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SELF-ORGANIZATION AND LIFE: A SYSTEMIC APPROACH

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Abstract: We investigate the relation between self-organization and living processes from a systemic perspective. Emphasis is given to Aristotle's conception of four causes in order to provide foundations for a systemic approach to life. From this perspective, life is characterized as a self-organizing process that allows the emergence and evolution of systems capable of self-locomotion, in the Aristotelian sense of moving and growing.

Key-words: Life. Self-organization. Aristotelian's four causes. Order parameters.

INTRODUCTION

The relation between self-organization and living processes constitutes our main subject of investigation in this paper. Based upon Aristotle's characterization of four causes, we investigate the nature of self-organizing processes providing a framework for the following hypotheses:

1. The Aristotelian theory of four causes allows us to improve aspects of contemporary approaches to life characterized as a self-organized process.

2. Life can be understood in terms of self-organizing processes that allow the emergence and evolution of systems capable of self-locomotion, in the Aristotelian sense of moving and growing.

The hypotheses will be investigated, in Part 1, in the context of History of Philosophy, with special emphasis on Aristotle's ideas on the nature of causality and its relation to life and intelligence. These ideas are claimed to complement contemporary approaches to life such as those developed by Loewenstein (1999), Maturana & Varela (1980), Maturana (1992), Bohm (1980), and others.

In Part 2, based upon Aristotle's theory of causation, we then sketch a characterization of living organisms in terms of a systemic unity.

1. ARISTOTLE'S THEORY OF THE FOUR CAUSES AND ITS METAPHYSICAL BACKGROUND

Countless contemporary studies have already pointed out the problems that arise from the notion of causation adopted by classical mechanics. From the four causes (material, formal, efficient and final) initially proposed by Aristotle, only efficient causation has remained since it was the only one allowing immediate quantification.

On one hand, the possibility of having measurable/quantifiable relations between physical bodies was a great contribution provided by Physics in the 17th century, but it demanded, on the other hand, that the method of qualitative description would be abandoned. Malherbe observes (1994, p. 21) "[…] one does not talk anymore about the nature of things, but about nature as a system of relations, like a uniform totality of causes and effects". According to Malherbe, the ontological connection that would join the individual things to a world full of qualities is lost and reduced to a mere set of quantitative relations.

The immediate implication of such a reduction is that the physical reality and its mathematical expression are set apart. In other words, the methodological reduction promoted by classical mechanics, initially with mere epistemological pretensions, to describe the world adequately, starts to play an ontological role: the relations between things are quantifiable within the context of efficient causation because the mathematical expressions describing the movement of things constitute their *essence*. In the genesis of classical mechanics there seems to be a substitution of quantitative for qualitative ontology; with the intent of measuring perfectly, for which efficient causation lends itself quite well.

As we have already pointed out, however, to attribute such an ontological role to efficient causation implies distinguishing physics, as characterised above, from *physis* in the sense of nature with its two meanings: (1) the totality of beings and (2) the set of properties or qualities of a being. In this paper we suggest a reinterpretation of the notion of causation in order to recover its four senses originally considered by Aristotle: matter, form, movement and direction (*Physics*, 192 b/194). At the same time we claim that it would be necessary to return to a qualitative ontology if we want to describe the phenomena that escape from the reductionist grip, like for instance phenomena related to life.

Aristotle (2002) argues that in order to know the properties of natural entities or events one has to investigate their causal relations. These apply to all natural things composed dynamically by the mixture of matter and form that develops in specific directions. As mentioned, four inseparable causes - material, formal, efficient and final - are involved in this mixture. The material one corresponds to the basic elements constitutive of organic and inorganic matter; the formal one concerns their structure and function; the efficient cause sets the changes and all forms of motion; the final cause is related to the direction in which changes occur. These four causes always operate together in a systemic way, producing everything that exists in nature. However, organisms differ from non-living material in that they incorporate a principle of self-locomotion, in the Aristotelian sense of moving and growing.

