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Aristotle and the search of a rational framework for biology

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Abstract

Chance and necessity are mainstays of explanation in current biology, dominated by the neo-Darwinian outlook, a blend of the theory of evolution by natural selection with the basic tenets of population genetics. In such a framework the form of living organisms is somehow a side effect of highly contingent, historical accidents. Thus, at a difference of other sciences, biology apparently lacks theoretical principles that in a law-like fashion may explain the emergence and persistence of the characteristic forms of living organisms that paradoxically, given the current importance attributed to chance, can be grouped into organized structural typologies. Nevertheless, the present essay shows that since its origins in Aristotelian natural history, biology aimed at achieving rational, non-accidental, explanations for the wide variety of living forms endowed with characteristic behaviors that constitute the landscape of biological species.

Keywords: attractor, biological form, hypothetical necessity, neo-Darwinism, scientific explanation, teleology

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1. Introduction

> …when any one of the parts or structures, be it, which it may, is under discussion, it must not be supposed that it is its material composition to which attention is being directed or which is the object of the discussion, but the relation of such part to the total form. Similarly, the true object of architecture is not bricks, mortar, or timber, but the house; and so the principal object of natural philosophy is not the material elements, but their composition, and the totality of the form, independently of which they have no existence. (PA, I. 5, 645a 30-35)

The explanation of natural phenomena is a central goal of science. However, there is a need for criteria able to discriminate between scientific explanations and other sorts of explanations such as mythological, religious, traditional, etc. Scientific explanations are based on rules or principles considered as natural laws. Thus scientific explanations are attempts for establishing nomological (according to law) connections between phenomena (Kim, 1964). Every explanation constitutes and argument or set of arguments but true explanation is achieved when we become aware that the phenomenon explained has been fitted within a system of rationally justified beliefs present in our mind (Ponce, 1987). An important aspect of scientific explanation is the absent or minimal appeal to historical accidents, as the explanation is supported on principles that determine the course or organization of natural systems. However, the current standing of neo-Darwinism as the central guiding paradigm in contemporary biology, implies that historical explanations are the mainstay in biology. This situation derives from Darwin's assumption that living organisms continuously undergo small but random hereditary changes on which natural selection impinges, thus selecting the variants that are better adapted to the standing environment. Therefore, evolutionary change depends on the continuous random variation among the individuals that constitute a given species. Yet behind this assumption reasonably supported by evidence, there is another one rather questionable but sponsored implicitly or explicitly by most neo-Darwinists: any sort of life form may result from such piecemeal variations provided that it survives (Denton, 1988). Thus, it is assumed that living systems may display any set of phenotypical traits if such traits happen to be adapted to the current environment.

According to this view there are no laws or principles of structural and functional organization proper to biology and so, biology becomes a collection of historical narratives; for example: which species derives from which ancestors and under which historical circumstances, since the only necessary constraint is survival. Thus at a difference of other sciences, such as physics and chemistry, in which basic, law-like principles of organization allow to understand the observed structures in terms of regularities, biology is not intelligible in a law-like fashion but only in terms of survival, given that natural selection is currently posed as the only true explanatory principle in biology (Dobzhansky, 1973). Therefore, neo-Darwinian biology lacks principles able to explain why it appeared such a robust structure as the tetrapod limb and so, it should be acknowledged that the theoretical framework of current biology is rather limited when compared to the intellectual milieu of the rational morphologists from the XVIII and XIX centuries, such as Richard Owen, Geoffroy Saint-Hilaire or Georges Cuvier.

Modern genetics sustained by molecular biology provides reasonable mechanistic explanations for a vast number of phenotypical traits that distinguish the members of a given species from those members of another species. Such piecemeal variations are the fuel of speciation, understood as the superficial diversification of a basic morphological type, given that such a process do not lead to the emergence of new organs or structures or in other words, such piecemeal variation explains microevolution but it cannot explain macroevolution. Moreover, genetics cannot explain the origin of the whole form typical of a given species. These limitations pose the question of whether the explanations based on historical accidents are truly the mainstay for biology and so this scientific discipline must renounce to achieve rational explanations supported on law-like principles. However, a survey of the biological treatises of Aristotle, acknowledged in the Western tradition as the founder of biology, suggests that since its origins biology aimed at finding general principles, supported on both observation and reason, so that the explanations based on chance or historical accidents would perform only a marginal role in biology.

