The Emergence of Natural Hierarchies as an Analog/Digital Driven Process

Eugenio Andrade
Department of Biology
Universidad Nacional de Colombia
Mailing address: A.A. # 330413. Bogotá, D.C. Colombia.
E-mail: leandradep@unal.edu.co

ABSTRACT

This paper shows how semiotic agents (SA) capable of selectively recording a partial description of their environment account for the emergence of hierarchical organization. SA reveal an analog/digital duality and convert these two informational codes. The varying weights of each informational source provide an explanation of emergence throughout a developmental trajectory. In this manner, Taborsky's identification of six spatiotemporal codal zones is applied. Two types of emergence will be considered, analog driven and digital driven. The former deals with the exploration of a new shape space and their very basic work-actions, so leading to the emergence of a qualitative new instance by self-organization; the latter deals with the exploration of fine-tuned shapes and work-actions in the previous shape space through expansions in the digital informational space as a result of increasing neutral differentiation within an existing level. The former requires openness and starts as measurement in the Firstness-as-Firstness mode, while the latter profits closure and is a measurement in the Thirdness-as-Secondness mode. However, digital driven emergence can only be recognized as such when systems open up and manifests a new behavior. In consequence, evolving individuals keep their autonomy and evolvability by compromising between external circumstances and inner constraints, so to say by the introduction of a new level as a means to open it up and expand in the new shape space.

(**Keywords:** hierarchical organization, emergence, analog, digital, shape space, Peirce)

1 A CLASSICAL VIEW TO NATURAL HIERARCHIES

The mechanical perspective assumes the existence of basic building blocks of inert matter set in random motion by the action of external forces that operate respectively, as material and efficient causality. If it were so, the emergence of new levels of organization, though not forbidden, would be extremely unlikely with a statistical probability close to zero. These fundamental entities were originally conceived as devoid of inner structure (atomic) and their properties reduced to size, volume, mass and fixed shape. Thus, the

mechanical conception satisfies a criteria of logical consistency by means of the identification of fundamental units and interaction rules (syntactic) among them, so that the laws of nature could be formalized. By contrast, in the late eighteenth century Lamarck asserted that nature was sentient or endowed with *feeling*, a statement that implicitly postulated the existence of an inner structure, openness and capacity to respond to external influences. He formulated a vague version of this idea by pointing out that *feeling* and *sentiment* as such was absent in atomic matter, but rather it was an emergent property dependent on organization, the higher the organization the more intense the *inner sentiment* will manifest (Burkhardt 1995: 167-170). It was thus concluded that transformations in living nature proceeded from the simplest to the most *perfect* (Lamarck 1803:Chap VII). Perfection was then conceived as a growing differentiation of the parts followed by a higher sophistication of the systems of inner coordination in order to preserve the coherence of the activity as a cohesive whole. This concept of *perfection* was near to what intuitively is called today complexity. Very soon this concept paved the way to the idea that higher perfection implies the existence of higher levels of organization. Lamarck at times described the natural world as "full" and supposed that within each organic realm there was a graded series of complexity of organization. According to him nature has at its disposal intrinsic and extrinsic factors for producing transformations. The former is a vital force that tends to make organization more complex, it is a power inherent to organized beings alone. The latter corresponds to the conditions of life or external circumstances that exert a direct action on the properties, structure and heredity of living beings (Jacob 1982: 147-148).

The influence of the mechanical view prompted the search for the basic building blocks of living matter. The existence of fundamental units of living matter was accepted, more as an epistemological or rational requisite than a consensus over its ontological nature, and for this reason the identification of these basic building blocks has varied throughout history. For instance, Buffon's organic molecules (Jacob, 1982: 76), Darwin's organisms (Hull, 1978), Bichat's tissues (Albarracin 1983: 24), Virchow's cells (Albarracin 1983: 189-203), Weissman's biophores (Albarracin, 1983: 257-263), Fisher's, Williams' and Dawkins' genes (Depew and Weber 1995: 359-391), and Ghiselin's species (Ghiselin 1974). It is often assumed that the lack of knowledge about cellular inner structure, the existence of macro molecules and the poor description of microorganisms prevented nineteenth century scientists from formulating a hierarchical view, with the exception of Weissman, who asserted that natural selection did not act exclusively on organisms but also at the level of molecular and cellular organization (Buss 1987: 21-22).

Not until the second half of the twentieth century did a hierarchical view gain acceptance as a direct influence of the neodarwinian school, which conferred a mechanistic ontology to the study of natural hierarchies. It was then depicted as a nested organization determined by two opposing causes, an efficient cause operating upwards from the lower levels and a final cause operating downwards from the higher levels.

I suggest that the reductionist ontology prevented the development of a dynamical hierarchical perspective. Neodarwinian hierarchies are usually described within a binary ontology (Taborsky 2000, 2001) of micro/macro evolution, in this way neutralists and selectionists views are reconciled since processes at a lower hierarchical level can tolerate a wide span of variations as long as the structure and function of the higher level is maintained. A Peircian interpretation of neodarwinian hierarchies show how they are centered on the determination of the level of interest be it genes, organisms or populations (Angel, 2003). These levels are dealt with as definite or encoded within Secondness. A particular level of interest exhibits the freezing of lower level randomness (Firstness) constrained by the selective actions of the higher level that operates within Thirdness, and this overlooks the intrinsic dynamics and organizational patterns of the level in case. For Darwinians the level of interest is not considered as a real semiotic agent that participates in its own emergence, development and decay since Firstness and Thirdness are exclusively confined to properties of the lower and higher levels respectively. This is what happens when upward and downward causation are perceived as acting external to the emerging system. Upwards causation is equivalent to an efficient cause that fails to explain the assumed *a priori* random behavior of the micro level. In this picture randomness would be offset by the operations of the higher level that act in the form of classical natural selection (in place of final causality), so long as the Darwinist reduced natural selection to the culling off of the less fitted variants. Thus, purpose and intention was drastically eliminated in the workings of nature.