Organisms have the capacity to grow (actualizing their shape mainly thanks to the formal cause) and to move by their own means (operating the efficient cause). This is possible due to the organism's nutritional activities (by incorporating matter through the material cause) and biochemical transferring of kinetic energy (again via efficient cause) that will allow them to fulfill the goal of surviving (according to the final cause). As we are going to argue in Part 2, this dynamics characterizes a self-organizing process that allows a systemic unity, typical of living organisms, connecting its constitutive parameters.

From the Aristotelian perspective of causation, matter organises itself dynamically into different structures and directions. This conception is particularly connected with the idea of inseparability of matter and form: matter is what changes and form is that which has the tendency to change (*Metaphysics*, 1.070a). From such a perspective one can consider the dynamism of the physical world in terms of constant transformations (or alterations in the case of formal causation) that belong to the coming-to-be or becoming where a being loses some properties while acquiring others. According to Aristotle, matter as a whole is, potentially, both the opposites (*Metaphysics*, 1.069b 14-15), being and non-being, either accepting form or its absence. The direction of the transformations of matter will depend on its ability to change inherent potentialities and which depend on its form of organization. The passage of potentiality to action is part of the flow of generation and corruption within nature and, especially, living creatures. Aristotle also observes that while primary matter or substance can actualise itself in various directions, there are limits to the potentiality of actualising the form of a given matter.

According to Aristotle, matter and form are ontologically inseparable; it is just within the act of thought that the primary substances can be divided into form and matter, underlining the linguistic-conceptual character (or epistemological) of such a division. This division has a task to fulfill: it allows the classification of beings. The aim of this classification is to produce essential definitions of each class. Groups or classes of beings constitute, in turn, *secondary substances*, the objects of knowledge that will be investigated causally.

The method used by Aristotle to group species on the basis of sets of properties is the composition; because a definition cannot be about individuals, these are not the object of knowledge, as Aristotle points out in *Metaphysics* Z, 15, 1,040[1] -, but about groups or sets of beings possessing the same essential property. The essence or *form* defines the borders of the class to which different beings belong and it distinguishes each class from others. Once a being is correctly classified, this will immediately result in the definition of its essence. An example of this kind of classification is the definition of human beings as a rational animal. The capacity of reasoning is the essential property of the *form* of human beings, but belongs to all humans and not only to an individual. What we would like to emphasize is that, even when the individual being is unknowable, its essence - the form as object of knowledge - is inseparable from it: according to this line of Aristotelian reasoning, the form is inseparable from the body except for in thought, as we already observed.

The knowledge of the four causes allows the classification of beings in agreement with their qualities (what they have in common systemically

[1] For Aristotle, the singular being is not the object of knowledge because it is subject to generation and corruption.

with other beings and what they have specifically for themselves) in order to determine their essential definition. Such a definition of essential qualities concerns, for Aristotle, the immanent structure (or form, as we saw) of classes of beings, the observation of which can start a causal investigation.

In this context, human beings are considered capable of knowing in virtue of having certain sensorial, mnemonic potentialities and immanent reflexives:

> The animals other than man live by appearances and memories, and have but little of connected experience; but the human race lives also by art and reasoning. Now from memory experience is produced in men; for the several memories of the same thing produce finally the capacity for a single experience. And experience seems pretty much like science and art, but really science and art come to men through experience […]. (*Metaphysics*, A, 980b)

We understand that the development of one of the most complex human cognitive abilities, for example the inductive reasoning happens, according to Aristotle, in function of the unification of similar experiences. This unification is possible not only due to the remembrance (memory) of each individual experience with the same object or with similar objects, but also to the overlap between individual experiences that are unified by forgetting specific details.

