ASSUMING IN BIOLOGY THE REALITY OF REAL VIRTUALITY (A COME BACK FOR *ENTELECHY*?)

ARMANDO ARANDA-ANZALDO

INTRODUCTION

The dissolution of the organism into genes and the proteins coded by such genes was the mindless outcome of the rise of naïve reductionism in biology [1]. Yet, since Aristotle, the central question in biology had been the origin of organic form; a question that was put in the backyard by current neo-Darwinism for which the alteration in gene frequencies within a population—resulting from either differential survival, differential reproduction or differential elimination of individuals—is all that matters. Thus, for neo-Darwinism biological form is a kind of side effect resulting from the interactions between genes and their products. Current mainstream texts on molecular cell biology deal with the topic of organismic development, which is the emergence of complex organized structures and patterns from initially simpler cellular precursors, from the perspective of molecular genetics by spreading the notion of a genetic program for development [2]. According to this view, the genome that resulted from evolution by natural selection has the odd property of being a sort of software autonomously able to produce the very same hardware in which such software is expected to function. This weird idea is currently regarded as the state of the art by many a biologist, as it is considered a major breakthrough with respect to the previous mainstream view, that in order to make an elephant you just need to mix all the constituting proteins in a vessel (at the right temperature) following by a bit of shaking and then, *voilà*, your elephant. The current notion of a program ensconced in the genome able to direct the formation of an organism has the old flavor of pre-formationism but now the tiny dogs, little cows or *homunculi* thought to be lurking in the interior of the germ cells have been substituted by all-powerful master-genes that from their nuclear abode direct biological development [3]. It is against this ideological background that Linde's paper

Laboratorio de Biología Molecular, Facultad de Medicina, Universidad Autónoma del Estado de México, Toluca, México. / aaa@uaemex.mx

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is a most welcome contribution to the slow but necessary return of the organism as the central theme in biology [4]. Linde's account discusses the evidence that living matter is an active entity able to exhibit order spontaneously. Indeed, as shown by Newman, whose scientific work is a major inspiration for Linde's reflection, a lot of fundamental physics is involved in the many morphogenetic and patterning effects in living systems that are the outcome of basic physical properties of cells and tissues [5,6].

One may agree with Linde on that organic morphogenesis is not akin to a crystallization process or on the fact that self-organization is so prevalent in nature that evolution cannot ignore it, so that self-organization (SO) proposes what natural selection (NS) disposes [7]. However, I cannot concur with the suggestion endorsed by Linde that SO is in itself the creative factor in biological evolution and as such the true explanation for biological form. Such a disagreement is not because I concur with neo-Darwinians in believing that NS is the actual creative force in evolution since at best NS is only a sieve that discards what it is not fit enough for survival [8]. Anyhow, seating SO instead of NS in the driver's seat of evolution is not a real solution for the question of how organic form becomes and transforms in time. Linde follows Kauffman in implying that SO is enough for explaining the emergence of biological form and that this is a scientific, non-mystical or tainted of vitalism approach for understanding organic development since the capacity for self-organization is also observed in the inanimate realm [9]. Nevertheless this position shies away from the obvious fact that so far all living things derive from previous living things and that nobody has observed any inanimate SO system such as a BZ reaction or a set of Bénard cells becoming a living entity. Therefore, life sustains any process of organic development which, although sharing many common properties with other physical systems, cannot be reduced to just another case of SO. Indeed, the fact that life has a material substrate do not explains what life is.

SELF-ORGANIZATION IS BY ITSELF NOT A CAUSAL EXPLANATION OF ORGANIC FORM

Some may think that life itself is not an issue when explaining the origin and evolution of organic form, but I contend following Aristotle, that one must not confuse mere shape with true form. For Aristotle form is both a cause and the principle of intelligibility. When we grasp what a thing is, we are grasping its form, i.e., the nature of that in virtue of which the thing behaves in the ways it does. In this manner, form is actuality, or being, in the sense that if something has form X, it *is* an X. Form is the organizing and limiting principle of everything in our world. Thus form is prior not only in the order of explanation of the development of natural things, but also in *logos*, in intelligibility. For Aristotle form is the active, determining

principle of a thing as distinguished from matter, which is the passive, potential principle. It is form that directs the process of its own development from a potential to an actual condition. Therefore, the form of a thing is closely related to its essence since it is that which enables a thing to do what it has to do, then form is its basic quality.