Nonetheless, classical hierarchical approaches in which some subunits are included into higher level subunits that are included into even higher level subunits relaxes classical atomism and inevitably leads to discussions about the autonomy of every type of unit. But this autonomy is often obscured by both the random fluctuation from the lower levels, (overstressing the Firstness-as-Firstness mode) and the restrictions imposed by the higher level that manifest as a constraining statistical law or code (overstressing the Thirdness-as-Firstness mode). In this vein, Neodarwinism considers that the surroundings pose problems that are to be solved by the evolving entity, in a process in which it "adapts" to a pre-established environmental condition. So to say, it is assumed that

among the random variants in a population of evolving entities, very few already exist that possess an adequate fit to a stable environment as an *a priori* condition. That is, the metaphor of adaptation was taken for granted, so legalizing a divorce between selection and variations.

This view installs a deep cut off between DNA/protein, genotype/phenotype, and genealogical/ecological hierarchies[10] (Eldredge 1985:144-174). Thence, energy flows, interactions and coding relations between adjacent levels of organization are erroneously interpreted, for example, in the idea that the phenotype depends exclusively on the genotype.

However, semiotic agents as "units of experience" behave simultaneously as replicators[11] and interactors[12] and the intimate association between these two aspects is one of the consequence of their semiotic agency. Moreover, interactor-replicator duality is a specific case of the more general analog-digital code duality, because interactions are measurement operations made possible by analog-analog[13] recognitions and to be a replicator implies to have generated a digital record that can be copied. This duality is an expression of the underlying unity Analog-Digital-Semiotic work-actions (Andrade 2002).

To conclude, classical hierarchical theories are formulated in a manner in which closed causal loops are obliterated. However, to define hierarchies from the point of view of the evolving semiotic agent implies to introduce a criteria that takes into consideration its self-referentiality. The point is, that the specificity of the interactions is a characteristic of the evolving systems themselves and is not specified either by the nature of the lower levels or by the constraining action from the higher levels. Instead, I propose that a level of organization must be explained in terms of its semiotic agency that defines the relations with the adjacent lower and higher levels. Thirdness is a characteristic property of the emerging systems, a SA that feeds by the potentiality (Firstness) contained not only in the lower levels but also in the higher order level and drives its self-organizing process towards a more definite and stable entity (Secondness). Evolution is a non-linear process

[10] A scalar genealogical hierarchy is defined for reproductive and replicating units and is a consequence of their inner tendency to produce more of itself. On the other hand an ecological hierarchy is defined for units of energy transfer mediated by specific interacting entities.

[11] "Entities that pass on their structure directly in replication" (Hull 1980).

[12] "Entities that produce differential replication by means of directly interacting as cohesive wholes with their environment" (Hull 1980).

[13] Analog is defined as "direct and holistic pattern recognition" of external motifs by some structural motifs of the semiotic agent. Analog refers to the fact that this recognition is made either by structural complementarity or by similarity and thus, it permits the establishment of non-random interactions. Analog information preserves the coherence of the living entity as it interacts with the environment.

that takes place in a moving trajectory that unfolds within six spatial and temporal modes (Taborsky 2001, 2002), thence, it is interesting to identify the modes in which the fluxes of energy and information take place within and between hierarchical levels. Beyond the polar duality global/local, universal/particular, knowledge is found in a continuum of intermediary modes. In order to discern whether a process takes place within inner/ external, and local/global zones, one can attempt to identify for each transition the mode in which Peirce's categories interlock. To assume the operation of Thirdness-as-Thirdness in an aspatial and atemporal zone is equivalent to accepting the continuity of the process as the true universal that is beyond the formalizability of natural processes, this continuity and non-formalizability reminds us of what Aristotle anticipated when he proposed the continuity of the causal agencies as expressed in the need to close the circuit from Final to Efficient causality[14].

2 SEMIOTIC AGENCY

Each level of the organized hierarchy has to be understood as a population of units of experience that is to say as converters of analog-digital information and energy conveyors and users. Therefore, a process of emergence has to be tackled from the perspective of the emerging and evolving unity itself. A semiotic agent (SA) can be understood as an Information Gathering and Using System (IGUS) in the way it was described by Zurek (1989, 1990) and extended to living entities by Andrade (1999, 2003). In this model a SA has a general propensity to interact that can be visualized as an IGUS that probes its surroundings by measuring and processing the results in order to optimize the amount of useful work. In this model Shannon's information and Chaitin's algorithmic information can be added so long as they are referred to the same semiotic agent. Shannon's information or the potential choices available to the IGUS measures its openness to the surroundings, its capacity of being affected by what is out there in the environment. However, as the number of measurements proceeds, its uncertainty about the environment decreases and the gained information increases the size of the digital record that can be measured as Chaitin's algorithmic complexity (K). In this case the randomness of the internal digital record

[14]For him nature is meant in the sense of a developing process that actualizes *form*. That is, the priority of *form* and the *formal cause* over the other Aristotelian causes has to do with the fact that *form* is the principle or cause of movement (Aristotle. Phys.III,1). Aristotle says that the three causes formal, efficient and final (i.e. form, source of change, and end) often coincide. The usual interpretation of this is that efficient cause is a *form* operating *a tergo*, and final cause a *form* operating *a fronte*. In many cases *form*, source of change, and end, coincide because **when a *form* is a source of change, it is a source of change as an end.** In other words, Aristotle's presentation of the four causes implicitly states the complementarity of final and efficient causes for material processes, but marks *form* or formal cause as mediator between them.

represented as K correspond to compressed information of known states (encoded interactions not data), so that it becomes a source of organization and uncertainty decrease about the external circumstances. K is a measure of closure[15] because the informational dependence on the digital makes it relatively unaffected by external informational sources. In the case of organisms, the digital record is a particular encodement in the internal zone that connects it with the global realm inasmuch as it is shared by the population. On the other hand, the passage from H to K is like trespassing the threshold of the external/internal, so it is manifested as codified in the Secondness-as-Firstness mode.

A SA is a unique individual that merges and transforms the internal and external flows of energy as it develops, and its operations are always connected to the global through Thirdness (Tabosky 2002). In the movement from the external to the internal zones, it encodes information and shapes matter, and in the movement from internal to external it renews potentiality and refuels its expansive drive. As a result the Self has extracted the energy that drives its developmental trajectory. Classical models of cognition do not consider these two movements because they are indebted to an externalist or mechanical ontology. They just go one way, from external to internal and are not naturalistic because they take recognition and classification for granted as if it were energetically free. To be a unit of replication, variation, selection and interaction stems from their semiotic agency and not the reverse.

I propose to define individuals as real unique units of experience, activity and interaction that drive themselves along their developmental trajectories. In this manner the ontological nature of these units become more evident because only those entities that can be shown to have had an "independent" or "free living" existence at a particular time in evolution could be considered as a SA that is characteristic of a hierarchy level.

