Cybernetics And Human Knowing. Vol. 11, no. 4, pp. 11-19

Answering Cuvier:
Notes on the systemic/historic nature of living beings

Claudia Cecchi,[1] Alexander Vargas,[2]
Cristián Villagra,[1] and Jorge Mpodozis[3]

Georges Cuvier, founder of vertebrate paleontology and an anti-evolutionist who argued that in living beings the relation between the parts (organs) and the whole (the organism), as well as the relation between the whole and its environment (way of existence or adaptation), are so exquisite and particular that a spontaneous or random origin of the living beings is totally unthinkable. Accordingly, he established a fundamental question, namely: "how did living beings come to exist if not as a result of intentional design?" Here we argue that the current use of the notions of a genetic developmental program and of evolution as a process of genetic change are ultimately unsatisfactory as an answer to Cuvier's question. We propose a biological-historical approach to this question, based on the systemic-historical conceptualization of Natural Drift. Specifically, we propose that an organism comes to be a unique organized whole of mutually correspondent parts that exist as such through realizing a particular mode of relationship with its environment, neither as a consequence of design, nor by the operation of an internal building plan or program. This happens because the organism and its parts have arisen together in a historical systemic process that follows the course of the realization of the organism through its relation with its environment, both in ontogeny and phylogeny.

Cuvier's question and fundamental biological observations

Georges Cuvier (1769-1832), the founder of modern comparative anatomy and the father of vertebrate paleontology, was an anti-evolutionary thinker[4] who, paradoxically, realized and established biological principles that have had a deep meaning in evolutionary thinking. One of these ideas is The Law of Specific Correlation: "the principle of the correlation of structures in organic beings, by means of which each sort of creature could in a pinch be recognized by each fragment of each of its parts" (Cuvier, 1825). To illustrate this law he gave an example:

> if the intestines of an animal are organized in such a way as to digest only fresh meat, it is necessary also that its jaws be constructed to devour its prey; its claws to seize and tear it apart; its teeth to cut and chew it; the entire system of its organs of motion to rush and catch the prey; its sense organs to perceive it from far away. It is even necessary that nature has placed in its brain the required instinct to know how to hide itself and set traps for its victims. Such will be the universal conditions for the kingdom of the carnivores; all animals destined to this kingdom will infallibly combine them,

---

1. Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile
2. Programa de Morfología, Facultad de Medicina, Universidad de Chile
3. Departamento de Biología, Facultad de Ciencias, Universidad de Chile. Please direct correspondence to E-mail: epistemo@uchile.cl
4. The anti-evolutionist thought of Cuvier, evident in all his work, is particularly explicit in his famous polemic with Jean-Baptiste Lamarck.

> because its race would not have been able to survive without them. Under these general conditions, there exist particular ones, relative to the size, species and habitat of the prey for which the animal is structured. From each of these particulars modifications result in the detail of the forms which derive from the general conditions. Thus not only the class, but the order and the genus, up to and including the species are found expressed in the form of each part. (Cuvier, 1825)

Regardless of whether this principle has any heuristic value or not,[5] it is interesting to analyze the fundamental biological observations that give support to it. First, Cuvier points out that every organism forms a unitary whole, "a unique and closed system, in which the parts are mutually correspondent and work together in the same specific action through a reciprocal relationship." Second, Cuvier emphasizes that each unique organism realizes a unique mode of life, a particular mode of organism/medium relationship on which the realization of the organism depends. Third, Cuvier realizes that even though every kind of organism is unique, the enormous diversity of living beings can be arranged in an orderly and inclusive system of increasing generality, in which each category represents a structural plan or organic arrangement common to all the living beings belonging to that category (see also Cecchi, Guerrero-Bosagna, & Mpodozis, 2002).

In Cuvier's thinking, the distinction of the organic arrangements is not only useful for the identification of natural groups. For the father of paleontology, this structural plan represented the *condition of existence* for each living being, or, in his owns words, the *final cause*, in the Aristotelian sense, of living beings. Cuvier (1836) wrote:

> Natural history has a rational principle that is used in an advantageous way in many cases; it is the condition of existence, ordinarily called the final cause. Because nothing can exist if it does not have the conditions that allow its existence, the different parts of each being must be coordinated in such way that it makes possible not only the whole being itself, but also the relationship with its environment. The analysis of these conditions frequently leads to general laws, as demonstrable as those derived from calculus or from experience. (p. 6)

