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" *MILIEU* ", " ENVIRONMENT ", AND " SYSTEM " : THE TRANSFORMATIONS OF THEORETICAL TERMS IN SCIENCE, FROM MODERN TO CONTEMPORARY

Giovanni Iorio Giannoli* and Paolo Quintili**

Introduction

The history of science provides many examples of the semantic transformation of theoretical terms that take one direction in a heuristic sense and then acquire another, different, and sometimes contrasting meaning in a new context, even just a few decades later, and in the same historical and epistemological area. This is the case for the term " evolution " with reference to living beings. At the time of the Genevan physiologist Charles Bonnet (1720-1793) and his " preformism ", the French word *évolution* denoted the process of the deployment of preexisting forms of living organisms, all already contained in the egg, as in the flower blossoming from seed, or the butterfly emerging from a caterpillar. Later on, in Charles Darwin's evolutionism " evolution " is quite different.

There is a lesser known case of semantic transformations or permutations of theoretical terms which concerns the concept of *milieu*, that is, the living environment of an organism or parts of an organism. From the onset of the modern era to the present day, words denoting this concept have undergone a significant semantic shift. The relationship between organisms and their environment has become progressively more intimate and more complex.

For Descartes, *milieu* was an omnipresent material element, separate from the bodies. But even then for the doctors of Montpellier, and for Buffon, environmental factors seemed able to *cause* healthy or pathological changes in individuals and within species. According to Diderot and Lamarck the causal role of the environment becomes decisive in the internal organization of living beings and in the natural history of the species. Darwin removes any teleological concept from the theory of natural evolution, but identifies the *conditions of life*, the *struggle for survival* and the *selection* as decisive factors in evolution, given the limitations

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placed on available resources and the different reproductive potential of each species and variety.

Yet the developments of physics and biology in the eighteenth and nineteenth centuries suggest a contradiction, or at least a paradox, in the natural history of the world. According to classical thermodynamics, the physical world was destined to move towards heat death and disorganization. Instead, according to biology, natural evolution seems to produce increasingly complex and organized bodies. This apparent contradiction (related to the odds that the environment and individuals follow different laws) is corroborated by the fact that – for philosophical and psychological reasons – in the classical paradigm individual entities have a clear priority with respect to their substrata (as if individuals were ontologically different entities with respect to the environment in which they exist).

In contemporary dissipative thermodynamics, the theory of autopoietic systems, and the idea of the ecosystem provide an adequate conceptual framework to overcome the apparent aporia between dissipation and evolution : both organisms and their environments can be considered as *systems*, at different levels of description. In short, the difference between individuals and their environments may simply be a matter of perspective, or a matter of scale.

1. Descartes' model of the living being : the third kind of matter, or " first element "

In Descartes' time the term *milieu* indicated in general " *l'élément physique dans lequel un corps est placé* ", as claimed by Descartes to Marin Mersenne in a letter of 9 January 1639 on the great problem of the existence of " subtle matter " that " occupies " the space apparently left free between extended bodies in motion. As Descartes said :

> " To suppose a body moving in a non-resistant *medium* is to suppose that all the parts of the surrounding liquid body are disposed to move at the same speed as the original body in such a way as to leave room for it and take up its room. That is why every kind of liquid resists some movement or other. To imagine matter which resisted none of the different movements of different bodies, you would have to pretend that God or an angel was moving its parts at various speeds to correspond with the speed of the movements of the body they surround [*environnement*] " (Descartes 1981, p. 62).

In today's terms, we can say that Descartes introduces the meaning of *milieu* as the " set of material elements and physical conditions which surround, influence, or affect living organisms " (Quemada 1985, " Milieu "). In support of the thesis of this physical *milieu* in the same letter to Mersenne, Descartes explains the existence of a *third kind* of matter : " another matter very, very thin which I wanted not to mention in my *Essays*, to reserve it entirely to my *World* ". According to Descartes, in the world of physical bodies there is no space that is not full of “ thin ” matter and especially of a matter that is so adjustable, elastic, and plastic that it adapts dynamically to all forms of extended bodies. This different kind of matter, which is “ incomparably more subtle ”, consists of parts that are so small and which move so fast that they have no definite shape. These *particules* in turn take the form required to fill up the interstices that other larger bodies do not occupy (AT II, p. 483)[1].