2. The biological treatises of Aristotle

The term biology appeared for the first time in Lamarck's *Hydrogeologia*, published in 1802, and there is no equivalent term for it in the works of Aristotle and yet, it is an accepted fact that the collected works of Aristotle contain a large number of observations and theoretical reflections concerning issues that in current terms fall within the domains of zoology, comparative anatomy, physiology, embryology, botany and ecology, disciplines that conform a large portion of the contemporary landscape of biology. For Aristotle the study of living beings was a fundamental aspect of the study of nature. Indeed, a survey of the classical Becker, reference edition of Aristotle collected works, indicates that from a total of 1,462 pages, 426 (~ 30%) deal on biological subjects. The main Aristotelian works dealing on biological matters are History of Animals (HA), Parts of Animals (PA), Generation of Animals (GA), Movement of Animals, Progression of Animals and On the Soul (OS). On the other hand, careful analysis carried out by some classical scholars in the past century, indicated that Aristotle's biological treatises correspond to his mature philosophical perspective that illuminates his logic, physics and metaphysics (Grene, 1963, During, 1966). However, although others scholars have challenged this conclusion (Graham, 1986) it is hard to refute that Aristotle's biology is a foundation stone for his philosophy (Thomson, 1913; 1940).

3. The concept of nature in Aristotle

For Aristotle the most important concept in relation to nature is that of end or purpose (*telos*). Aristotle applies this concept to both animate and inanimate objects as he assumes that any material body has a specific nature or essence (*physis/ousia*) that rules its behavior and so it drives the material body to find a proper place or to achieve a particular condition. Therefore, terrestrial objects move towards the center of the Earth while fire rises up and away from the center. For Aristotle change/movement is the process by which a given nature (essence) may achieve its inherent purpose. When such a purpose is not yet realized, it is regarded as being potentially (*dynamis/dunamis*) but when that purpose is achieved then it becomes actualized. Thus, Aristotle defines change/movement as the actualization of a potentiality, and such actuality (*entelechy*) of a former potential is an end or completion of something (During, 1990, p. 952-956). This view is quite in contrast with that of contemporary physics in which the laws of movement are the same for any sort of matter. Indeed, modern physics considers matter as constituted by finite kinds of elementary particles and that the whole phenomenology of the universe is the consequence of the positions and movements of such elementary particles. However, Aristotle was skeptic that the mere spatial movement of particles could explain all types of change, for him the qualitative differences among substances were real and so qualitative changes cannot be reduced to variations in the position or movement of elementary particles. That is why he rejected the atomic theory of Democritus. Thus, Aristotle postulates that there is a prime matter (*proto-hyle*) that is a general, indefinite substrate with potential to be transformed into a specific substance when it is endowed with a specific form (*eidos/morphe*/ soul). Such a form is the essential property of a given substance that becomes what it should be. Therefore, all material bodies are conceptually conformed by matter and form (*hylomorphism*) that are in the same relationship as potency and act: prime, non-differentiated, matter has the potential to become something when it receives a given form (it becomes informed matter able to be perceived by the intellect). Thus. Aristotelian matter is quite different from the matter of contemporary scientific materialism. For example, in Aristotelian terms the head of a sculpture has the shape but no the form of a real head, since it cannot perform the functions and purposes of a real human head. Moreover, for Aristotle a human corpse has lost its soul which is the form of the living human and as such the corpse has lost its human essence, because what a thing is, is always determined by its function: a thing really is itself when it can perform its function; an eye, for instance, when it can see (Meteorology, IV. 12, 390a, 10). It must be stressed that for Aristotle the soul (*psyche*) is not a supernatural entity but it is the 'first actuality' of a natural body that has life potentially (OS, II. 1, 412a, 27). Thus, the soul of a living thing is the capacity to engage in processes or activities that are characteristic of the natural kind to which such a living thing belongs. Soul is the first actuality that drives animal development, that consists in a serial passage from potentiality to actuality, so that each actualization results in a further potentiality until the developing system achieves its end (*telos*): a fully completed and functional embodied form which is the culmination of such a development. Therefore, soul is the form of a living thing understood not as its figure or shape but as its actuality: that in virtue of which it is the kind of living thing that it actually is.