Thus, according to Cuvier, the structural plan of a given organism is the particular one that satisfies the conditions of existence, in other words, the final causes, of such organism. Considering all this, a fundamental and challenging question is established: How did living beings come to be so constructed? Cuvier believed that the arrangement of the parts is so intricately directed to the construction and survival of an organism that a spontaneous or random origin is totally unthinkable. For him, the only possible explanation for the constitution of living beings was that they are an outcome of a design, namely a plan generated by a creator (as stated in Cuvier, 1836, preface.) This explanation may be acceptable in a religious or metaphysical domain, but it is not

5. When a paleontologist identifies a fragment as belonging to one taxonomic group or another, a "best estimate" can be carried out of the possible appearance of an organism (at least in general terms). Although the remarkable mutual correspondence among the parts of an organism can justify some predictive ability, prediction actually depends heavily on previous knowledge of the morphology of organisms. Some predictions can eventually found to be mistaken. An interesting example are the fossils of conodonts and other early Cambrian organisms which were interpreted in very different ways before more complete specimens were found (Gould, 1989).

acceptable in the domain of biology. Biology, like every other modern science, looks for operational generative explanations that can be formulated and validated in the domain of human experiences. From a biological point of view we may dismiss Cuvier's answer, but we cannot dismiss his question. What then would be an acceptable biological answer?

The genetic reductionist answer: A throwback to Aristotelian formal causes.

The development of the concept of organic evolution in the 19th century led to a big shift in the answer to the question of the origin of living beings. Where Cuvier sees the expression of structural plans and final causes, the evolutionist sees similarities that reveal a community of descent and a phylogenetic bond of origin among living beings. Organic evolution was initially conceived as a purely operational, non-finalist theory and, as such, marked a departure of biological thinking from the Aristotelian metaphysical tradition. In the words of Darwin (1872/1958, p. 387), "nothing can be more useless than trying to explain similarity patterns between members of the same class alluding to utility or to a doctrine of final causes." However, the development of a particulate genetic view of inheritance and the incorporation of such a view in the explanation of evolution by the theory of Natural Selection, resulted in a clear return of biology to Aristotelian metaphysics which to this day still permeates mainstream biological thinking.

According to Aristotle, both the spontaneous arising of natural systems and the construction of artificial systems require a "formal cause," that is an "abstract agent" that contains and is capable of specifying the defining relations (the order between the parts) of the system. In his house metaphor, the formal cause is the blueprint of the house (Aristotle, 1987). The formal cause has the property of *giving form to* (to inform) the raw matter in a process that does not produce any change in the cause itself, because the formal cause is an idea (entelechy) and does not have a structural existence. In other words, the formal cause of something contains *the information* to determine that particular thing.

In modern biology, the genome is viewed as the part of the organism that contains the information that determines all of the properties of the organism and specifies all of the processes for producing those properties. In other words, genetic information is viewed as the formal cause of living beings. Of course, complex organisms arise from a developmental process that entails cellular multiplication and differentiation, but this process is viewed as following a sequential path instructed and directed by the genome and the information it contains. Thus, in our modern neo-Aristotelian biology, the genome acts as the vehicle (or code) of the "information," inheritance results from the copy and trans-reproductive donation of this vehicle, and, as the mechanism of copy is not perfect, evolution may occur as a consequence of natural selection of the most successful variations of the informational vehicle (see Dawkins, 1978 for a detailed exposition of this way of thinking). One can say that, from Cuvier to the present day, biological thinking has done no more than make a small shift in its Aristotelian inspiration: namely moving from final to formal causes.

This genome-centered view has an implicit response to Cuvier's question: the harmonious and perfect arrangement and relationships between parts is not a matter of design, rather it is the result of the action of the genome, the informational component of the organism that specifies and directs a developmental process that gives rise to all the other components of the organism and to the appropriate organic relations between them. From this perspective, the history of the organisms as such virtually does not exist; it is reduced to the history of this determining part. Organisms are little more than packages carrying genes, and development is no more than the expression of an informational program coded by the genome.

We consider that this notion about the genome and its informational role lacks biological operational meaning, and ultimately leads to a denial of the systemic nature of living beings. Lets us reflect upon this from a purely operational point of view.

In current thinking, the notion of information is applied when a kind of key-lock structural relation between two or more systems, or components of a system, is distinguished and the importance of one of the components (the informative one) wants to be emphasized. "Communicational," "coded" or "semantic" situations do not differ from this as they are ultimately based on the observation of structural correspondence between the states of two or more systems. From an operational point of view it is easy to see that the expression "the key has the information to open the lock" is only metaphoric. First, that expression does not refer in any meaningful way to the structural process by means of which the lock is opened when the key is inserted in. Second, because the "informative content" of the key is such only in the structural context provided by the lock, one can say, with equal logic, that the lock has the information that allows the key to open it. (What is usually said is an equally operationally meaningless expression, namely that the key is capable of "decoding" the lock).