In phenomena related to living beings, we are for the most part dealing with this third kind of extremely “ subtle matter ” that Descartes called the “ first element ” in the *Principia Philosophiae* (*Pars* III, Art. 49-52 ; AT VIII-1, pp. 104-105) and in *Le Monde* (AT XI, p. 24), which is just as invisible as “ subtle matter ” (formed by spherical particles), but which is highly mobile, has no shape, is malleable, and pervades the sky in the manner of Epicurean “ fire ” – the soul matter of men and beasts. Descartes’s reasoning lead to the crucial conclusion of the *uniformity of species and nature in the matter of bodies* : “ there is no matter in the universe that cannot subsequently receive all forms ” (AT II, p. 485). In medical-biological terms, this was the explanation for the great plasticity of organic phenomena, related to the generation of living beings in the fluid *milieu*, which is “ extremely thin ” and mobile. This *milieu* had nothing to do with the notion of *milieu intérieur*, developed by the French physiologist Claude Bernard (1813-1878) in the mid-nineteenth century in his writings on experimental medicine. Descartes’ notion of *milieu* only had a physical-dynamic or kinetic meaning. Nevertheless, the notion of *milieu intérieur* is reminiscent of the Cartesian explanatory context, of a purely rational idea that was founded two centuries earlier. From the medical point of view, the concept of *milieu intérieur* was a powerful tool in the experimental explanation of endogenous phenomena of the organism, as strictly distinguished from external pathogens affecting that medium and, through it, the entire body (Bernard 1966, pp. 172-176).

The physiological writings of Descartes, like those of the physicians of the post-Cartesian age, provide evidence of a mechanical-dynamic account of living beings which proved effective in medical and anatomical pathology and contributed to the dominance of Descartes’ theory of matter. Compared to the physical science of the Aristotelian school, the leap remarkable. Matter was no longer opposed to form but to *esprit*, the (human) mind ; although reduced to mere *res extensa*, it behaved plastically and was extremely complex in its “ thin ” states. The smallest material components of the “ first element ” constituted the *milieu* within which the generation and formation of the organism took place, as in the case of the fetus being formed by a mechanical-dynamic epigenesis (Descartes 2000, pp. 125-126). The biological work of Descartes was dominant for more than half a century in France and Europe until the emergence of the Montpellier medical school, whose vitalism produced a profound change of paradigm[2].

1. Hereafter, the acronym AT (with volume and page numbers) denotes the standard edition of Descartes’ works (Descartes 1996).

2. See Quintili 2009, chapter 2 : “ La raison sensible des médecins et des philosophes ”.

2. The “ milieu ” and the living being : the biological philosophy in the eighteenth century

Descartes’ “ first element ” was short-lived. The *milieu* in which particles of organic matter moved was matter itself. It surrounded microscopic beings and occupied all the space of physical nature. But the discovery of the void and the experiments of Blaise Pascal (1623-1662) and Evangelista Torricelli (1608-1647) in the mid-seventeenth century created a crisis in this representation of nature and natural phenomena, including those relating to living beings. By the first half of the eighteenth century new perspectives and new explanatory paradigms had emerged in physics as well as in the life sciences, from the same underlying heuristic contexts in which Descartes’ science had previously thrived. Mechanism did not die out but underwent a profound change. In the first half of the Enlightenment, different models of ‘machine’ and ‘mechanism’ of a purely *materialistic* type were forged in the medical and philosophical schools in France and elsewhere in Europe.

Why were doctors so important ? One of the oldest medical schools in Western Europe was in Montpellier and dated back to the thirteenth century. In the late seventeenth century, it witnessed animated debates on important issues regarding the generation of life, the nature of animals, and the formation of organisms. At the time, the role and tasks of institutional *médecine* went far beyond the specialized field of treating diseases. The figure of the *médecin* was a mixture of what we would now call a biologist and/or an experimental physiologist, with a classical medical training. Especially in Montpellier, being a doctor meant studying the phenomena of organic life, reproduction, inheritance, behaviour and the transformation of the organs, together with botanical expertise.