4. Causality in Aristotelian science

For Aristotle in order to proceed to explain something, we must first consider the following questions: what is the thing to be explained? And why there is such a thing? Both questions cannot be answered without the use of reason and so the explanation is equal to a reason for something to be, for something to occur (a *logos*). The *logos* establishes a relationship between the notion to be defined with another, more fundamental and defining notion, or a relationship between a given statement and another, foundational, demonstrative or proving statement. Our rational beliefs are organized upon such explanations.

From the Aristotelian perspective, any theory aiming at explaining the facts in the universe depends on the principle of causality. Therefore, we must ask what is a cause? Perhaps this word of the common language had its origin in the common human experience that through our deliberate actions we can produce changes in the real world. Such changes are the effects and the actions that produce them are the causes. Bertrand Russell in a famous and very critical paper on the classical notion of cause (Russell, 1912) noticed that the concept of cause is somehow linked to the notion of will (volition). Science, for Aristotle, is the knowledge based on causes, and the notion of cause is derived from the notion of principle. Thus every cause is a principle but not every principle is a cause. Therefore, a given cause is a principle for some things. In Aristotelian science a principle is everything from which something begins and a cause is everything from which something starts, either as movement or being. At the ontological level the causes are the principles of being but at the logical level the causes are the principles of knowledge. The demonstrative principles that rule the process of science result from abstractions based on causes, thus science is causal knowledge. The cause gives reason to the effect, phenomenon or thing and as such is both a principle of universality (conceptualization) and a principle of argumentation (demonstration). Therefore, given that cause is a foundation of reason, it becomes the core of any explanation.

5. The four Aristotelian causes

In classical times the notion of cause was loosely defined until Aristotle undertook its analysis. The Greek term *aitia* used by Aristotle refers to everything that contributes to an effect and he suggested that for constituting a new object we should consider four aspects: first we must consider the stuff necessary to make the object, this is the material cause. Then we must consider that which provides its specific nature to the object, this is the formal cause. Next we need to consider that which introduces the formal cause into the material cause, this is the efficient cause. Finally, we need to consider the reason or purpose by which the efficient cause acts on the formal and material causes, this is the final cause. For example, when producing a statue depicting blind justice, the material cause is the block of marble, the formal cause is the figure to be sculpted upon the marble, the efficient cause is the craftsman with his tools sculpting the marble and the final cause is the concept or idea (blind justice) represented by the statue. Thus the Aristotelian doctrine of causality consists in determining the relationship among the four types of cause and somehow reinforces the link between the idea of cause and the notion of will since for example, in the Aristotelian cosmos the efficient cause of the celestial movements is an intelligence that operates in a fashion analogous to human will. Nevertheless, we must be careful to point out that in the Aristotelian worldview the final cause does not implies the notion of an intentional agent operating for achieving the constitution of a given object. For Aristotle the notion of final cause is close to that of function or purpose, so that the final cause for the eye is vision without implying a conscious designer shaping the eye for the purpose of vision.

The current and common confusion of the final cause with a conscious agent results from a theological interpretation of Aristotelian causality that equals divinity with the final cause. However, since Galileo the trend in science is to consider only material and efficient causes when explaining the natural phenomena, and the ignorance of final causes is perhaps the consequence of avoiding, at any rate, a hint of religious outlook that may interfere with a neutral, objective description of nature. Nevertheless, for Aristotle the final cause is the main cause, because it causes the causality of the other three causes as they align towards an end. However, when considering the explanation of something Aristotle assigns a chief role to the formal cause because the final cause is extrinsic while the formal cause is intrinsic to the process or phenomenon to be explained. Thus the formal cause is the one that unifies all the other causes. The causal perspective on knowledge and explanation in Aristotle aims at achieving the intelligibility of the formal cause that is: of form. Aristotelian science proceeds by means of classification and argumentation, and in these cognitive endeavor the fundamental element is form. Thus in material bodies the part that bears intelligibility is form while the one that poses a limit to cognition is matter. From the epistemological perspective what is truly universal is that which is conceptualized be means of abstraction and this corresponds to form. Therefore, what we may truly know about matter is always through form and in relation with form. Hence, formal cause or form as such is both the principle of intelligibility and of universality.