For Aristotle each individual substance is a *hylomorphic* composite involving both matter (*hyle*) and form (*morphé*, *eidos*). Aristotle's definition of the soul in *De Anima*, says that soul is the being-at-work-staying-the-same of an organized body, and this becomes the definition of form in book eight of the *Metaphysics.* This is not just ancient, impractical metaphysical ramble since, for example, molecular biology arose as a branch of science on the principle that knowing the structure (form) of a molecule leads to knowing its function. A principle fully instantiated in the case of DNA, where knowing its structure immediately lead to knowing how it works as the depositary of heredity (genetic information). Indeed in Aristotelian terms function follows form. Further, if something appears to have the shape of, say, a horse but it is unable to perform the functions that a real horse does, then it does not has the true form of a horse and so it is not a horse (it might be for example a drawing, a photo or a sculpture of a horse). In the same way a given SO process may have the shape of a certain process X that occurs in living matter, but if such a SO process do not has as an outcome, the actual living process X then it is not a full account or explanation for that living process. This perspective holds that SO corresponds to a phenomenology that may be observed in both living and non-living entities, but that SO do not exhausts the causal explanation of actual living processes (such as embryonic morphogenesis) as myriad SO processes that occur do not correspond to actual living processes. Therefore, although some SO process occurring in inanimate things may be analogous to SO process occurring in living things, the last kind of SO must include something absent in the first kind in order to become a full explanation of living process. What is missing is a quality or form proper to the living process in question. The previous statements may smack of vitalism and certainly such is the case.

VITALISM VS. SPONTANEOUS GENERATION

Canguilhem suggested there is still scope for vitalism understood as the double negation of mechanistic physicalism and animism (more properly hylozoism, understood as the notion that all matter is in some sense alive), the two methaphysical interpretations of the causes of organic phenomena, inasmuch vitalism is nothing more than the full awareness of the specific originality of living process [10]. To be sure, embracing SO as the central causal explanation for organic development implies a sort of hylozoism, a

corollary of which is that "inanimate" matter has latent powers of abiogenesis: the principle that life may arise from simple inorganic matter because life is a property or derivative of matter. Such a principle sustains the old notion of spontaneous generation and all the ongoing "research" on the origin of life. Still, despite Pasteur successful experiments for refuting spontaneous generation and the overwhelming evidence that all living things so far come from another living thing, biology is trapped in a schizoid conundrum sustained up to now, *alas* in Darwin's speculation that life came by from a "warm little pond, with all sorts of ammonia and phosphoric salts, lights, heat, electricity, etc. present, so that a protein compound was chemically formed ready to undergo still more complex changes [11]." It must be acknowledge that this little passage has had a lot of impact on literary fiction as shown by the long list of books dealing with the origin of life, while experimentally the topic has not gone much further than the Miller-Urey experiment showing that amino acids may be produced from random reactions hastened by electrical sparkles among elementary constituents [12]. Indeed, others have produced in "abiotic" conditions further building blocks (nucleotides, lipids, etc) of known biomolecules and from these simple results they dare to infer that the complex cellular organization arose in a similar fashion. Anyhow, so far nobody has been able to synthesize a "protocell" using basic components and this stresses the fact that life is not just an emergent property of matter. On the question of why we do not see abiogenesis happening all the time, the mainstream still clings to the ad-hoc explanation suggested by Darwin: "at the present day such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed [11]." It is remarkable that such kind of argument can be regarded as an explanation by many a biologist. Even so, since Haeckel upheld the unity of organic and inorganic matter and suggested that all actions of both types of matter derive from a common, single set of laws [13], thus implying that living and non-living things are essentially the same, this has been a mainstream creed despite the evidence against it.

