THE PROCESSING OF INFORMATION (ANALOG/DIGITAL) IS THE CAUSAL FACTOR OF THE EMERGENCE OF NATURAL HIERARCHIES

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ABSTRACT. This paper defines living units of development and evolution as agents that selectively record a partial description of their environment. This perspective allows to understand the emergence of hierarchical organization as information processing that uses simultaneously analog and digital records. The varying weights of each informational source explain the emergence of levels of organization throughout a developmental trajectory. Two types of emergence will be considered, analog driven and digital driven. The former deals with the exploration of a new shape space and the definition of their very basic work-actions, bringing forth a qualitative new instance by self-organization; the latter deals with the exploration of fine-tuned shapes and derived 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 an analog-analog recognition, while the latter requires closure. 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 (analog informative sources) and inner constraints (digitally recorded information) by the introduction of a new level.

KEY WORDS. Code duality, hierarchical organization, emergence, analog information, digital information, shape space, sequence space.

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 this were so, the emergence of new levels of organization would be, though not forbidden, extremely unlikely with a statistical probability close to zero. These atomic entities were originally conceived as devoid of inner structure 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,

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in the late eighteenth century, Lamarck, with an anti-newtonian accent, dared to assert 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 made clear that *feeling* or *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). Then it was 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 in 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 such fundamental units of living matter was accepted, more as an epistemological or rational requisite than as 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 macromolecules 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 this reduccionist ontology prevented the development of a dynamical hierarchical perspective. Neodarwinian hierarchies are usually described within a dualistic ontology of micro/macro evolution; in this way neutralists and selectionists views could be reconciled since processes at a lower hierarchical level tolerate a wide span of variations as long as the structure and function of the higher level is maintained. Neodarwinian hierarchies are centered on the determination of the level of interest, be it genes, organisms or populations. These levels are dealt as definite or determinate in relation to its adjacent lower and higher levels. A particular level exhibits the freezing of lower level randomness constrained by the selective actions of the higher level, and this fact overlooks the intrinsic dynamics and organizational patterns of the level in case. For Darwinians the level of interest is not considered as a real information processing agent that participates in its own emergence, development and decay since "randomness" and "selection activity" 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 abates 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 randomness) and the restrictions imposed by the higher level that manifest as a constraining statistical law or code (overstressing its selective actions). 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 [1] (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, living units of experience behave simultaneously as replicators [2] and interactors [3] and the intimate association between these two aspects is one of the consequence of their information processing activity. Moreover, interactor-replicator duality is a specific case of the more general analog-digital code duality (Hoffmeyer and Emmeche, 1991), because interactions are measurement operations made possible by analog-analog recognition 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, 2003).

In this paper, analog information is defined as "direct and holistic pattern recognition" by some structural motifs of the evolving agent within a continuous threshold of variability. 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 reversible interactions. (Root-Berstein and Dillon, 1997). If the motif recognized by the agent is external, then we can talk about interaction and measurement that leads to internalization of information. If the recognized motif is internal we have an interaction that results in aggregation of structural subunits that produce a higher level organization. This analog information between inner constitutive components preserves the coherence of the agent as it interacts with the environment. Digital information refers to encoded information in the form of a record that has the structure of a text composed of basic symbols, such as DNA. This text can be modified by discontinuous variations such as mutations and recombinations. Semiotic work-actions refer to the processes of transformation and use of information inasmuch as this actions are executed by the evolutionary units or agents themselves.

To summarize, 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 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 information processing agency that defines the relations with the adjacent lower and higher levels. Self-organization is a characteristic property of the emerging systems feeded by the potentiality, contained not only in the lower levels but also in the higher levels, that drives it towards a more definite and stable entity. Evolution is a non-linear process that takes place in a moving trajectory that unfolds within a continuum of different spatial and temporal dimensions, 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 population/individual, global/local, universal/particular, external/internal, knowledge is found in a continuum of intermediary modes. In order to discern whether a process takes place within inner/external, local/global, individual/population zones, one can attempt to identify for each transition the mode in which analog and digital informational processes interlock. To assume that the continuity of these natural processes is beyond formalization, reminds us of what Aristotle anticipated when he proposed the continuity of the causal agencies as expressed in the necessity to close the circuit from *final* to *efficient* [4] causality.