The origin of life, regardless of the commitment to any particular theory about life emergence, represents a symmetry break where a Self emerges and differentiates from a non-Self, so creating the inner and outer distinction (Taborsky 2001, 2002). So, for instance Fox (1984) proposed that life emerged at the molecular level as likely proteinoids

[15] It is worth remarking that the property of closure does not make the SA "closed" in the sense of isolated from the environment; or unaffected by environmental influences. "Closure" means that SA responds to habitual external challenges in an established way compatible with an encoded record of the network of constitutive interactions. Openness means that SA can respond to new external challenges in a new manner by reconfiguring and recoding their inner constitutive network of interactions.

that participated in the formation of self-referential catalytic networks. To the extent that the properties of the molecules were complementary (Root-Bernstein and Dillon, 1997), the production of higher order metabolic complexes or closed autocatalytic circuits as described and formalized by Kauffman was favoured (1993: 301-310). These emerging entities evolved into self-reproducing systems that acted as organized wholes or interacting agents that carried digitally encoded information that could be replicated. Instead of being considered as passive units of selection they are rather to be seen as agents of inner measurement in the sense of Matsuno (1996). But evolution produced new type of closures and symmetry breaks, for instance, as new units were produced the previous units were kept off external environmental interactions (Buss 1987: 87). However, Buss remains trapped in the binary ontology of the classical view for he proposes that lower level units may affect higher level units as long as the perturbations from the lower levels do not compromise the perpetuation of the higher ones. Therefore, the lower unit may establish two types of interactions with the higher order units, a creative one and a conservative one. Conflicts between adjacent levels of organization would lead to structure destabilization, unless they are solved by reciprocal structural adjustments that result in synergistic reinforcement by the definition of new types of interactions.

By contrast, instead of focusing on the reciprocal adjustments between adjacent levels of organization I consider this interface as the nurturing ground for the emergence of a unit of experience belonging to a new level of organization. A unit of experience interacts or measures, and its ensuing adjustment is equivalent to the creation of a record (Andrade 1999, 2000). Agreeing with Lemke (1999), it is the new level that buffers the conflicts and redefines the relations between preexisting adjacent levels.

3 TWO TYPES OF EMERGENCE: A HEURISTIC DISTINCTION?

The problem of emergence can be stated this way: “A brings forth B”, but “B cannot be explained solely in terms of A”, or “B cannot be reduced to A”. The reduction of B in terms of A becomes impossible because of the emergence of something new in B. But where do novelties come from? This problem arises because the context has been obliterated in this picture. In other words, there cannot be emergence in a closed system. What is new in B and was absent in A is its *form* that results from the interaction of A and its surroundings (E). Then, A + E = B. But, E is made invisible in classical approaches that assume the stability and constancy of fixed environmental parameters (boundary conditions). Thence, the isolation from the environment is basically the source of the emergence problem. In order to clarify this problem it is necessary to identify two types of

emergence, that I identify as (1) Analog driven emergence[16] and (2) Digital driven emergence.

1. ANALOG DRIVEN EMERGENCE

This is the emergence of a new ontological level with a distinctive qualitative behavior that is characteristic of a new organized functional structure that acts as a coherent whole. It can be identified with Cariani's creative emergence (Cariani 1991). I remark the fact that the new level defines the space of all basic tasks or operations that can be performed within the said level and that can be mapped in shape space[17]. It is understood to be produced by a self-organizing process or what is known as "order out of chaos" (Prigogine and Stengers 1984: 177-209). I propose that this emergence is produced by a process of internal measurement that leads to the establishment of new analog-analog relations between already existing components, and the establishment of relations with novel environmental referents that become significant for the developing SA. In terms of logic, this corresponds to a transition in which an external observer needs to incorporate new predicates in order to provide a description (Matsuno and Salthe 1995), or the addition of new kinds of letters to an alphabet. I believe that this type of emergence is characteristic of sudden evolutionary transitions (punctuated equilibrium) and involves non-random interactions between constitutive subsystems (Root-Bernstein and Dillon 1997; Fox 1984).

Analog driven emergence cannot be formalized[18] because it expresses the relation between the SA itself and its partially describable external environment in the form of a process that converts analog into digital information. SA's subjective aims, feeling, ex-

[16] Analog is defined as "direct pattern recognition" of some motifs by some structural motifs of the SA that results in the establishment of non-random reversible interactions (Root-Bernstein and Dillon, 1997). Analog refers to the fact that this recognition is made either by structural complementarity and/or similarity within a continuous threshold of variability. If the motif recognized by the SA is external, then we can talk about interaction and measurement that leads to internalization of information. Also, analog information between inner constitutive components preserves the coherence of the SA as it interacts with the environment.

[17] Shape-space is a hypercube that formalizes all possible shapes or structural conformations that the set of all chains of symbols of fixed length can attain, provided interactions between the constitutive symbols take place, i.e. RNA and peptides secondary and three-dimensional structures. The dimensions of the hypercube depend on the number of shape parameters selected to define the shape. Shape-space parameters thus determine the size and mathematical dimensions of the shape-space; its size is relative to an external observers' ability to discriminate. The more parameters that are included in the description, the greater its size. However, with the introduction of functional considerations, discrimination can be made good enough so as to obtain molecular recognition, i.e. antigen-antibody, enzyme – substrate, etc. So, the construction of shape-space is aimed at identifying a minimum set of parameters that are able to discriminate functional interactions or to assure the executions of basic tasks (or operative size), (Perelson 1988; Kauffman 1993: 142-172).

[18] Formalization is understood as the reduction of a phenomenon to a set of syntactic rules by the elimination of self-referents.

perience and the capacity to interact are encoded in Firstness, so that they constitute a more general notion than that of measurement and are an *a priori* condition of it, and are at the very source of creative and unpredictable interactions with external referents. Nonetheless, to represent interactions as measurements helps to formalize what can be, and at the same time, to shed light on the problem of how coding is achieved. Measurement, recording and action are SA's responses to the concrete and immediate challenge of external circumstances and create the possibility of unpredictable functional interactions. The creation of a new digital record proceeds by partial internalization of external referents and reorganization of previous existing records, in accordance with the interactions established with the surroundings. There will always be a number of undefined motifs that can be potentially recorded, and which one is to be incorporated into the digital record cannot be predicted beforehand.