The Montpellier school was unique in accepting students from all over Europe, even non-Catholics. Since the late seventeenth century, Montpellier had become a key centre of international studies of medical and biological sciences. So-called “ practical medicine ” – conducted at the patient’s bedside and/or focusing on the prevention of disease, with an emphasis on lifestyle and hygiene, together with the study of biology – was at a very advanced stage of development compared to other universities, even challenging Paris, the temple of medical conservatism. The ‘practical’ approach to medical-biological science in aetiology had the advantage of giving greater weight to the contribution of external *environmental* factors with respect to the mostly (if not exclusively) ‘internalist’ approach taken by scholastic medicine, influenced by the Galenic tradition. Indeed, at the end of the seventeenth century the Parisian medical school was not so very distant from Molière’s caricature in *Le malade imaginaire*.

In Montpellier, on the contrary, the effects of mineral water on kidney disease, the impact of air and earth quality on health, the effects of dust on workers’ lungs, and so forth, had all been studied since the early eighteenth century. Montpellier medicine was the first ‘art’ to be scientifically interested in the action of environmental changes on the nature and structure of organized bodies, both in the short and the long term. For the first time in history an interest developed in what are now called ‘environment’ and ‘health’, with important implications for the entire field of natural philosophy. In short, the aim was to define the law of the transformation of bodies according to the impact of the external *milieu*. Two intellectual figures stand out : François Boissier de Sauvages (1706-1767)[3], and Théophile de Bordeu (1722-1778), the initiators of the vitalistic and organicist approach to medicine. They focussed on the external environment in the study of diseases and vital phenomena, both in nosology and in aetiology. Bordeu emphasized *glands* and their actions, as “ *animal in animali* ”, that is, as relatively autonomous bodies, within the “ federation ” represented by the living being. The description and classification of diseases, according to the Linnaean method, by internal and external agents and pathogenic causes became more important in Boissier de Sauvages, as in the *Nosologie méthodique ou distribution des maladies en classes, en genres et en espèces suivant l’esprit de Sydenham, & la méthode des botanistes* (Lyon 1772).

The way opened up by doctors would be followed by other naturalists in the same period. In 1749, Georges-Louis Leclerc de Buffon (1707-1788) published the first volume of his *Histoire naturelle générale et particulière*. It is a key date for the science of the Enlightenment. Buffon presented a picture of the origin of the universe and the Earth, largely trespassing the logical and historical limits imposed by theology. The biblical God became a mere *factor* of motion and matter, elements that acted and developed according to their own laws. In 1751, the Faculty of Theology of the Sorbonne intervened to censure and correct the first volumes, which contained “ principles and maxims that did not conform to those of religion ” (Buffon 2007, p. 411).

In the *Supplément* to *Natural History*, released later in the 1770s, Buffon introduced the concept of *milieu ambiant*, indicating the outer elements that surround and contain the bodies (celestial ones in particular). The context was the first *Mémoire*, entitled *Expériences sur le progrès de la chaleur dans les corps*, which focussed on the cooling of the earth by means of (or in) the air. According to Buffon, it corresponded to the chemical-physical expansion of the material particles of heat and fire, which in turn depended largely on the properties of matter itself, where “ contact ” with the *milieu ambiant* was less important.

According to Buffon, the dynamics of physical and chemical phenomena related to the formation of the Earth and planets obeyed their own internal laws, with little input from the *milieu*. In the sections of *Histoire naturelle* that dealt with living beings Buffon did not privilege the influence of the external *milieu*. In the eighteenth century, until Diderot and Lamarck, “ The time of living beings and the earth time ignore each other [...]. It is rare that they meet and interfere ” (Jacob 1970, p. 150). A real causal theory of the appearance and mutation of spe-

3. See Quintili 2009, chapter 2.3. Sauvages created the new motto of vitalism : *Nulla mutatio sine vi mutante, ergo omnia symptomata a vi quadam mutante dependent* (*Pathologia Methodica, seu de cognoscendis morbis,* Amstelodami, 1752).

cies, based on the time variable, had not yet been developed. Indeed, in Buffon's eyes the relationship between living species and the earth (the *milieu* in which they live) was extrinsic and not particularly influential on the life of species. The cause of the variations within the " family " – taking the dogma of the uniformity of species as given – was the so-called " degeneration " of animals. Buffon added this notion to the concepts of *climat* and *ciel* among the factors modifying the original (fixed) core of species, whose basic types were ideally referred to the creative act of God. In Buffon the concept of 'climate' plays the same role that the concepts of *milieu ambiant* and 'conditions of life' were to play for French and English naturalists in the nineteenth century.