Aristotle also suggested that causes might be grouped in pairs (GA, I. 1, 715a, 5-10). Sometimes the final and the formal cause can be considered as a single or the same cause, while the material and efficient causes may also be considered as very close entities. In PA book I, Aristotle describes his general method for the study of biological phenomena and yet there is no mention in it of the notion of natural law. In Aristotle's epoch the notion of law was only applied to political or moral issues. However, the Aristotelian way for describing natural phenomena strongly suggests the notion that there are regular, constant relationships between phenomena. Aristotle enunciates rules and principles akin to the contemporary notion of natural law but with a fundamental difference: he never suggests that such principles universally apply in a ruthless fashion, instead he suggests that they correspond to that which more often occurs, to that which generally happens. Moreover, the most fundamental principle that sustains Aristotelian biology it is never explicitly stated, although it is implicitly present in all the biological treatises after HA: all vital phenomena depend on natural causes, since Aristotle never considers non-natural or supernatural causes for explaining biological phenomena. Thus, when Aristotle describes some monstrosity or biological anomaly, he never recurs to the action of displeased or malignant deities but explains these phenomena as the result of the interplay between natural causes. However, like Plato, Aristotle doubts that natural phenomena may occur only for mechanical reasons. Indeed, in the first chapter of GA, Aristotle affirms that the production of natural phenomena requires the four types of cause. However, for Aristotle it is the final cause the one with the largest capacity for explaining biological phenomena, even though he acknowledges that the material cause is important for explaining the accidental differences among members of a species, such as color of the eyes, of the skin, the pitch of voice or even monstrosities, given that such differences have no particular purpose.

6. Aristotle on necessity

Necessity has its origin in matter but Aristotle distinguishes two types of necessity: a simple one that only applies to things that are forever, things the causes of which cannot be other than they are, and another one that operates in the living world; the hypothetical necessity (Physics, II. 9, 200a, 13) that depends on an end beyond itself, since the nature (form) of a living thing is the internal source of change within itself, the organizing principle that directs its development towards its particular end. If nature as form is prior to nature as matter, nature as that-toward-which, nature as end, is the biological manifestation of nature as form. Therefore, that what shall be, the culmination of development, controls necessity. Such is a necessity that flows backwards from the achieved *telos* to the process that leads to such an end or towards the structure of the parts that contribute to such an end. For example, in contemporary terms, the several global or local organizers described in varied embryonic developmental processes, such as the Spemann organizer in amphibians, the Hensen node in the chick, and the equivalent node region in the mouse, might be the embodied manifestations of the hypothetical necessity that establishes a set of 'attractors' along the developmental pathway that allow us to rationalize in a retrospective fashion the process of ontogeny, in the same way that a satellite view of an earthly landscape allows us to understand and then to predict the course taken by water flowing upon such a landscape in its relentless voyage towards the ocean. Thus, necessity subordinated to end is what according to Aristotle the true naturalist/biologist is seeking to understand. Moreover, for Aristotle the function of each part, of each organ can only be fully understood by relation to the whole:

> For no bone in the body exists as a separate thing in itself, but each is either a portion of what may be considered a continuous whole, or at any rate is linked with the rest by contact and by attachments... And similarly no blood vessel has in itself a separate individuality; but they all form parts of one whole (PA, II. 9, 654a, 34-37; 654b 1-3).

7. Hypothetical necessity and contemporary attractors

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 a 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. There is a debate on the origin of the concept of attractor, since attractors consisting of more than one point seem to have been first considered by Auslander, Bathia and Seibert, in a mathematical paper from 1964. However, also there is evidence that this neologism was already used in 1966 by the Fields' medal mathematician René Thom to whom Stephen Smale, another Fields medal winner, attributes the neologism, (Thom, 2016). In any case, the concept of attractor reintroduces the final cause in the discourse of contemporary science. Attractors may be classified as steady-state, periodic or chaotic, but 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.