The passage from analog to digital is contextual and concerns the SA (Andrade 1999), (Andrade 2000), as a self-referential agent. In addition, SA represent a principle of coordination, since the measuring and recording operations cannot continue forever for a decision has to be made about where to stop measurement and recording. The following actions are necessarily self-referential and therefore unformalizable: 1. The choice of measuring standards. Which structural device is to be used in order to single out external motifs? 2. The extension of measuring, or how far does measurement have to go? 3. In what way does the SA modify and condense the internal record? 4. The decision about measurement completion or pragmatic sufficiency of gathered information. When is enough to stop? 5. The interpretation of the records or how the ensuing actions are defined? To summarize, self-referentiality is an unavoidable characteristic of SA encoded in Thirdness for they are always creating, updating, internalizing, interpreting and discarding a partial record of their environments.

So, for example phenotypes as analog information systems can exhibit some adjustments or accommodations in the presence of external stimuli, so to say that subtle changes of *form* can be understood as analog encoding which can be further used as a condition for digital encoding. In my view analog encoding has also an internal component that corresponds to what Maynard Smith (1990) has defined as Epigenetic Inheritance Systems (EIS) that are responsible for the stable transmission of functional states of genes and cell structures. Jablonka et al. (1992) identified several Epigenetic Inheritance Systems (EIS) that transmit phenotypic stable differences between cells with identical DNA through many cell divisions. According to Jablonka and Lamb (1998), EIS can be influenced by the environment and produce a directed, rapid and reversible adaptive re-

sponse. In this context, the dichotomy between innate and acquired characteristics proves to be inadequate at the phylogenetic scale, because any phenotypic feature results from an interaction between genetic and environmental factors. The best example of incorporation of external information from the environment by a natural system is *genetic assimilation*. Waddington (1976: 30-34) defined genetic assimilation as the phenomenon by which mutations get fixed in the genome in the context of variation that has already taken place in the presence of external stimuli, so that they will develop the phenotypic feature before the stimulation, in complete absence of the stimuli. In my interpretation, this phenomenon entails that selection has been performed by the SA that participates in the formation of its own adaptations.

The heredity of adaptations is explained in a more general way by Peirce's notion of *habit*. *Habit* is the higher probability to repeat in the future something that has taken place in the past, or the higher probability to respond in the future, in the same way, as it did in the past in the presence of certain stimuli, (Peirce, CP 1.409). When the stimulus is removed and no longer present, the *habit* tends **to affirm itself**, thence whenever uniformity increases, *habit* is at work. (Peirce CP: 1.415, 1.416). While *habit* and consciousness[19] were traditionally considered as themes that could be applied exclusively to describe the laws of mind, nowadays they are components of the physical explanation. Peirce has made possible the reconciliation between the laws of mind and the laws of matter.

2. DIGITAL DRIVEN EMERGENCE

This type of emergence is made possible through duplication, reorganization, recombination and mutation of the digital record (Andrade 2002) that may (not necessarily), elicit the emergence of fine-tuned and/or neighboring functions within an already organized and functional whole. This process is akin to Cariani's recombination emergence (Cariani 1991) and can be confused with Schrödinger's "order from order" emergence. Nevertheless, I argue that for this type of emergence to be possible it requires a randomization through Firstness in the Digital Informational Space[20]. The classical example is the

[19] One can understand consciousness as analog pattern recognition embedded in a feedback loop: stimuli, adjustment, selection, recording, variation, and new stimuli. Consciousness is a property of every natural system that possesses the capacity to create and to internalize a partial record of its environment.

[20] Digital Informational Space is a generalization of the sequence space concept. Sequence space is a mathematical representation of all possible sequences of fixed length that can be imagined by permutation of their basic symbols. Sequence space is represented as a hypercube of n-dimensions in which every point stands for one sequence and the dimension of the cube corresponds to the length of the binary chain

case of Ohno (1970) gene duplication that accounts for evolutionary novelty. As a consequence of an event of gene duplication, neutral mutations accumulate while the functionality of the individual is preserved, in this manner potentiality is refueled from within to be manifested in the external domain only when it matches the possibilities offered by a changing environment. In this case emerging novelties are of quantitative nature like gradual increments in complexity and inner differentiation. This is a very common phenomenon that happens in most evolutionary transformations within existing levels of organization like gradual transitions, terminal phylogenetic branching, terminal modifications of ontogenetic programs and most of the process that can be accounted by selection of fined-tuned structures in Kauffman`s rugged landscapes (1993: 95-109). This in an emergence that starts to be "incubated" in closure, however it can only be detected if the system "hatches" or opens up to new environmental resources. Structural closure is propitiated when the external environment remains constant; if the system remains closed, these digital expansive events can be identified as neutral mutations. Following Kimura (1983: 104-113) environmental stability favors proliferation of neutral variants.

In terms of logic, this emergence corresponds to a description that can be produced by recombining the basic preexisting symbols, like the construction of a new string from existing alphabet letters for there is no need to include new predicates. Notwithstanding, it cannot be purely syntactical for emergence is also semantic and pragmatic. The trap lies in the fact that if the new emerging behavior or function is a slight modification of a preexisting one, for mere practical purposes one can consider them as equal and therefore conclude that it was not needed to incorporate new symbols into the digital description. Thus, one cannot avoid asking how different are these two types of emergences? The distinction between analog and digital driven emergences is subtle and flimsy though it is heuristically powerful. They both require a randomization and openness, and it cannot be denied that transformations in quantity are often a precondition for qualitative change. In the case of living systems for which function is critical, how can you say that there is emergence if the behavior remains stable and unchanged? Emergence is usually associated with functional changes in the expected behavior, however little they may be, and this implies not only a permutation of basic constitutive symbols but also the establishment of a new type of behavior or relation with the environment. This fact narrows the gap between the two types of emergence.

(Hamming 1950). This representation was originally applied to proteins (Maynard-Smith 1970), and later to RNA and DNA sequences (Eigen 1986).

What is more, I argue that the distinction lies in the fact that while the former requires openness (excitability and responsiveness to certain ambient environmental conditions) the latter demands a previous latent stage of closure (homeostatic independence from ambient environmental perturbations). Also, if one considers these types of emergences within a functional context the distinction between them is the same as the difference between the space that contains all basic functions or tasks that can be accomplished and the space that embraces all highly specific tasks that can be performed by the same system. It is the difference between coarse graining and fine-tuning, or the degree of resolution with which one is interested to retrieve a description. It boils down to the degree of resolution you want to gauge. And I arrive at a point that can only be solved empirically for particular cases studied within the heuristics of shape-space concept (see footnote 6).

