become an entity

Hermeneutic Triangles of Representations



which is interdependent with both the ecoment and its constituents. The reader is referred to earlier papers which relate this notation to causality - both from a energetic as well as a biological viewpoint. [Alavanja, et al, 1989, Chandler, 1985, 1986]

In summary, strict computability for a complex system requires a congruence among the basic scientific activities: to observe, to describe and to symbolize. Quantum mechanics has provided mathematical structures which have the potential to relate quantitatively the lower three degrees of organization [Pauling, 1970]. A challenge to computing anticipatory systems is to create the mathematical structures which unionize the relationships between the higher degrees of organization as sketched in Figure 1 above.

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