The genotype-phenotype relationship (whether the phenotype is meant in a cellular or organismic sense) to which the notion of genetic information is currently applied, is indeed an operational configuration of the key-lock type, in which the genotype (the nuclear DNA type) contributes to determine in a cell or organism the expression of a particular set of structural features, but only by participating in a process that takes place in a structural matrix (the cytoplasm, the developing organism) that is structurally distinct and operationally complementary to the genotype. Thus, in parallel with the lock-key analogy, the expression "the genome contains the information to build an organism" lacks operational meaning, and can only be understood in the biological domain as a metaphor.

Furthermore, the use of the informational genetic metaphor leads to the disregard of a basic systemic condition: that the properties of a system as a whole (the arm, the eye) and the properties of the components of the system (the muscle cells, the retinal neurons, the genome) are constitutively different, in such a way that the former are not reducible to the latter. This is the case even though the system and the components are generatively related (the muscle cells participate in the leg). Although a structural mechanism exists that relates the transcription of a particular gene with the development of a particular phenotypic trait, one cannot say, with operational meaning, that the gene by itself has the property of specifying that trait. Rather, the genetic relation between gene and the trait is the result of the operation of a structural mechanism in which the gene participates only as a component.

Finally, this genetic deterministic view has led to the denial of one of the fundamental systemic observations made by Cuvier, namely that the existence of the parts is subordinated to the existence of the whole, as the whole is the "condition of existence" of the parts. Thus, changes of a part will result in changes of the properties of a system only if such change takes place in a context of other corresponding changes in the structural matrix in which the part operates. Otherwise such a change would be silent (would have no effect) or it would be destructive (the system would disintegrate). In other words, a genetic change alone does not determine a viable change in the phenotype of the organism if this genetic change is not accompanied by (or happen in the context of) a corresponding change in the whole structural matrix in which the gene participates as a component. Thus, the supposition that genetic changes by themselves are going to direct an organism through evolution also lacks a biological operational meaning.

Given these reasons, we think we can properly say that the current biological view of the genome as the formal cause of living beings is ultimately inadequate as it does not provide a legitimate biological answer to Cuvier's question. At this point the reader may be willing to accept this dictum: Changes in a system only take place as systemic changes.

The systemic/historic answer.

So far we have shown that the question of Cuvier cannot be properly answered in the domain of biology from a genetic-reductionist perspective. In what follows we will show how his question can be answered from a systemic-historic perspective, such as the one put forward by Maturana and Varela (1986) and later developed by Maturana and Mpodozis (1992, 2000).

1. Ontogeny as a historical structural drift

According to Maturana and his coauthors, the ontogeny of an organism courses constitutively as an epigenetic[6] structural drift that is not genetically determined. Thus, ontogeny takes place as a historical process of structural change that follows the contingent dynamic of the organism/medium interactions through which the organism realizes its existence. In this ongoing process, the organism (the whole) lives in a permanent dynamic of transformation, in which each change is allowed by the prior

6. The biological concept of epigenesis implies that although development of the phenotype is made possible by aspects of an initial structure (including the genome), it is not determined by it. See Maturana and Mpodozis (2000) for a more detailed exposition.

state and at the same time sets the boundaries for the following changes and states. Of course, this dynamic of transformation occurs through changes of the parts (the structural composition of the organism), but the consequences of these changes at the organismic level do not depend on the changing part, but on the relations of that part with the others in the constitution of the organism (the organization of the organism[7]). Structural changes, either resulting from the internal dynamic of constitution of the organism, or triggered by the organism /environment relationship, will either result in the conservation of the organization of the organism and thus allow the realization of the organism in its dynamic of interactions with its medium, or the organism will disintegrate. In other words, during the ongoing realization of the organism, the changes of the parts will follow the changes of the organism/medium relationship, allowing the continuous realization of the organism through these interactions. If this were not so the organism and all its parts would disintegrate, as the realization of the organism as a whole is the condition of existence of its organic components. Therefore, the structural present of an organism is, and can only be, the result of a history of structural drift through which the organism and the structural components that realize it as a whole have arisen together, in a continuous epigenetic manner.

Note that this biological view is substantively different from the gene-centered view, where the developmental process is directed towards the formation of a final phenotype by a genetic plan. In the gene-centered view, genes establish and determine the direction that the structural change of the whole follows, regardless of the historical dynamics of the whole. The biological point of view which we have stated here rescues the systemic reciprocal relationship between the whole and the parts and the importance of the organism/environment relationship as a central process in the establishment of the course of the structural ontogenetic changes that take place in the developmental process from which the resulting phenotype arises.