Buffon described the essential changes in the structure of the Earth in the first volume of *Histoire naturelle* (1749), where he proposed a new cosmogenesis, a secular but speculative explanation of the way in which planets can arise. The Earth itself would be formed by the separation of a mass of matter from the Sun, because of enormous cataclysms (like falling comets) : this mass would be " coming out in the form of a stream, where the moving matter in front accelerates the matter behind ", according to the Newtonian principle of attraction[4]. Life on Earth began when the crust cooled down and environmental conditions became suitable for the formation of organic molecules and " organic internal moulds " (*moules organiques intérieurs*)[5]. The system was unlikely to undergo further radical change. This is also the reason for degeneration being, according to Buffon, a surface phenomenon : it is reversible, and does not affect the unity of the species.

In the eighteenth century, the term 'climate' usually applied to the Earth's surface between two parallels[6], but Buffon gave it a much broader meaning, encompassing all aspects of life in the material environment of an animal species or population (soil, vegetation, climate, etc.). This meaning spread rapidly and passed into general use. Man began to " change his sky " (namely his place of belonging) when he " moved from climate to climate ", experiencing alterations that changed his nature, in direct proportion to the influence of the new climate.

Buffon upheld the theory of monogenism. Intra-specific changes related to the influence of " climate " and " heaven " did not endanger the original unity of each species. It does not present the " causal theory of the appearance of species and their relatives " (Jacob), which founded the perspective of transformist change. Nevertheless, the historical weight of Buffon's natural philosophy consisted in stressing the role of external environmental factors (*climat* and *ciel*) in the deter-

4. See Buffon 2007, pp. 107-132, in particular, p. 115.

5. See Roger 1993, pp. 527-584, in particular his considerations on this important notion, p. 539 : " Buffon soulignait fortement la différence avec 'l'historie physique' de la théorie de la terre, et 'l'hypothèse' de la cosmogonie 'où il n'entre que des possibilités' […]. L'*Histoire des animaux* revenait elle aussi à plusieurs reprises sur ces problèmes. Buffon y affirmait encore une fois la relativité, mais aussi la légitimité de notre connaissance " ; and pp. 574-575.

6. See S. Schmitt, in Buffon 2007, p. 1265, n. 60.

mination of intra-specific variation and the inheritance of acquired characteristics (see Roger 1993, p. 568).

Diderot’s philosophical-biological perspective (in its overtly materialist inspiration) went in the same direction. In the second half of the eighteenth century the “ new scholars ”, as J. Roger defined them, always took the autonomy of the universal forces of nature (the “ secondary causes ” of old metaphysics) more seriously, turning their gaze to material factors, previously considered by Buffon as accidents occurring in a limited time-frame (the intra-family variations). Diderot reflected at length on new works by P.-J. Barthez (1734-1806), physician and physiologist of Montpellier and author of *Nouveaux éléments de la science de l'homme* (1778) ; on Bonnet’s *Essai analytique sur les facultés de l’âme* (1760) ; and on *Médecine de l’esprit, où l’on cherche : 1° le méchanisme du corps qui influe sur les fonctions de l’âme ; 2° les causes physiques qui rendent ce méchanisme ou défectueux ou plus parfait ; 3° les moyens qui peuvent l'entretenir dans son état libre* (2^{nd} edn., 1769), by the physiologist and anatomist A. Le Camus (1722-1772). These works introduced some theoretical concepts, insisting on the “ influence of the body on the living being ”, in terms of a direct action on organisms by external, environmental elements which fell under Buffon’s concept of *climat*.