On the other hand, Rosen (2000: 184) stated that closure or buffering environmental conditions is an ubiquitous characteristic of organisms that appears at the expense of opening up the system to others. If that is so, living systems pass from digital driven to analog driven emergency. In this manner the circuit of causality is closed for a form of final cause conceived as the tendency to fill up the AIS[21] leads inevitably to feed the efficient cause as a new AIS appears ready to be occupied.

4 SEMIOTIC AGENTS FOLLOW AN ONTOGENETIC TRAJECTORY

A semiotic agent experiences and senses its world as a cohesive individual, to do so it must capture energy by processing (encoding and decoding) analog and digital information, in order to pull itself through its developmental process. A SA is an individual as long as it shows spatiotemporal cohesiveness in ontogenetic development. To consider a SA as a basic developing process helps to frame an alternative ontology to classical gene reductionism, by means of which Developmental systems theory (DST) can be interpreted. Oyama defines a developmental system (DS) as a "mobile set of interacting influences and entities" comprising "all influences on development" at all levels (Oyama 2000: 72), and Griffiths and Gray (1994) affirm that it involves a whole matrix of resources and interactions that permit reconstruction of ontogenetic and developmental information in each generation. Likewise, my model proposes that the fundamental unit of

[21] Analog Informational Space (AIS) is generalization of the Shape-space concept. That is the world of all possible stable conformations that can be attained. The components of AIS are responsible for coupling with external referents, thus, providing meaning, functionality and semantics. Expansion in AIS shows a tendency towards saturation.

evolution is neither the individual gene nor the phenotype, but the interacting unit or SA that by measuring and recording is responsible for the renewal and updating of the ontogenetic information in each life cycle.

The ontogenetic process is classically understood as the transformation of the digital into analog, or a genotype that produces a phenotype, as a one way deterministic process. However, all along the process analog and digital information are in operation, therefore it is more accurate to say that the SA goes from an initial state (analog**/digital)-i, through an intermediary state (analog*/digital*)-m, and then to a final state (analog-/digital**)-f, where the star (*) denotes the relative weight of the informational component.

In consequence, I assert that ontogeny as a continuum process operates in the six spatial and temporal zones of codification defined by Taborsky (2000, 2002), because some resources from the environment and inner encoded information permit it to actualize and update the developmental information as it develops. Ontogenetic variations create long term canalizations that can be verified at phylogenetic scale. But, to what extent do the emerging units develop and evolve depending on either a self-organizing processes restricted by specific surrounding conditions, or inherited encoded information that impose structural constraints? To answer this question one must be reminded of Salthe's developmental trajectory (Salthe 1993: 181-185) depicted in the curve of entropy dissipation per mass unit over developing time (Salthe 1993: 9). From left to right: A: Early development, B: Maturity, and C: Senescence (See figure 1). I assert that analog and digital information act all throughout development, nonetheless each stage can be characterized by the relative weight attributed to the analog and the digital information component.

A) EARLY DEVELOPMENTAL STAGE

This stage represents the full potentiality; that is the newly emerging system as such in the inner and local realm that is in virtual possession of a maximum number of potential choices. This is the realm of pure potentiality, the Firstness-as-Firstness [1-1] mode. This inner potential for analog-analog interactions will decrease for the emerging individual along its ontogenetic trajectory because the more couplings are established the lesser the likelihood that new couplings can be possibly established. That is to say, a constraining law acts at the onset of the emergence of the prospective individual that feels equally attracted by every external object, yet it does not establish differences since all potential

couplings are equally likely and remain potential. Measurement comes when distinctions are made forced by the need to match something leaving other choices behind. As it develops, a law of probabilities (Thirdness-as-Firstness, [3-1]) manifests and triggers a symmetry break with the creation of an interface inside/outside (Secondness-as-Firstness [2-1]), that sets the boundaries of the new emerging level of organization, that is an activity that codifies energy within inner local boundaries. The informational encoding is equivalent to genetic assimilation that happens first as a modification of the analog record induced by the presence of an stimulating external object and leads to the creation of a symbolic digital record as some internal processes have been reoriented. This phase is paid by dissipating entropy to the outside, but this is done as if this dissipation were controlled by the emerging agent through its access to Firstness in its exploration of new semantic, syntactic and pragmatic possibilities. At these early stages, development is more dependent upon the analog information component that provokes a tendency to match some elements present in their surrounding so connecting possibilities to many levels simultaneously or the domain of Thirdness-as-Thirdness. This fact manifests as the inner drive characteristic of Lamarckian evolution in response to the nature of the surrounding conditions that excites variability while favoring the actualization of some potential interactions. This excitation of variability is a consequence of the high degree of structural openness, so that the evolving agent responds to external perturbations within an organizing functional context that permits it to access and consolidate the new possibilities.

When this phase is channeled by Habit we have the mode Thirdness-as-Firstness [3-1] that channels progressive evolution as in Lamarckian evolution. Agreeing with Taborsky (2001, 2002), Thirdness-as-Firstness [3-1] is external and in my view corresponds to a creative (*heterorhetic*) response that has become habitual (*homeorhetic*) for the evolving individual and that matches the potential given by the inner drive with the higher level of organization. Novelty as a *heterorhetic* response is an internal action whose underlying intention is beyond what classical science can explore and that is the reason why neodarwinians prefer to consider it as a random error that threats nature intelligible order.