2. Reproduction, inheritance and phylogenetic structural drift

From a biological-historical point of view, the trans-generational conservation of traits in a lineage of organisms is not the result of the repetition of a developmental program, but rather it is the result of the trans-reproductive repetition of a particular epigenetic pathway (Maturana & Mpodozis, 2000). Reproduction is a systemic phenomenon that happens when an organisms fractures (or two organisms undergo

7. Even though the topic requires a more detailed treatment than is possible here, it is worth mentioning that the notion of organization can be considered the systemic-historic counterpart of the Aristotelian notion of form. Both concepts allude to the relations between the components of a system that define and realize a system as an entity of a particular kind. Both notions are epistemologically ineludible in dealing with systems (for example living systems) that have continuous structural change as a "condition of existence" and therefore exist as "purely relational" entities. In the Aristotelian world, the form of a natural system can not be anything but the effect of an acting formal cause. In the systemic-historic world, the organization of a natural system arises spontaneously from the deterministic encounters of a set of interacting elements; hence it does not requires the action of any "cause" of special "organizational" process to occur. Thus, in the systemic-historic world, organization is not a goal to be achieved or maintained, nor is it the manifestation of an intrinsic "tendency" of a system. Changes of a system do not happen so as to maintain organization. Instead, the organization is conserved trough these changes or else the system disintegrates.

fracture and fusion) in a manner that gives the offspring an initial structure or "total genotype," (that is the structural matrix of biological molecules topologically and metabolically arranged in a particular organization) similar to the parental one, and places the offspring in an interactional context or environment similar to the parental initial environment (Maturana & Mpodozis, 2000). In other words, reproduction is a biological mechanism that allows for the inheritance of an initial structure as well as an initial organism/environment relational context from which the epigenetic conservation of the particular phenotype and mode of life of a lineage may result. A lineage is established when a particular mode of life or organism/environment relationship is conserved trans-reproductively. Thus, when we identify an organism as belonging to a natural taxonomic group, we are identifying a particular kind of epigenetic pathway conserved through the conservation of a particular history of organism/environment relationship.

Each time that a change occurs in the ontogeny of a lineage in a way that this change begins to be conserved through reproduction, a new lineage is originated. The cleavage of a lineage and the foundation of new lineages occur as historical processes, because the transformation which founds a new lineage is a modification of an ancestral mode of life, it is a modification that is allowed by the epigenesis of the ancestral lineage. Thus, phylogeny and ontogeny are historical processes of the same kind, namely structural drifts, trough which the organic components that realize an organism arise and change, following the historical realization of the organism in its interactions with its medium, and allowing the continuous realization of the organismic mode of life.

Since the genes and the genotype constitute part of the organism in the same way as any other component, they too will necessarily change in the evolutionary history of a lineage. However, changes in the genetic components, like changes in any other component, do not direct or establish evolutionary changes. Rather, the change in the mode of life or organism/environment relationship is the central factor that allows or does not allow the incorporation (conservation) of a particular change in the genotype or in any other organic component in an evolving lineage. For this reason we can say that in the process of phylogenic change the genotype, like any other component of an organism, will change in a manner that allows the realization of the new epigenesis through which the organisms of the new lineage result. If this does not take place, the new lineage comes to an end.

As we stated before, this systemic relation is overlooked in modern mainstream developmental and evolutionary biology by the unidirectional concept of a developmental program or genetic instruction, which so closely resembles the Aristotelian formal cause. Development does not occur directed by a program or instructed by a formal cause to produce a certain phenotype; rather the phenotype is a result of development, understood as the ontogenetic history of the individual. As noted by Cuvier, the relationship among the parts of the whole, and of the whole itself with the environment, is exquisitely arranged such that the whole is conserved; a fact that he believed required intelligent design as an explanation. Here we emphasize that the changes in the parts and in the relation to the environment, rather than occurring *such that the whole is conserved by design*, have in fact occurred *in conservation of the whole throughout the spontaneous drift of its ontogenetic and phylogenetic history.* Therefore it is not surprising that organisms are found to be in correspondence with their own organic composition and environment, both during ontogeny and phylogeny.

3. Answering Cuvier.

We can now say that an organism is a unique organized whole of mutually correspondent parts that exist only in realizing a particular mode of relationship with its environment, neither as a consequence of design nor as the result of an internal component that acts as a building plan or program. Rather, this happens because the organism and its components have arisen together in a historical systemic process that follows the course of the realization of the organism through its relation with its environment, both in ontogeny and phylogeny. As the organs that form an organism can only arise as a result of the historical epigenetic process that gives rise to the organism itself, the reproduction of an organism necessarily entails the reproduction of this epigenetic history. There is no biological way to construct an organism and its organs other than systemic epigenesis. This is our answer to the question posed by Cuvier.