EVOLUTIONARY AGENTS PROCESS INFORMATION

Each level of the organized hierarchy has to be understood as a population of units of experience, that is to say of converters of analog-digital information and energy users. Therefore, a process of emergence has to be tackled from the perspective of the emerging and evolving unity itself. An evolving unit 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 an evolving unit has a general propensity to interact, and is imagined 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 (H) and Chaitin's algorithmic information (K) are referred to the same 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 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 [5] because the informational dependence on the digital makes it relatively unaffectable by external informational sources. In the case of organisms, they bear an inner digital record that is shared by the population. On the other hand, the passage form H to K is like trespassing the threshold from the analog-external to the digital-internal.

An evolving unit 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 or population domain. 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 for granted, as if it were energetically free. To be a unit of replication, variation, selection and interaction stems from their information processing 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 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. For instance, Fox (1984) proposed that life emerged at the molecular level likely as proteinoids that participated in the formation of self-referential catalytic networks. To the extent that the properties of the molecules were complementary (Root-Berstein and Dillon, 1997), the production of higher order metabolic complexes or closed autocatalytic circuits was favored (Kauffman, 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 to be seen as agents of inner measurement in the sense of Matsuno (1996). Evenmore, evolution produced new types 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; 2003). In accordance with Lemke (1999), it is the new level that buffers the conflicts and redefines the relations between preexisting adjacent levels.

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 problems 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: (1) analog driven emergence and (2) digital driven emergence.

1. ANALOG DRIVEN EMERGENCE

This is 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), though 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 [6]. 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 agent. 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-Berstein and Dyllon, 1997; Fox, 1984).

Analog driven emergence cannot be formalized because it expresses the relation between the agent itself and its partially describable external environment in the form of a process that converts analog into digital information. Formalization is understood as the reduction of a phenomenon to a set of syntactic rules by the elimination of self-referents. Agents' subjective aims, feeling, experience and the capacity to interact 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 the agent's responses to the concrete and immediate challenge of external circumstances and can 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 self-referential for it concerns the agent (Andrade, 1999; 2000; 2003). In addition, information processing represents 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 agent 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 evolutionary agents 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 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 response. 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 agent 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 were traditionally considered as themes that could be applied exclusively to describe the operations of "mind", nowadays they are physically accounted as information processing that starts as analog pattern recognition embedded in a feedback loop: stimuli, adjustment, selection, recording, variation, and new stimuli. In this sense "consciousness" is a property of every natural system that possesses the capacity to process information, so creating and internalizing a partial record of his environment.

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 is required a randomization and expansion in the Digital Informational Space (DIS [7]). The classical example is the 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 rugged landscapes (Kauffman, 1993: 95-109). This is 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, since emergence is also semantic and pragmatic. The trap lies in the fact that if the new emerging behavior or function is but a slight modification of a preexisting one, for mere practical purposes one can consider them as equal and therefore conclude that there is no need 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 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, where 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 minimal 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.

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. So we arrive to a point that can only be solved empirically for particular cases studied within the heuristics of shape-space concept (see note 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 because a sort of final cause, conceived as the tendency to fill up the Analog Informational Space (AIS [8]) inevitably feeds the efficient cause as a new AIS appears ready to be occupied.

EVOLVING AGENTS TRANSIT THROUGH A DEVELOPMENTAL TRAJECTORY

An evolving 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 trajectory. An evolving agent is an individual as long as it shows spatio-temporal cohesiveness in ontogenetic development. To consider an evolving agent as a basic developing process helps to frame an alternative ontology to classical gene reductionism, by means in which the 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 evolution is neither the individual gene nor the phenotype, but the interacting unit or agent 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 evolving agent 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 is a continuum process of analog and digital information processing, 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; Salthe, 1995). 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.