B) STAGE OF DEVELOPMENTAL MATURITY

As the process goes on, a law of probabilities acts Thirdness-as-Firstness [3-1]) and as a digital record appears in a condensed form (Thirdness-as-Secondness [3-2]) a new definite and cohesive mature individual materializes in the Secondness-as-Secondness [2-2] mode. According to Taborsky (2002), Secondness-as-Firstness [2-1] is an analog measurement in the inner local domain that creates the conditions for the exteriorization of the

experience as the new individual is actualized in the mode of Secondness-as-Secondness [2-2] in the local and external domain. Active individuals drive their own development that elicit the establishment of new couplings, and record the information in a compressed way by removing redundancy. This is a clear expression of Thirdness (Andrade 2000). During this period individuals show an increase of compressed digitally recorded information that enhances their asymmetry with the surroundings. Thirdness-as-Firstness [3-1], gives the conditions for trespassing the boundary internal/external (Secondness-as-Firstness [2-1]) and realizing the existence of a definite and mature individual (Secondness-as-Secondness [2-2]). The increase in digitally encoded information is achieved by including newly encoded motifs and by removing redundancy. The action of Thirdness results in a real compression that requires the consolidation of a formal system capable of executing this operation. Thirdness is responsible for the tendency to optimize individual efficiency in terms of extraction of work by record compressions. Consequently, the mutual information content between semiotic agent and its environment, $K_{(agent:environment)}$, and between its analog and digital informational records, $K_{(analog:digital)}$ increases. This stage is poised somewhere between maximum uncertainty about the environment [1-1] and inner determination by the digital record [3-2] and therefore variations would reflect a compromise between the surrounding conditions (ecological) and the nature of organisms (genetic). This unpredictability for an external observer is the reason why authors like Maturana and Varela (1992: 94-117) understand evolution as a process of natural drift, nonetheless this argument may obscure the intentions and evaluations made by individuals within their communal context, that result in their own choices sometimes more dependent on their analog information [1-1], [2-1], and at other times more dependent on the digital information content [3-2]. Emergence and evolvability are properties dependent on Thirdness that merges the internal [3-2] and external [3-1] in the global realm. Thirdness is a cognitive process that is both external and internal and works by taking up information from spontaneous drives [1-1], established interactions [2-2], experience or habits [3-1] and digitally recorded information [3-2]. Thirdness organizes all these informational resources into a global knowledge in a unified dynamic mind that is predisposed to work in synchronic coordination with parallel ongoing asynchronic processes. Thus, the emergence of every definite individual happens in the domain of Thirdness. The varying weights of analog and digital informational sources is what the individual manages to control as a semiotic agent.

At this stage the SA presents an apparent simultaneous deterministic and random behavior. The former is the result of adjustments produced in response to the functional re-

quirements of the higher level that is attained by the increment of digital:analog mutual information content. The latter is a consequence of the inner intentions of the evolving agent that may take an unpredictable route that perturbs the higher level and reorganizes the lower levels so decreasing digital:analog mutual information content.

C) DEVELOPMENTAL SENESCENCE

At this stage the internalized information encoded as a digital version that connects to the global domain enables the evolving units to stabilize in a constant environment. This phase corresponds to the maximum value of analog and digital shared information content $K_{(analog:digital)}$, or organisms and environment shared information content $K_{(organism:environment)}$. In this phase, the structural closure makes them more dependent on internalized information, and less susceptible to be excited by new external referents. Potentiality has lowered to a minimum, and makes the individuals highly dependent on their own informational load that slows down and thwart further exchanges of energy with the environment, so threatening to breakdown the inner structure. At this final stage, potentiality is not completely exhausted and takes the form of random genetic mutations. The end point of development is attained when the structure of the evolving individual decays by destroying the boundaries inside outside, and returning its material components to the environment[22].

5 EMERGENCE OF NEW LEVELS OF ORGANIZATION

The emergence of new levels occurs in a time space zone with a prevalent weight of analog information and through development shifts towards a zone with an ever increasing weight of digital information. The operations of the analog take place in the Firstness-as-Firstness [1-1], and Thirdness-as-Firstness [3-1] modes, and the actions of the digital occur as a movement within the Thirdness-as-Secondness [3-2] mode (Taborsky 2002). However, when organisms stabilize in a constant environment the evolving individuals can only undergo internal expansions of the record that manifest in terms of increasing redundancy and cumulative random variations (neutral mutations). Consequently, a new realm of opportunities is created by connecting Thirdness-as-Secondness [3-2] to the Firstness-as-Firstness [1-1] mode by the actions encoded in Thirdness-as-Thirdness. And,

[22] If as Taborsky (2002) affirms Thirdness-as-Thirdness [3-3] is pure aspatial and atemporal mind, though it is being operating all through on each individual, this zone would be accessed through the individual's death, for the recycling of material components and the evolution of the environment offers new possibilities for the continuity of life (Angel, M. 2003).

if the opportunities provided by the higher levels are expanded the emergence of functional modifications is favored.

Classical Hierarchical Theories treat evolving units as if emerging on top of a varying adjacent micro levels constrained by a relatively stable environment. However, the higher level (the environment as an evolving system) is always being transformed, given the continuity created by the interactions between inclusive existing units. Likewise, the lower adjacent level is modified by the very actions that favor the emergence of the new level. Thus, higher and lower levels are not static and are in an ever-going process of 'becoming' by providing restrictions and offering possibilities to the newly emerging entities. In addition, emergence makes reference to Peirce's Secondness for what emerges is a definite individual that holds some determinate relationships, nonetheless emergence is a consequence of Thirdness in the internal and externals domain that connect to the global, and as such will be considered in the following model. That is, what emerges is both an object and an interpretant.

STEPS TOWARDS EMERGENCE:

First step, let "L_o" stand for the ground level for practical and ontological reasons. As the network of non-random interactions corresponding to this ground level "crystallizes" forming stable aggregates (L_o) their own AIS[23] and DIS starts to be randomly explored (Andrade 2002). This happens within the [1-1], [3-1] modes. Therefore, to start with analog and digital mutual information content ($K_{digital:analog}$) has a low value.

Second step, when the basic space of (L_o) is configured, or AIS-(L_o) approaches saturation (still in early developmental phase "A"), a new level (L_1) starts to emerge by creating higher order aggregates from L_o aggregates. This newly formed (L_1) aggregates accesses a new exploratory realm or AIS-(L_1). While expansion continues exploring the basic L_1 forms, the search for fine-tuned shapes in the adjacent lower level L_o continuous.

[23] I have argued that the hierarchical organization of nature is driven by the tendency to fulfill the Second law in the real existing world of shapes and forms, thus showing a rapid filling up of the AIS (Andrade, 2000, 2002). It is important to distinguish between two types of shape space: the very basic and the fine tuned one. The former corresponds to crude shapes of basic forms that permit the entity to cover all catalytic tasks in the sense of Kauffman (1993) though some tasks may be accomplished with poor efficiency. This space will be accessed by self-organization (analog driven emergence). The latter corresponds to highly specific shapes and appears as a result of adaptive processes that permit an entity to access neighboring tasks and functions within an already organized whole. This space is accessed by selection in rugged landscapes, (Kauffman, 1993). The filling of the AIS that drives the emergence of new levels corresponds to the space of basic shapes. Digital driven emergence takes place in the fine-tuned shape space. In opposition to the accepted view, there is no need whatsoever to try a mega-astronomic number of possible permutations in sequence space for emergence to take place.