According to Diderot, the external form of organic beings was deterministically due to a mix of causes that could be primarily traced back to the *time factor*. Buffon's idea of a biological “ prototype ” for all organic beings was revived and referred to a general cosmological hypothesis that distributed the phenomena of morphological differentiation over time. The long series of “ *metamorphoses* ” of living forms was produced by “ a significant period of eternal time ”, after which the bodies seemed to have reached a stable state. Yet although the “ organic molecule ” was eternal and immortal, a species might still be “ exterminated, in the long run ” (Diderot 2004, p. 137).

In this respect, Diderot mentioned the biological work of the Dutch naturalist Petrus Camper (1722-1789), in particular his work on the morphology of living forms, the study of faces and jaw angles, which were variable in humans as in other animals according to precise numerical correlations. Changes would be due to the influences of climate and environment on the manners and forms of material and organic life. Diderot’s argument concluded with a general statement, grounded in his new transformist materialism : there is a mutual causal relationship between needs and functions, in the production of new organs. A new image about the *natural time* of all organisms was introduced :

> “ The shape of animals is determined by internal and external causes, which (being different) must produce different animals. The organization of each animal determines its functions, its needs, and the needs sometimes have an influence on the organization. [...]. The influence of the needs on the organization can yield organs or at least transform them ” (Diderot 2004, pp. 137-138).

The *climat*, the *milieu*, and the interplay of needs and functions determine the set of processes that transmit acquired biological characteristics and generate organic forms in accordance with mechanical epigenesis. Lamarck's " zoological philosophy " (" a corpus of precepts and principles on the study of animals ") is the best legacy of the materialist tradition in science and philosophy of the eighteenth century.

3. Lamarck's *milieu* and Darwin's " conditions of life "

In the early nineteenth century Jean-Baptiste Lamarck's pioneering research on invertebrate organisms and the living world, made a comparison with Buffon's synthesis necessary. In his *Philosophie zoologique* (1809) the study of the *milieu(x)* or the *milieu ambiant*, singular or plural, became critical in the analysis of changes in the forms and structures of living beings. Buffon's notions of *ciel* and *climat* – which still had a limited explanatory power in the *Histoire naturelle* – were no longer legitimated, nor was the link that Buffon had established between them and the " degeneration of the animals ". Lamarck made a clear distinction between *dégradation*, which covers the external causes acting on a hypothetical nucleus of the original morphology of living beings (similar to Buffon's notion of " degeneration "), and " *organisation* ", which measures the development of individuals and depends on a multiplicity of causes, both internal and external. " *Organisation* " interacts with degradation, because " the means by which animals normally live, the particular places of residence, forced by circumstances, habits, ways of living etc. have a great power (*puissance*) in modifying [their] organs " (Lamarck 1809, pp. 143-144).

This is the core of Lamarck's thesis on the role of external causes – that is, the *milieu(x)* – on the transformation of animal organs according to the dialectic between functions and needs, and in line with his general perspective of organic " transformism ". The concept of *milieu(x)* applied to all morphological variations. The influence of the *milieu* was considered to be greater as the degree of development and the complexity in the organization of living beings was smaller (Lamarck 1809, xvi). According to Lamarck the *milieu* become, " the main cause that supports [the] movements and life of organized bodies ", the " power " that excites the vital movements of all primordial animals and the transformations of more complex ones. " This thought ", says Lamarck in the *Introduction*, " is the keystone of the research undertaken in this work ". Descartes' notion of *milieu* (as an *internal* physical element, in the kinetic processes of " thin " or " very thin matter ") extended *outside* physical entities, becoming a veritable *puissance*, or principle of motion in organic transformations. Lamarck firmly believed in Buffon's *dégradation des êtres*, defining the different ranks in which to place living beings, according to their degree of " perfection " ; but he always emphasised the difference between " degradation " and " organisation ", where the second was basically dependent on the *milieu* :

> “ No doubt that [the] general form [of fish], their lack of narrowing between the head and body to form a neck, and several fins which act as limbs, are the results of the influence of the dense *milieu* that they inhabit and not those of the degradation of their organization ” (Lamarck 1809, pp. 155-156).