4. Corollary.

What we have said here regarding organisms as multicellular systems can be extended to all natural systems as long as they satisfy the following two conditions:

a) they must be dynamic, that is to have a continuous structural change as a condition of existence; and
b) they must be discrete, that is to have a self-generated boundary as a condition of existence.

Cells as molecular systems satisfy these two conditions. Interestingly, most of the molecules that compose modern cells (such as proteins and DNA) cannot be formed in nature in places other than in the cellular context. Thus, bio-molecules are ontologically related to cells in the same way that organs are related to organisms (as organs do not exist nor can they be formed in nature in places other than in the organic structural context). We think that this is a clear indication that bio-molecules and the cells that they compose have arisen together from the spontaneous historical process of origin and evolution of cells as multi-molecular totalities.

References

Aristóteles. (1987). Acerca de la generación y la corrupción. Libro II. In *Tratados breves de historia natural* (E. La Croce & A. B. Pajares, Trans., pp. 100-121). Madrid: Editorial Gredos.

Cecchi, M.C., Guerrero-Bosagna, C. & Mpodozis, J. (2001). El delito? de Aristóteles. *Revista Chilena de Historia Natural, 74*, 507-514.

Cuvier, G. (1825). *Discours sur les revolutions de la surface du globe* (3rd ed.). Retrieved June 21, 2004 from www.mala.bc.ca/~johnstoi/cuvier.htm (Translated from French by the authors.)

Cuvier, G. (1836). *Le règne animal distribué d'apres son organisation.* Paris: Chez Crochard et CIB Libraires. (Translated from French by the authors.)

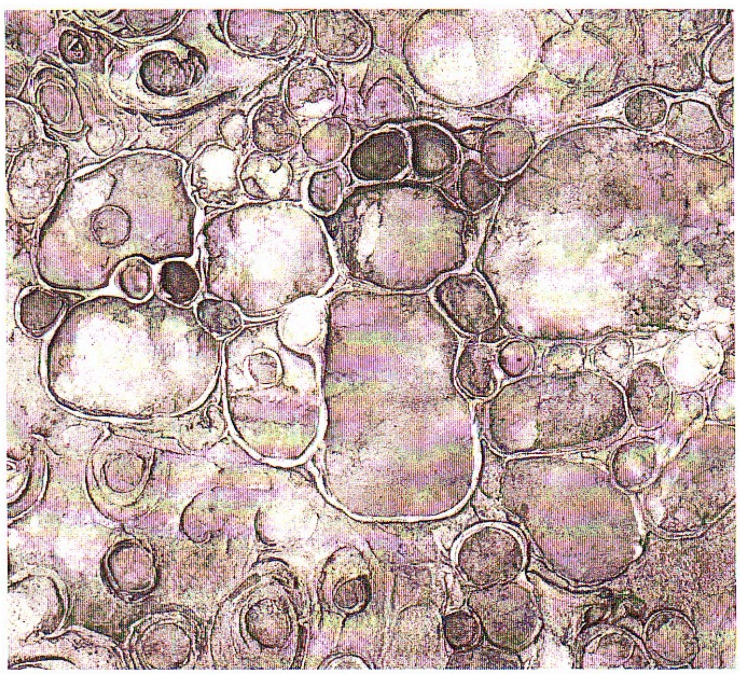
Darwin, C. (1958). *The origin of species by means of Natural Selection* (6th ed.). New York: The New American Library. (Sixth edition originally published in 1872 by Down & Beckhenham)

Dawkins, R. (1978). *The selfish gene.* Oxford: Oxford University Press.

Gould, S. J. (1989). *Wonderful Life: The Burgess shale and the nature of history.* New York: W.W. Norton.

Maturana-Romecin, H. & Mpodozis, J. (1992). El origen de las especies por medio de la deriva natural o la diversificación de los linajes a través de la conservación y cambio de los fenotipos ontogénicos. *Revista del Museo de Historio Natural de Chile.* Publicación ocasional 46. (96 pp.)

Maturana-Romecin, H. & Mpodozis, J. (2000). The origin of species by means of Natural Drift. *Revista Chilena de Historia Natural, 73*, 261-310.



Sacred Heart (Detail), 2000, acrylic and mica on canvas

The tree falls in the wood
We hear the heartwood crack
stillness breaking

When hearts break
Why do we not hear
the startling sounds of separation?