Early in the twentieth century Hans Driesch experimentally demonstrated 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). Thus, at a difference of a purely 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 (Driesch, 1908). This position is quite different to materialistic reductionism in which a living process is just a particular case of material processes in general.

The concept of potentiality generally refers to any "possibility" that a thing can be said to have. Nevertheless, 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 (Sachs, 2015). On the other hand, actuality is the motion, change or activity that represents the exercise or fulfillment of a possibility, when a possibility becomes real in the fullest sense (Durrant, 1993). Entelechy is an ancient Greek neologism (*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" (Sachs, 2005). 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 should be according to their proper and "complete" nature. Thus 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 (Driesch, 1908). Indeed, Driesch approach for explaining organic development was rooted in vitalism, understood as the notion that the processes of life are not explicable by the laws of physics and chemistry alone and so, that life is somehow self-determining.

The rise of molecular genetics in the second half of the twentieth century leads 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 and 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, we may only see what it is already 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 reductionist biology, that discards formal and final causes from the causal analysis by concentrating only in the material and efficient causes. This is exemplified by the following 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 passing pedestrian. The authorities want to determine what caused the death of the pedestrian. Thus, they fit a dummy in the original position of the killed pedestrian and then run a fast car starting from the original avenue but then 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 current experimental biology is carried out according to this weird experimental logic (Thom, 1990a).

Attractors imply the actualization of a 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 partial), 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. In principle, when a dynamical system is not yet in the attractor such an attractor lies in the future of the system. Thus, 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 a qualitative entity 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 about 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 attractors in time until reaching one among those included in the set with foremost stability.

Purely physical self-organizing systems such as the Belousov-Zhabotinsky 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 the time being. 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 (Bynum, 1975). Therefore, although there is a common basic mathematical definition that may be applied to any attractor, there are different categories of attractors (in the same fashion that Driesch suggested the existence of different sorts of entelechies) 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 truly interact with higher level attractors.

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. However, Thom suggested that science recurs to the theoretical perspective for reducing the arbitrariness of phenomenological descriptions engaged by proximate causes (Thom, 1980; Thom, 1990b) and for him any theory implies the existence of imaginary entities that are postulated to exist and correspond to the vectors of causality linking cause and effect (Thom, 1990a). 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 working with such theories (Margenau, 1977). 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 current biology for assuming virtual or theoretical entities makes it walk in circles and thus hinders its possibilities for reaching deeper understanding.

8. The limited role of chance in Aristotelian biology

Chance is excluded from Aristotelian causality since for Aristotle fantasy and disorder cannot be causal factors in nature. Indeed, Aristotle considers that the same causes generally produce the same effects as he acknowledges a regular behavior in nature from which some general rules may be inferred. For example, he suggests that animals endowed with a large number of teeth usually live longer than those with a reduced number. Also, he suggests that animals that produce less yellow bile live longer than those that produce more of it. To the contemporary mind such statements may look useless or naïve but nevertheless they reflect the will to find general principles that correlate with specific biological phenomena. Thus Aristotle proposes that the character and sensitivity of an animal depends on the quality of its blood so that an animal with blood of a lesser density is more intelligent and vivacious, while animals devoid of red blood are generally fearful (PA, II. 4, 650b, 20-35). Animals with a large heart are generally shy while those with a relatively compact heart are assertive (PA, III. 4, 667a, 15).

Aristotle also derives some principles from his studies on comparative anatomy. For example, he proposes that only viviparous animals with lungs have epiglottis. Also he proposes that red-blooded animals always move using at most four points of mechanical support. Therefore, those animals that use more than four points of support are unlikely to be red-blooded. Thus, starting from the previous principle Aristotle explains why birds while red-blooded are biped, as they have two wings and so if they were endowed with four legs they would have more than four points of support, something that is impossible for red-blooded animals. Another Aristotelian rule of animal movement is that all animals with legs have them in pairs. In the case of quadrupeds Aristotle notes that such animals always move by a diagonal movement of their legs: the movement of the right anterior leg is followed by that of the left posterior leg, that one of the left anterior leg is always followed by that of the right posterior leg.