THE NEED FOR APPROPRIATE LEVELS OF EXPLANATION IN BIOLOGY

At about the same period of Haeckel's musings, Hans Driesch was experimentally demonstrating the teleological behavior of embryonic developing systems, by showing that a living embryo self-regulates to form a whole organism despite the removal of a significant part of its constituting material (in this case, one whole cell or blastomere from an early two-cell stage embryo). Differently to a mechanical device, the embryo remains a whole after the removal of some of its parts. Driesch fully assumed the

epistemological consequences of such finding when suggesting that a guiding *entelechy* explains the wholeness and teleological behavior of embryonic developing systems [14]. This position is quite different to materialistic reductionism in which living process is just a particular case of material processes in general. On the other hand, current thought on SO implies an hylozoism that is closer to that of the old alchemists that aware of the specific nature of living matter suggested that all matter is in some sense alive, thus explaining affinity and reactivity among chemical materials. In both situations the problem is that a common level of explanation is invoked for explaining phenomena that belong to quite different categories. For the alchemist it is love that promotes the reaction between mercury and sulfur, and for the unabashed materialist it is chemical affinity derived form quantum mechanics that ultimately explains the sustained complex spatio-temporal order of biochemical pathways in living entities. Thus, what is needed from all this talk about SO as applied to living processes is a clarification on whether the kind of emergent complexity observed in inanimate SO processes is just made extensive to SO living processes. In such case this point of view is just another form of reductionism implying that life is just an emergent property of matter, or if there is a full acknowledgement that a higher-order complexity is present in a living process that cannot be reduced to a simpler level without leading to disappearance of the living process itself.

POTENTIALITY AND ACTUALITY

In order to analyze causality and motion (change) Aristotle uses the dichotomous principles of potentiality and actuality. The concept of potentiality generally refers to any "possibility" that a thing can be said to have. Aristotle did not consider all possibilities the same, and emphasized the importance of those that become real of their own accord when conditions are right and nothing stops them [15]. On the other hand, actuality is the motion, change or activity that represents an exercise or fulfillment of a possibility, when a possibility becomes real in the fullest sense [16]. *Entelechy* is an ancient neologism (Greek: *entelécheia*) coined by Aristotle that very often has been translated as 'actuality' (anything which is currently happening) but more recent translations suggest "being-at-work-staying-the-same" or "being-at-an-end [17]." Entelechy is then a kind of completeness, a continuous being-at-work, a specific way of being in motion. All things that actually exist are beings-at-work, and all of them have a tendency towards being-at-work in a particular way that would be their proper and "complete" way. Driesch suggested that living things develop by *entelechy*, a purposive and organizing field that he conceived as "mind-like", that is, non-spatial, intensive, and qualitative rather than spatial,

extensive, and quantitative [14]. In such manner, Driesch approach for explaining organic development was a form of vitalism understood as the doctrine that the processes of life are not explicable by the laws of physics and chemistry alone and that life is somehow self-determining. During the first half of the twenty century, further development of experimental embryology provided ample evidence for the existence of morphogenetic fields as shown by the work of Gurwitsch, Weiss, Spemann and several others [18].

THE NARROW WINDOW OF EXPERIMENT

The rise of molecular genetics in the second half of the twentieth century lead to a shift in the kind of experiments used in experimental embryology so that now most experiments on this topic are designed for putting into evidence the role of genes and their products as determinants of embryonic development. Obviously, such experimental designs are not the right framework for studying things like entelechy. Indeed, experiments are on the one hand narrow windows and, on the other, contrived schemes for observing or asking questions to natural systems. Any experimental set up depends on implicit or explicit theoretical assumptions and that includes preconceptions or prejudices about the workings of nature. Therefore, experiments can only produce a limited set of answers that may be biased by the theoretical background. In other words, depending on the experimental system used, one may only see what it is expected to be seen. On that account, the presence or activity of entelechy cannot be documented through the looking glass of the current experimental approach in biology that discards formal and final causes from the causal analysis by concentrating only in the material and efficient causes. This is exemplified by a mock experiment, suggested by René Thom: a fast car coming from an avenue crosses a bridge upon a river and gets into a further road where it hits and kills a pedestrian. The worried authorities want to determine what actually caused the death of the pedestrian. In such fashion, they fit a dummy in the original position of the killed pedestrian and then run a fast car starting from the original avenue but blow up the bridge and so the car fells into the river unable to hit the dummy. From this experiment they conclude that the standing bridge was the cause of the pedestrian's death. As pointed out by Thom, a lot of experimental biology is carried out according to such a weird experimental logic [19].

WHAT IS AN ATTRACTOR?