This brief summary of the Aristotelian ideas allows us to question a set of religiously inclined interpretations of Aristotle that suggest that there exists an ontological abyss among living beings because the human reflexive capacities are of "divine origin". In contrast, a contemporary reading of the above passages allows us to assume that, for Aristotle, there is a (quantitative) difference of complexity among living beings, from insects to human beings, in virtue of their distinct sensorial and mnemonic capacities and not necessarily a qualitative difference. After all, the substantial substratum of all beings is the inseparable unity of matter and form.

When considering his causal doctrine, Aristotle retells the appearance of cognitive abilities in their historical order (which was considered irrelevant from the platonic perspective), suggesting a gradual *complexification* of these abilities in living systems in agreement with their sensorial and mnemonic capacities. He says, still in *Book A* of the *Metaphysics* (980 27 - 980 b 25):

> By nature animals are born with the faculty of sensation, and from sensation memory is produced in some of them, though not in others. And therefore the former are more intelligent and apt at learning than those which cannot remember; those which are incapable of hearing sounds are intelligent though they cannot be taught, e.g. the bee, and any other race of animals that may be like it; and those which besides memory have this sense of hearing can be taught.

The importance attributed to the capacity of communication allows us to perceive the cognitive relevance of mutual interaction. However, even though animals are capable of hearing, to remember and to take heed of voices of command are abilities considered more intelligent. Other animals, such as bees, for example, are also considered intelligent. These animals, although devoid of hearing, show their intelligence through collective systemic actions, as their abilities reveal themselves in their interaction with the environment. Here, we have an example of empirical knowledge about non-human animals that express their intelligence in everyday behaviour.

The common element that connects all living organisms seems to be the incorporation of self-locomotion abilities that allows the development of a systemic order considering both organisms and environment. In what follows, we are going to inquire into the main properties of self-organization and systemic order.

2. SELF-ORGANIZATION AND SYSTEMIC ORDER

Grounded on Aristotle's lessons on the nature of causality, we shall now investigate the relation between self-organization and living processes.

As pointed out in Debrun (1996), D'Ottaviano et al. (2000) and Gonzalez & Haselager (2003), the label 'self-organization' refers to a process through which new forms of organization may emerge spontaneously from the dynamic interaction established between elements that are initially independent. The spontaneous characteristic of a self-organizing process requires that no *a priori* plan or central controller should direct the development of the process in question: its systemic organization, when it happens, should result mainly from the exclusive dynamics of the process of interaction between its elements.

Conventionally, two basic phases can be established in a self-organizing process (Ashby, 1962 and Debrun, 1996): In the first, known as *primary self-organization*, organic or inorganic elements (with independent behaviours) get together, ideally by chance. This casual encounter may initiate an interaction amongst independent elements in such a way that they become coordinated and interdependent. In this primary phase, spontaneous interactions may give place to new forms of organizations. It is in this context that Ashby (1962) stresses that a process is "self-organizing in the sense that it changes from *separated parts* to *parts joined*" without the presence of any kind of pre-established program.

Examples of primary self-organization can be found in processes of pattern formation of organic and inorganic matter such as piles of sand, cells, molecules, organisms, social groups, etc., which are formed spontaneously. Aristotle's hypotheses, mentioned in Part 1, on the degree of complexification of matter involved in living beings seems to illustrate the dynamics of primary self-organization: From the mixture of basic non-organic elements such as minerals, air and water may emerge the basic substances that are going to compose the homogeneous parts of animals, such as bone and flesh. In this process, even though the activity of individual elements may be governed by local constraints, the overall emergent pattern expresses a collective effect that is not governed by strictly local constraints. Each singular element plays a role in the dynamics of a self-organizing process, but its emergent organization (that occurs at a higher level) is the product of a singular *collective* interaction. Furthermore, there may be a qualitative, fundamental difference between elements when considered in isolation and collectively. Thus, for example, in the case of living beings, as suggested by Aristotle (1997), the combination of basic natural elements like earth, air and water may result in the formation of bones, tissues and the like. This suggestion allows us to improve aspects of contemporary approaches to life characterized as a self-organized process, such as the one proposed by Maturana & Varela (1980) concerning autopoiesis – the basic unity of life. This concept is defined through a definition of "living machines":

> An autopoietic machine is a machine organised (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which: (i) through their interactions and transformations continuously regenerate and realise the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realisation as such a network (1980, p. 78-79).