Some Aristotelian principles apply to the whole of the animal kingdom: all animals are made from the same natural substances or elements: earth, wind, fire and water, and all animals inhabit in one of these elements or in a milieu dominated by one of them. For example, fish in water and birds on air. Another general principle is that all animals must feed themselves in order to grow and develop; no animal escapes this rule no matter how ephemeral it might be. Indeed, in modern physiology survives the Aristotelian rule that when in an animal a small change in a first principle (such as gender/sex) undergoes a sudden change, then a number of details that depend on such a principle are also modified (GA, I. 2, 716b, 2-10). Aristotle offers the example of castrated animals, in which the elimination of small distinctive organs (testicles) leads to a transformation in body appearance, physiology and behavior of the animal. Thus:

> small changes are the causes of great ones, not per se but when it happens that a principle changes with them. For the principles, though small in size, are great in potency (GA, V. 7, 788a, 11-13).

Moreover, differences between the major animal families are also explained on the basis of the previous rule, for example:

> And so by the occurrence of modification in minute organs it comes to pass that one animal is terrestrial and the other aquatic, in both senses of these terms (HA, VIII. 2, 590a, 4-6).

Aristotle establishes a correlation between the celestial bodies, not generated and imperishable, and living beings, subjected to generation and corruption, for then affirming that both kinds of beings are worth of study and admiration since there is beauty in every work of nature. In animals, beauty is rooted in the subordination of the parts to become a whole so as to achieve an end or purpose, while in the case of celestial bodies the regularity of their movements are a manifestation of order in nature. Thus for Aristotle the vital functions are the subject of wonder in the same fashion as the regular movements in the heavens, as they bear witness to the existence of purpose in nature (PA, I. 5). Moreover, according to Aristotle the observation of the universe leads to the conclusion that nature makes nothing in vain and such a principle is also manifested in the properties of animals (OS, III. 12, 434a, 30-32). In both Aristotelian cosmology and biology nature always knows what it wants and where it goes, never acting lightly or capriciously. For example, the fact that fish do not have eyelids is not by chance but the consequence that such structures made for protecting the eyes from dust and air impurities are completely useless in water that poses a hindrance to sharp vision but where, according to Aristotle, there are less objects that may knock against the eyes and so, instead of providing eyelids to fish, nature has given them eyes of fluid consistency so a to counterbalance the opacity of water (PA, II. 13, 685a, 7-10).

9. The equilibrium and the economy principles of Aristotelian biology

The conformation of animals is for Aristotle the source of important considerations. He notices that a large number of animals present a bilateral symmetry and so they have right and left halves, therefore most organs are distributed in pairs. Such a symmetry is a manifestation of equilibrium and beauty. Thus the principle of equilibrium is fundamental for explaining the forms of animals:

> all influences require to be counterbalanced, so that they may be reduced to moderation and brought to the mean (for in the mean, and not in either extreme, lies their substance and account (PA, II. 7, 652b, 16-18).

Therefore, nature always knows how to compensate the excess of something by the juxtaposition of its contrary. The equilibrium principle is also the basis for the Aristotelian way of explaining the place occupied by certain organs and for justifying their role in the physiology of the corresponding animal. For example, given that Aristotle had no real clue about the role of the brain, but starting from the principle of equilibrium coupled to the notion that nature makes nothing in vain, he suggests that the brain is a counterpoise to the heart as container of vital heat, because the body needs a structure for attenuating the heat emanating form the heart, and such is the brain (PA, II. 7, 652b, 20-26). Moreover, the fact that in humans the tip of the heart is displaced towards the left side is not by chance, but for compensating the heat loss from the left half of the body which, according to Aristotle and for reasons related to the actual distribution of tissues, it cools down in man quicker than in other animals (PA, III. 4, 666b, 8-11). On the other hand, the spleen has its place in the left upper abdominal quadrant so as to be the counterpoise of the liver located in the right upper abdominal quadrant.