In a SO system a global structure spontaneously emerges from the local interactions of its constituents (agents). SO is then a collective process distributed over all the agents and the resulting organization is intrinsically robust, resistant to perturbation as individual agents may be elimi-

nated or replaced without damaging the system. A SO system is intrinsically "adaptive": it maintains its basic organization in spite of continuing changes in its environment. Nevertheless, the appearance of a global organization implies that the outcome of the originally local interactions is not arbitrary but "preferred", as some configurations are "fitter" than others (such fitter configurations imply the synergy between the agents that constitute the system). Mutual fittings between the agents determine a functional (purposeful) structure, maximizing collective fitness. The resulting organization imposes constraints on the individual agents. In modern terms, the fitter configurations correspond to the attractors of the system. For any dynamical system the *phase space* is the abstract space in which all possible states of the system are represented, with each possible state corresponding to one unique point in the phase space. That part of the phase space corresponding to the typical behavior of the dynamical system is known as the *attracting set* or *attractor*. More formally, for a dynamical system an *attractor* is a closed subset Γ from the system's phase space so that, despite starting from multiple possible initial conditions, the system evolves towards that set. Although attractors may be classified as steady-state, periodic or chaotic, in essence any attractor corresponds to a steady-state akin to a state of minimum free-energy at the bottom of a "well of potential" that corresponds to a basin of stability, the basin where the attractor exerts its "strongest attraction", thus precluding the system from leaving it too easily or not at all.

ENTELECHY AND ATTRACTORS

Attractors imply the actualization of potential, hence when the system is at or "within" the attractor it may be said that it is being-at-work-staying-the-same or being-at-an-end. Moreover, since the attractor regulates the behavior of the parts or elements of the system (agents), this is a case of top-down or downward causation (from the complex or global to the simple or individual), completely different from the bottom-up causation that tries to explain the behavior of a complex system as the additive result of the properties of its elementary constituents. When a system is not yet in the attractor such an attractor lies in the future of the system, then by definition attractors are non-spatial entities, at least not in Euclidean space. Even more an attractor corresponds to a form of behavior or activity for the system and as such it is qualitative besides being intensive as it determines the behavior of the system once "within" the attractor. Therefore, all the properties attributed by Driesch to entelechy can be also predicated of the attractors. For many dynamical systems there is more than one attractor, and the development or evolution of very complex dynamical systems (such as living systems) implies visiting several attrac-

tors in time until reaching one among those corresponding to foremost stability. Purely physical SO systems such as the BZ reaction, currents in electrical circuits or the atmospheric winds have their specific attractors (e.g., the BZ, van der Pol and Lorenz attractors) for which there are defined mathematical descriptions. However, things like cellular phenotypes or the behavior of living flocks correspond to higher-order attractors for which no thorough mathematical description exists for now. We may conceive further higher-order attractors that correspond to the typical morphologies of whole living systems. If such is the case, then evolution of life on earth would not be just a chancy, historical and arbitrary process (as claimed by neo-Darwinism) but an exploration of life's phase space in which there is a collection of attractors that correspond to possible stable typologies that define an Aristotelian *scala naturae* or great chain of being [20]. Therefore, although there is a common basic mathematical definition that may be applied to any attractor, there are different categories of attractors which cannot be reduced to a single common mathematical description, and so higher-order attractors cannot be reduced to lower level attractors nor systems bound by nature to lower level attractors can interact with higher level attractors. According to this notion, the set of attractors determining the dynamics of living systems is neither identical or commensurable with the set of attractors involved in the dynamics of non-living systems, and as such life dynamics including embryonic development do not corresponds to a particular case of SO, but it represents a different kind of SO.

ATTRACTORS AND REALITY

Do attractors exist or are they mere intellectual constructions? And if such is the case, how it is possible for an abstract entity to influence a process with a material substrate? This sort of vexed question is characteristic of current biological science that is trapped within the mindset of naïve positivism and its fear of metaphysical entities. Thus, in cosmology and physics one may speak of "superstrings", "time-warps", "gluons" or "charmed quarks" without worrying about the fact that such entities are not endowed with rock-hard materiality. The explanatory and predictive success of deep physical theories is based on introducing many levels of abstraction, from objects to microscopic entities to particles to force fields to probability distribution functions, and the like. All these theoretical entities are based on metaphysical requirements that are applied *de facto* by scientists when applying such theories [21]. On the contrary, in experimental biology there is fear, for example, of exploring a morphogenetic field that cannot be weighed, measured with a ruler or observed under the microscope. This limitation of biology for assuming the reality of

virtual entities is making it walking in circles and thus hindering its possibilities for reaching deeper understanding.