Third step, the newly emerging level L_1 begins to unfold into two ever more precise and definite instances: digital ($L_{1digital}$) and analog ($L_{1analog}$) that are kept together by its own semiotic action that hold $K_{(digital:analog)}$ at an adequate value enough to maintain the cohesion and closure of the system. Emergence modifies existing patterns of connectivity as a result of non-random interactions between constitutive units. Internal cohesion does not depend on external restrictions, rather it is an intrinsic intention that is attained by means of increasing mutual information content between the evolving unit and its environment, for the individual is a realization of a potential in a defined environment, a step from Firstness (internal/local) to Secondness (external/local) by the actions of the evolving individual within the communal domain of Thirdness that merges internal and external zones. As a property of Secondness, cohesion provokes a closure that attenuates and buffers both the effects from the higher levels and the perturbations it may provoke into the surroundings. The information of an emerging level is actualized by using constitutive information contained in the lower level plus incorporating information from the higher level, so that the conflicts between preexisting levels are smoothed and buffered. Thus, the emerging level gains autonomy that confers it a stability threshold against both genetic and environmental perturbations.

And fourth step, as this tendency consolidates and the new AIS ($L_{1analog}$) approaches saturation, a new level (L_2) can emerge in between by integrating (L_2) aggregates. Evolutionary potential is congruent with the expansion in shape space that does not stop just because this space is near saturation or filled up, so that the spontaneous emergence of a new level confers new potentialities. The fact that what appears as digital in one level becomes analogue in the newly emerging level is a phenomenon that ensues as a consequence of mutual informational gain between analog and digital informational records. Likewise, analog on the level itself becomes a discontinuous element for the newly transformed higher level because of the increase of mutual information content between the new level and its environment (adjacent higher level). What emerges is a new qualitative level of semiotic interpretation that is always contextualized.

6 CONCLUSION

The identification of the six spatio temporal codal zones produced by iteration of Peirce's categories provides an alternative ontology useful for the understanding of biological development, evolution, and the emergence hierarchical organization. Emergence of more complex hierarchical levels is a spontaneous tendency through which nature pulls itself by using analog and digital informational sources. Both analog and digital driven emer-

gences cannot be severed for they act simultaneously all through, nonetheless there are stages in which one can identify a major weight for each one of these informational sources. While the analog has a major weight, the digital has lower, and the reverse is also true, that is that they complement each other. It is as if a magnitude that one could imagine and make equal to the product of both remained constant, (Analog x Digital = constant).

Therefore, for a new level to appear two conditions are required simultaneously,

1. So long as the emergence is analog driven, it requires a saturation of the basic shape-space (AIS) corresponding to the lower adjacent level that provides the emerging unit with the opportunity to expand the realm of possibilities by opening up the whole hierarchical system to a new AIS space. This process requires openness and is codified in Firstness-as-Firstness[1-1] and Secondness-as-Firstness [2-1] modes.
2. So long as the emergence is digital driven, it requires a decrease of mutual information between digital and analog records of the evolving level, so that the emergence of a new level is needed in order to keep the cohesion of the organized hierarchy. Decreases of mutual information content are produced by the conjoint action of accumulated mutation in developmental senescence and environmental changes. This process requires closure and is codified in the Thirdness-as-Secondness [3-2] mode, but inevitably leads, by the operations of Thirdness, to an opening that provokes an analog driven emergence. Therefore, organisms as SA regulate their closure by introducing new levels of organization as a continuous manifestation of the interlocked Peircian manners of being.

ACKNOWLEDGMENTS

I am grateful to Edwina Taborsky for valuable comments and thorough reading of the manuscript. Also, I am indebted to Melina Angel and Lucia Velasco for thoughtful discussions about Peirce semiotics.

REFERENCES

Albarracin, A. 1983. *La teoría celular, historia de un paradigma*. Madrid. Alianza Universidad.

Angel, M. 2003. *Estructura y Función en la Organización en Niveles Jerárquicos: hacia una comprensión de la continuidad en la naturaleza.* Bogotá. Universidad Nacional de Colombia. Forthcoming.

Andrade, E. 1999. 'Maxwell demons and Natural selection: a semiotic approach to evolutionary biology.' In: Special Issue Biosemiotica. Eds. T. A. Sebeok, J. Hoffmeyer and C. Emmeche. *Semiotica* 127: (1/4): 133-149.

Andrade, L.E. 2000. From external to internal measurement: a form theory approach to evolution. *BioSystems* 57: 49-62.

Andrade, L.E. 2002. The organization of Nature: Semiotic agents as intermediaries between digital and analog informational spaces. *SEED Journal (Semiosis Evolution Energy Development)* 2 (1): 56-84.

Aristotle. 1992. *Physics (*Book I and II). tr. William Charlton. Oxford: Clarendon Press.

Burkhardt, R.W. 1995. *The Spirit of System. Lamarck and Evolutionary Biology.* Cambridge, MA. Harvard University Press.

Buss, L. W. 1987. *The evolution of individuality.* New Jersey. Princeton University Press.

Cariani, P. 1991. Emergence and Artificial Life. In: Langton et al. (Eds.) *Artificial Life II. SFI Studies in the Sciences of Complexity.* Vol. X Addison Wesley.

Depew, D.J. and B.H. Weber. 1995. *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection*. Cambridge MA. MIT Press.

Eigen, M. 1986. The Physics of Molecular Evolution. *Chemica Scripta* 26B: 13-26.

Eldredge, N. 1985. *Unfinished Synthesis. Biological Hierarchies and Modern Evolutionary Thought.* New York. Oxford University Press.

Fox, S. W. 1984. Proteinoid Experiments and evolutionary Theory. In *Beyond Neo-Darwinism.* Pp. 15-60. Ed. Mae-Wan Ho & Peter T. Saunders. London. Academic Press, Inc.

Ghiselin, M.T. 1974. A radical solution to the species problem. *Systematic Zoology* 23: 536-544.