One fundamental property of self-organizing processes is that they allow the emergence of order parameters. As characterized by Haken (1999, 2000), order parameters can be described as high-level patterns that result from the interaction between low-level components. Once created, order parameters constrain (enslave) the behaviour of the low-level components from which they originate. These may change, in a circular feedback way, the high-level order parameters, as happens, for example, with the behaviour of parents: As soon as babies are conceived, their existence changes the behaviour of their parents that, in turn, changes the behaviour of the babies and so on.

Through primary self-organization, different forms of organization may come to existence, but only a small number of them will evolve. Their emergent order parameters are, in general, fragile and unstable; they may disappear at any time, because the interaction between the elements at the lower level (that allowed their emergence) had no time to adjust, mature or to grow in a stable way. Stability, development and preservation of order parameters require training and refined mechanisms of learning and adjustment that, in the fullness of time, are going to characterize the second phase of self-organization.

Secondary self-organization involves, amongst others, cooperation, competition, circular feedback and, principally, learning mechanisms that are fundamental for the dynamics of reciprocal adjustment of parts in their mutual systemic interrelations as indicated in Gonzalez & Haselager (2003). In the case of living beings, these properties are intrinsically related to the flow of information available to organisms as they interact with the environment (initially through touch) in their different levels of existence.

Aristotle's inquiry into the composition of the parts of animals (in *On the parts of animals,* 1996) illustrates again the dynamics of secondary self-organization: Once non-organic elements combine, allowing the formation of tissues and bones, their combination may give place to more complex forms, such as limbs, face and fingers, through the dynamics of interaction and adjustments between elements at the lower level. Finally, the persistence of the whole organism in the domain of life depends on a complex systemic order, acquired through secondary self-organization. Life can be understood in terms of self-organizing processes that allow the emergence and evolution of systems capable of self-locomotion, in the Aristotelian sense of moving and growing.

It could be argued that, according to contemporary Biology, the formation of organs does not characterize a self-organizing process because genetic pre-establish rules shape, with small variations or mutations, the whole process of interaction between genes making predictable its future development into limbs, face, fingers, etc.

A possible answer to this objection is that the origins and stability of the genetic code itself can be understood in terms of primary self-organization. As suggested by Loewenstein (1999, p. 36):

> We begin with the development of carbon chains. […] With the formation of asymmetric molecules the channeling of information into molecular structures gathered way. The prime movers of that trend were molecules with a spine of carbon atoms. These molecules were somewhat lopsided from the start; other atoms, at first probably a few, were positioned unevenly about that spine. So, these molecules were either left- or right -handed. With time, and under the influx of information, the carbon spine got longer and the number of the attached atoms, larger, but the original hand remained, perpetuated by the inter-molecular transfer of information. So, today every biological molecule worth its name has a handedness that is the same in every organism, from microbe to man – glucose and amino acids are left-handed, the sugar in DNA and RNA are of one hand, proteins corkscrew to the right, and so on, to the highest tiers of molecular organization.

If this story is correct, then from the spontaneous interaction between carbon-containing molecules a self-replicating matrix emerged. Once this matrix came to existence, and became stable through secondary self-organization, then different forms of systemic organization started to develop culminating with the formation of organisms.

It should be stressed that an important aspect of this secondary process of self-organization is that the elements belonging to different levels of complexity grow in the context of the *whole* organism, which can be seen, in its totality, as the highest order parameter originated from the lower level components (organic and non-organic). This happens because, as mentioned, once order parameters are formed, they constrain the behaviour of the components at the lower level from which they originate.