Attractors posses an objective efficacy even when they are not fully actual yet (the basin of attraction), as they guide a real process towards a definite outcome. De Landa, following Deleuze, has suggested a way for approaching the ontological status of attractors by suggesting that they do act as the structure of a space of possibilities since from all possible outcomes only one or a few become regularly actualized, indicating that the space of possibilities is constrained (it has structure). Although the possibilities constituting this space may not be real, the structure of the space may be considered real yet not actual but virtual, the last term not to be understood as in virtual reality (like in computer games) but in the sense of a *real virtuality* [22]. Now it may be the right time for biology to assume the reality of real virtuality in order to proceed with the thorough causal study of biological form.

REFERENCES

1 Aranda-Anzaldo, A. (1997), "The gene as the unit of selection: a case of evolutive delusion," *Ludus Vitalis* V(9): 91-120.
2 Alberts, B., et al (2000) *Molecular Biology of the Cell,* 4th ed. New York: Garland Science, chapter 21.
3 Aranda-Anzaldo, A. (2000), "The Hox-gene research programme and the shortcomings of molecular preformationism," *Riv. Biol*. 93: 57-81.
4 Linde Medina, M. (2010), "Natural selection and self-organization: a deep dichotomy in the study of organic form," *Ludus Vitalis* XVIII(34): 25-56.
5 Newman, S. A., and Comper, W. D. (1990), " 'Generic' physical mechanisms of morphogenesis and pattern formation," *Development* 110: 1-18.
6 Forgacs, G. and Newman, S. A. (2005), *Biological Physics of the Developing Embryo.* Cambridge: Cambridge University Press.
7 Batten, D., Salthe, N. S. and Boschetti, F. (2008), "Visions of evolution: self-organization proposes what natural selection disposes," *Biological Theory* 3(1): 17-29.
8 Darlington, P. J. (1983), "Evolution: questions for the modern theory," *Proc. Natl. Acad. Sci. USA* 80: 1960-1963.
9 Kauffman, S. (1993), *The Origins of Order: Self-organization and Selection in Evolution*. Oxford: Oxford University Press.
10 Canguilhem, G. (1965), *La Connaissance de la Vie*, 2em ed. Paris: Vrin, p.156
11 Darwin, F. (ed.) (1887), *The Life and Letters of Charles Darwin, Including an Autobiographical Chapter*. London: John Murray, volume 3, p. 18
12 Miller, S. L. (1953), "Production of amino acids under possible primitive earth conditions," *Science* 117: 528-529.
13 Haeckel, E. (1929), *The Riddle of the Universe*, London: Watts & Co. Translation by J. McCabe of the original 1901 edition.
14 Driesch, H. (1908), *The Science and Philosophy of the Organism*. London: Black.
15 Sachs, J. (1999), *Aristotle's Metaphysics, a new translation by Joe Sachs*, Santa Fe, NM: Green Lion Books, p. lvii.
16 Durrant, M. (1993), *Aristotle's* De Anima *in Focus*. London: Taylor & Francis, p. 206.
17 Sachs, J. (2005), "Aristotle: motion and its place in nature," *Internet Encyclopedia of Philosophy*.
18 Beloussov, L. V. (1997), "Life of Alexander G. Gurwitsch and his relevant contribution to the theory of morphogenetic fields," *International Journal of Developmental Biology* 41: 771–779.
19 Thom, R. (1990), "La méthode experimentale: un mythe des epistemologues (et des savants?)", dans *Apologie du Logos*. Paris: Hachette, pp. 606-617.
20 Bynum, W.F. (1975), "The great chain of being," *History of Science* 13: 1-28.
21 Margenau, H. (1977) *The Nature of Physical Reality*. Woodbridge: Ox Bow Press.
22 De Landa, M. (2005), "Space: extensive and intensive, actual and virtual," in *Deleuze and Space, I. Buchanan & G. Lambert (eds.), Edinburgh: University of Edinburgh Press, pp. 80-88.*