Griffiths, P.E. and Gray, R.D. 1997. Replicator II: Judgment day. *Biology and Philosophy* 12(4): 471-492.

Hamming, R.W. 1950. Error detector and error correcting codes. *The Bell System Technical Journal* 26: 147-160.

Hull D.L. 1978. A Matter of Individuality. *Philosophy of Science* 45: 335-360.

Hull D.L. 1980. Individuality and Selection. *Annual Review of Ecology and Systematics* 11: 311-312.

Jablonka, E., Lachman, M. And Lamb, M.J. 1992. Evidence mechanisms and models for the inheritance of acquired characters. *Journal of Theoretical Biology* 158: 245-268.

Jablonka, E. and M.J. Lamb. 1998. Epigenetic inheritance in evolution. *Journal of Evolutionary Biology* 11: 159-183.

Jacob, F. 1982. *The Logic of Life. A History of Heredity.* New York. Pantheon Books.

Kauffman, S. 1993. *The Origins of Order: Self-Organization and Selection in Evolution.* New York: Oxford University Press.

Kimura, M. 1983. *The Neutralist Theory of Molecular Evolution*. Cambridge. Cambridge University Press.

Lamarck, J-B. 1803. *Zoological Philosophy.* New York. Hafner. Translated by H. Elliot and reprinted in 1963.

Lemke, J.L. 1999. Opening Up Closure: Semiotics Across Scales. *Closure, Emergent Organization and their Dynamics*. University of Ghent, Belgium.

Matsuno, K. 1996. Internalist stance and the physics of information. *Biosystems* 38: 111-118.

Matsuno, K. and Salthe, S. 1995. Global Idealism/Local Materialism. *Biology and Philosophy* 10: 309-337.

Maturana, H. & Varela, F. 1992. *The Tree of Knowledge. The Biological Roots of Human Understanding.* Pp: 94-117. Boston, MA. Shambala.

Maynard-Smith, J. 1970. Natural Selection and the Concept of Protein Space. *Nature* 225: 563-564.

Ohno, S. 1970. *Evolution by Gene Duplication.* Berlin. Springer Verlag.

Oyama, S. 2000. *Evolution's Eye: A Systems View of the Biology-Culture Divide.* Durham, Duke University Press.

Peirce, C.S. [1965]. 1987. *Collected Papers.* Cambridge, MA: Belknap Press. *Obra Lógico Semiótica* tr. and ed. Armando Sercovich. Madrid: Taurus Ediciones.

Perelson, A.S. 1988. Toward a realistic model of the immune system. in A.S. Perelson. ed. *Theoretical Immunology II*: *Santa Fe Institute Studies in the Sciences of Complexity*. Pp: 377 - 401. Reading, Mass. Addison-Wesley.

Prigogine, I. ans Stengers, I. 1984. *Order out of Chaos. Man's new dialogue with nature.* Toronto. Bantam Books.

Rosen, R. 2000. *Essays on Life Itself. (Complexity in ecological systems series).* New York. Columbia University Press.

Root-Bernstein, R.S. and Dillon P.F. 1997. Molecular Complementarity I: the complementarity theory of the Origin and evolution of Life. *Journal of Theoretical. Biology* 188: 447-479.

Salthe, S. 1993. *Development and Evolution. Complexity and Change in Biology.* Cambridge, Massachusetts. A Bradford Book. The MIT Press.

Salthe, S.N. 1999. Energy, Development, and Semiosis. in Edwina Taborsky ed. *Semiosis, Evolution, Energy: Towards a Reconceptualization of the Sign.* Pp: 245-261. Aachen: Shaker Verlag.

Taborsky, E. 2000. The complex information Process. *Entropy (On-line journal)* 2: 81-97.

Taborsky, E. 2001. The internal and external semiotic properties of reality. *SEED Journal (Semiosis Evolution Energy Development)* 1 (1): 1-17.

Taborsky, E. 2002. The natural dynamics of Semiotic realism. Forthcoming.

Waddington, C.H. (1976). Las Ideas Básicas de la Biología. In: Hacia una Biología Teórica. Madrid. Alianza Editorial.

Zurek, W.H. 1989. Algorithmic randomness and physical entropy. *Physical Review A*. 40 (8): 4731 - 4751.

Zurek, W.H. 1990. Algorithmic information content, Church - Turing Thesis, Physical Entropy, and Maxwell's demon. In: Zurek, W.H (ed.), Complexity, Entropy, and the Physics of Information, SFI Studies in the Sciences of Complexity, Vol. VIII. pp: 73-89. Addison-Wesley.

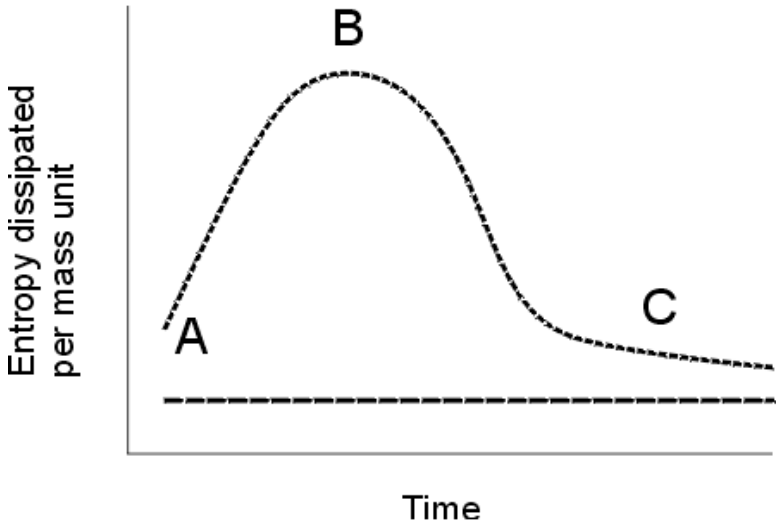

Figure 1: Entropy dissipated per mass unit along developmental time according to Salthe (1999). Phase A, stands for early development, or the stage where analog driven emergence operates in the modes [1-1} and [3-1] that leads to the interface [2-1]. Phase B, stands for maturity, or the stage where the conversion between analog/digital information reaches its maximum as a result of the operations in the [3-3] mode that consolidates the Self in the [2-2] mode. Phase C, stands for senescence, the stage of a digital driven phase in the [3-2] mode. As it opens up a new curve that follows a similar trajectory will stem from C.