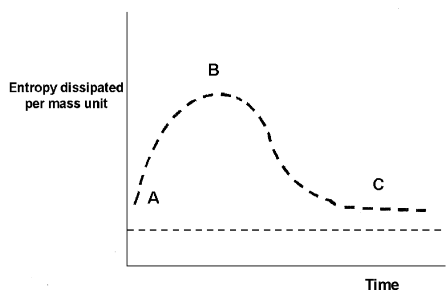

FIGURE 1
Entropy dissipated per mass unit along developmental time according to Salthe (1999, 1995). Phase A stands for early development or the stage where analog driven emergence operates and leads to a symmetry break. In this phase adaptive variations play a mayor role. Phase B stands for maturity, or the stage where the conversion between analog/digital information reaches its maximum as a result of information processing that consolidates the Self. Phase C stands for senescence, the stage of a digital driven phase. In this phase neutral variations play a major role.

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. 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 possibility that new couplings can be 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 manifests and triggers a symmetry break with the creation of an interface inside/outside 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 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. 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 a progressive and directed evolution. Analog emergence 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 providing the conditions for trespassing the boundary internal/external, and as a digital record appears in a condensed form, a new definite and cohesive mature individual materializes 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 cognitive activity (Andrade, 2000; 2003). During this period, individuals show an increase of compressed digitally recorded information that enhances their asymmetry with the surroundings. The increase in digitally encoded information is achieved by including newly encoded motifs and by removing redundancy. Thus, information processing results in a real compression that requires the consolidation of a formal system capable of executing this operation. This activity is responsible for the tendency to optimize individuals efficiency in terms of extraction of work by record compressions. Consequently, the mutual information content between the evolving agent and its environment, $K_{(agent:environment)}$, and between its analog and digital informational records, $K_{(analog:digital)}$ increase. This stage is poised somewhere between maximum uncertainty about the environment and inner determination by the digital record, 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 and at other time more dependent on the digital information content. Emergence and evolvability are properties dependent on the information processing agency that merges the internal and external in the population realm. This cognitive process is both external and internal, and works by taking up information from spontaneous drives, established interactions, experience or habits and digitally recorded information. The agent 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. The varying weights of analog and digital informational sources is what the individual manages to control as an information processing agent.

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

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. 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 the digital to the analog by the actions of the agent. Funthermore, 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 microlevels 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. What emerges is a definite individual that holds some determinate relationships; emergence is a process that happens in the internal and externals domain that connect the individual to the population domain, and as such will be considered in the following model. That is, what emerges is both an object and an interpretant.

STEPS TOWARDS EMERGENCE

I have argued that the hierarchical organization of nature is driven by the tendency to fulfill the second law of Thermodynamics in the real existing world of shapes and forms, thus showing a rapid filling up of the AIS (Andrade, 2000; 2002; 2003). It is important to distinguish between two types of shape spaces: 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.

First step, let "L_o" stand for the ground level for practical and ontological reasons, so to start with analog and digital mutual information zero content ($K_{digital:analog}$).

As the network of non-random interactions corresponding to this ground level "crystallizes" forming stable aggregates (L_o), their own AIS and DIS starts to be randomly explored (Andrade, 2002).

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 takes 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, it is rather an intrinsic intention that is attained by means of increasing mutual information content between the evolving unit and its environment, for the evolving individual is a realization of a potential in a defined environment by its own actions within the population context that merges internal and external zones. 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 type of shapes or a qualitative level of agents' interpretation that is always contextualized.

CONCLUSION

To understand biological development, evolution, and the emergence hierarchical organization as a continuum of analog/digital information processing may contribute to the construction of an alternative ontology to classical gene reductionism. Emergence of more complex hierarchical levels is a spontaneous tendency through where nature pulls itself by using analog and digital informational sources. Both analog and digital driven emergences 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, they complement each other.

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.

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, but inevitably leads to an opening that provokes an analog driven emergence. Therefore, living systems (or information processing agents) regulate their closure by introducing new levels of organization.

NOTES

1 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.

2 "Entities that pass on their structure directly in replication" (Hull, 1980).

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

4 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.

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

6 Shape-space is an 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 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).

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

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

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