Another important aspect of the self-organizing process, particularly in its secondary phase, is that even though it may involve a certain amount of mechanistic order - understood as a sequence governed by pre-established rules, laws or (genetic) programs, a systemic (not necessarily mechanical) kind of organization seems to be fundamental for its emergence, development and maintenance (Bresciani Filho and D'Ottaviano, 2000).

In a similar context, Bohm (1980, p. 173) stresses the systemic organization underlying the structure of living organisms:

> […] In a living organism … each part grows in the context of the whole, so that it does not exist independently, nor 'interacts' with the others without itself being essentially affected in its relationship.

Furthermore, the irreversible arrow of *time that brings novelties* in the dynamics of interaction between elements is essential to the systemic organization that emerges from the spontaneous interaction between its constituents. Even though there are relatively stable laws in the system, the dynamic characteristic of systemic order includes the irreversible arrow of time that shapes its evolutionary path creating a history and opening up new possibilities for the unfolding of its "implicate order" (Bohm, 1980, p. 177).

This sketched view of self-organization together with the Aristotelian conception of causation open up new perspectives to understand the contemporary notion of life initially characterized in terms of a self-replicating matrix. Furthermore, the presupposition of a systemic organization connecting patterns that evolve in accordance with the irreversible arrow of time allows us to characterize the living processes as an evolutionary, self-organized process.

3. FINAL COMMENTS

We have stressed in this paper that the Aristotelian theory of causality is fundamentally systemic in that each cause is mutually dependent on the others, and they operate together to preserve the holistic organization of nature. It was only in the seventh century that Galileo (followed by Descartes, Newton and many others) abolished the notion of final and material causes in the investigations of nature. By considering that "the laws of nature are written in the language of mathematics", Galileo preserved (for reasons that are not very relevant here) only the formal and efficient conceptions of causes. The first one was preserved because mathematical descriptions provide powerful tools to describe physical phenomena; the second one accounts for physical phenomena that can be measured with high precision. Material and final causes disappear in Galileo's description of nature, and with them the qualitative aspects of the physical and, especially, the biological (intentional) worlds.

By recovering the Aristotelian scenario, we believe that it is possible to understand the relation between self-organization and life from a systemic contemporary view. It can be argued that teleological suppositions could be problematic in relation to the central hypotheses of the theory of self-organization, for how could self-organized systems include pre-established purposes as implicit in the Aristotelian theory of causality? However, according to the Aristotelian theory of four causes the purposes are gradually established and dynamically actualized in consonance with the system's own potentialities and the general conditions of the environment. In the same way, the purposes of self-organized processes are manifested by their own paths as time puts together matter and form.

Finally, it could also be argued that by insisting on the importance of Aristotle's conception of final cause, we are reproducing the teleological fallacy, well known amongst scientists, and its undesirable theological ideology. It is possible to consider that Aristotle's teleology is actually a kind of theology, and that the general purpose of actions results from God's determination. However, this is only one (the religious) interpretation of the Aristotelian conception of teleology. As stressed by Halper (1999): "Aristotle's view shows that 'purpose in nature' need not mean a higher purpose beyond nature" (p. 906). This view is developed in detail by Jaeger's (1997) non-religious interpretation of Aristotle's teleology, according to which the general organization of natural, biological and social phenomena can be understood from the Aristotelian principle of *unity of the four causes*. The dynamical influence of the efficient cause allows the actualization of matter/form (material and efficient causes) that occurs in some specific direction (final cause). Moreover, we can consider that all organisms develop common forms of adjustments over large timescales, and that this co-existence could generate some kind of natural (self-organized, we can say today) harmony, in Aristotle's sense.

Supposing, with Aristotle, that everything in nature could be understood from the perspective that integrates the four causes, one question to be further investigated could be: what is the contribution of the theory of self-organization for the contemporary systemic view that integrates life and causation? This essay sketched an answer to this question; time may help us to discover a more developed and integrated answer to it.

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