In Aristotelian biology the exceptional development of a function or organ always occurs at the expense of another function or organ. This is a most fundamental rule. Therefore, no animal possesses both tusks and horn, nor yet do either of these exist in any animal endowed with saw-teeth (HA, II. 1, 501a, 18-19) accordingly then:

> it would appear consistent with reason that the single horn should go with the solid rather than with the cloven hoof. For hoof, whether solid or cloven, is of the same nature as horn; so that the two naturally undergo division simultaneously and in the same animals. Again, since the division of the cloven hoof depends on deficiency of material, it is but rationally consistent, that nature, when she gave an animal an excess of material for the hoofs, which thus became solid, should have taken away something from the upper parts and so made the animal to have but one horn (PA, III. 2, 663a, 28-35).

In the case of birds, the development of legs can only occur at the expense of the development of wings for flying. Thus wading birds have solid legs but fragile wings and they have reduced the size of their caudal feathers because, according to Aristotle, the matter necessary for increasing the size of the legs it is obtained at the expense of the stuff necessary for making feathers. That is why wadding birds when flying use their legs as rudders, as they lack the large caudal feathers that other birds use for the same purpose. In case of crustaceans, the lack of claws in shrimp is explained on the fact that they possess a larger number of legs than their lobster relatives.

The equilibrium principle also allows Aristotle to explain how the organism works. Thus for Aristotle it is not by chance that during pregnancy and lactation the menstrual cycle is suspended since the stuff for nourishing the embryo is equivalent to milk and similar to that shed with menstruation and so:

"*if the secretion is diverted in the one direction it must needs cease in the other, unless some violence is done contrary to the general rule. But this is as much as to say that it is contrary to nature, for in all cases where it is not impossible for things to be otherwise than they generally are but whether they may so happen, still what is the general rule is what is according to nature*" (GA, IV. 8, 777a, 16-21).

Aristotle also establishes a correlation between the typical size of the animals of a given species and their progeny, so that large bodied animals have less progeny than small bodied animals, and even in the vegetal world the smaller plants produce a larger number of seeds than the larger ones. Indeed, the following principle: "*every organism constitutes an ensemble, a unique and closed system in which all parts are mutually interlocked and concur towards the same action by means of reciprocal reaction*", known as the principle of organic and functional correlation, enunciated in the XIX century by Georges Cuvier, was based on the equilibrium principle of Aristotelian biology.

The principle of economy is another fundamental principle of Aristotelian biology. Such principle establishes that for obtaining a specific end or result nature always uses the least quantity of matter enough for achieving such a purpose. Thus the bones of vertebrates are not completely solid but more like thick but hollow tubes. The great length of the intestines is justified because it allows for a slower but more complete assimilation of food so as not to waste too much of it. In sharks the location of the mouth is justified so that they cannot swallow too much food in a single bite. Moreover, Aristotle notices that often nature use the very same organ for different functions. Thus the mouth has as primary function to be the gate for food ingestion but it also functions for the emission of voice and even as a defense or weapon (PA, III. 1, 662a, 20-24). However, this is not a universal rule as shown by the separation of the proboscis and the sting in bees, while in dipterans both parts and functions are integrated in a single organ. Therefore, nature does not apply the economy principle at any rate, instead the economy of organs and functions it is always for the sake of obtaining the best result for each particular species. For Aristotle the principle of economy is also manifested in the fact that nature provides specific organs only to such animals able to use them. Thus nature always provides the organ compatible with the function:

> For it is better plan to take a person who is already a flute-player and give him a flute, than to take one who possesses a flute and teach him the art of flute-playing. For nature adds that which is less to that which is greater and more important, and not that which is more valuable and greater to that which is less (PA, IV. 10, 687a, 13-17).

Aristotle differs from Anaxagoras who suggested that man was the most intelligent animal because it is endowed with hands. Instead, Aristotle suggests that man has hands because it is the most intelligent animal and as such man is able to use properly a large number of tools. Therefore, given that man is able to acquire and practice diverse techniques, nature has provided man with the most useful tool of all: the hand. The Sophists philosophers liked to suggest that man was an inadequate, badly constituted being since it comes about naked and barefooted but Aristotle challenges this view:

> For other animals have each but one mode of defense, and this they can never change, so that they must perform all the offices of life and even so to speak, sleep with sandals on, never laying aside whatever serves as a protection to their bodies, nor changing such single weapon as they may chance to possess. But to man numerous modes of defense are open, and these, moreover, he may change at will; as also he may adopt such weapon as he pleases, and at such places as suit him. For the hand is talon, hoof, and horn, at will. So too it is spear, and sword, and whatever other weapon or instrument you please; for all these can it be from its power of grasping and holding them all (PA, IV. 10, 687a, 25-30; 687b, 1-5).

10. Conclusion

Undoubtedly, for the contemporary mind many rules of Aristotelian biology are plainly mistaken or supported by erroneous observations and premature generalizations. However, Aristotle was the first thinker suggesting the need of finding general rules or principles derived from observations and not from *a priori* philosophical considerations, since as shown by Aristotelian scholars: searching the works of Aristotle for scientific demonstrations based on *a priori* first principles is rather fruitless. Indeed, most of the arguments from most of the treatises do not look like assertions of defining phrases followed by deductions from these. Most of them appear not demonstrative, but inductive, dialectical, or aporetic. They move from common experience or common opinions, weighing the views of others or analyzing difficulties, in hope of arriving at (but not starting from) an insight into some specific nature (Grene, 1972). Yet, Aristotelian scientific explanation aims at establishing the reasons for phenomena to occur. Thus Aristotle outlook differs from that of contemporary science more interested in how phenomena occur so as to achieve predictive power upon them, instead of searching for a deep understanding of occurring phenomena.

A basic Aristotelian principle that still permeates contemporary science states that the same causes must produce the same effects. This statement acknowledges the regularity of nature and so the possibility of achieving stable, communicable knowledge about nature. Inspired by this principle Aristotle tried to find rational explanations for biological phenomena.

However, an essential function attributed to causality is the possibility of inferring the future from the past and any system in which such inference is possible it is considered a "deterministic" system in which an event or sets of events are the determinants, that is the factors determining the system. Russell, as previously mentioned, was very critical of the old notion of cause and so he considered that that the statement "the same causes produce the same effects" was an unduly simplified, given that when the whole context of a phenomenon is considered then it looks very unlikely that the same cause produces the same effect as a matter of ruthless repetition (For example, while striking a dry match usually leads to ignition, striking a wet match not necessarily leads to its ignition). Instead, he suggested that the assumed sameness of causes and effects actually rests on the sameness of relations among factors involved in determining a phenomenon, as this is implied in the assumed constancy of natural laws (Russell, 1912). Thus, this sameness of relations is an empirical generalization from a number of natural laws which are themselves empirical generalizations (something completely in agreement with the Aristotelian outlook that derived its rules and principles from empirical observations). Therefore, instead of the old formulation that the same causes produce the same effects, what it is really assumed by modern science is the uniformity of nature that implies the permanence of natural laws, as precondition for the possibility of scientific knowledge.

Nevertheless, despite assuming the regularity of nature the Aristotelian outlook is not really concerned with the study of causes as a mean for achieving control upon nature (by being able to predict the future behavior of the natural system studied). Indeed, Aristotelian explanation is deeply associated with the need for making sense of natural phenomena, of finding meaning in them. This corresponds to understanding the form (or *logos*) of the phenomenon as well as its end or purpose (*telos*). This in contrast with current biology that explains all vital phenomena as events derived from chance and necessity within a universe lacking any sense or meaning (Monod, 1970; Dawkins, 1986). And yet, modern biology, that stretches from molecular biology to ecology, regularly uses teleological explanations (e.g., the shape of the beak in Darwin's finches is the right one for chipping the sort of seed that constitutes the meal proper to each kind of finch) which are usually understood as a way of talking, imposed on us by the limitations of human language. Thus, it is quite a paradox that contemporary biologists continuously recur to meaning despite their sustained effort for avoiding it.

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