The *Philosophie zoologique* is rich in examples drawn from the morphology of fish, insects, and plants. On the basis of empirical data, there was no longer any doubt that “ the cause that animates the bodies that enjoy life is in the *milieu* surrounding these bodies ”. This cause was variable in its intensity, depending on the location, season, and climate ; but the fact remained that “ it does not depend at all on the bodies to which it gives the life ”, yet only on the surrounding *milieux*, which precede them and which survive their destruction. The *milieu* was a general explanatory principle for changes in the forms and functions of living beings, in association with the inheritance of acquired characteristics (Lamarck 1809, p. 200 ; see also pp. 231, 238, 244, 367).

It was precisely on the theme of the *milieu* that Darwin resolutely distanced himself from the French naturalists in *Origin of Species*. The contrast concerned the role of the environment in the evolutionary process, and the concept of *milieu* itself, even in terms of vocabulary. In Darwin’s works the word *milieu* is absent, not only for theoretical but primarily for *rhetorical reasons*.

Darwin has been described as “ a shrewd rhetorician ” (Sheldon Davies 2007, p. 3). The new evolutionary movement had to deal with the Victorian “ natural environment ” in which it was nurtured, and it had to be careful to attract “ romantic ” readers with a captivating prose which,

> “ while effectively strangling to death the argument from design, is expressed in tones that sometimes verge on reverence. The news that God is dead is not put in the mouth of a madman but of a man who retains at least some traditional sensibilities of a believer – a sensibility, above all, marked with an appreciation of the foibles and pretensions of human reason ” (Sheldon Davies 2007, p. 3).

In the mid-nineteenth-century Darwin’s goal was to provoke “ failures of imagination in the Romantic view ” (Sheldon Davies 2007, p. 16), without offending the sensibilities of readers, using a traditional, understandable terminology (“ goals ”, “ purpose ”, “ design ”, etc.), and stimulating the “ historical Imagination of Nature ”. Taking into account the expressive and rhetorical side of *Origin of Species*, it is vital to understand that Darwin meant to express his ideas between the lines, and not explicitly.

An example of how to convince the reader through the use of a precise rhetorical strategy is Darwin’s use of the concepts of purpose and design. Darwin used these terms but reversed their meaning, giving them a non-finalistic sense and treating them as rhetorical devices. His aim was to exhaust some notions that had a strong grip on common sense : “ design ”, “ end ” (namely “ a persistent mode of understanding : the Psychological Power of Purpose ”). Darwin used them but bent them to new theoretical uses. In the final analysis, he showed how they were unsuitable and even problematic. The goal was reached very successfully[7]. A similar case concerns the notion of “ natural selection ”. Nature does not ‘act’ unless figuratively : it was another rhetorical illusion ; the term was introduced gradually, and utilized in a terminologically controlled way[8].

Let us now turn to the concept of “ conditions of life ” used by Darwin to describe the environment of living beings. In this case we do not have a simple choice of language or a rhetorical use of terms, but a key and heuristically productive concept. Let us see why.

At the beginning of *Origin*, Darwin sketches a brief history of the problem of organic variations with reference to the *circonstances ambiantes* (Darwin 1876, pp. 18-19). Before Lamarck, the idea of transformism was still linked to Buffon’s concept of prototype. It was revived by Geoffroy de Saint-Hilaire (1772-1844) and Charles’ grandfather Erasmus Darwin (1731-1802), a friend of Buffon and a leading member of the English Enlightenment[9]. Darwin observed : “ Geoffroy seems to have relied chiefly on the conditions of life, or the ‘*monde ambiant*’ as the cause of change ”. As for Lamarck and his *monde ambiant*, Darwin only mentioned him three times. After a laudatory reference in the *Historical Sketch* (“ He first did the eminent service of arousing attention to the probability of all change in the organic, as well as in the inorganic world, being the result of law, and not of miraculous interposition ”), a critical argument prevailed on the coexistence of highly differentiated organisms, both “ perfect ” and “ lowly ”. Darwin observed :

> “ Why have not the more highly developed forms everywhere supplanted and exterminated the lower ? Lamarck, who believed in an innate and inevitable tendency towards perfection in all organic beings, seems to have felt this difficulty so strongly, that he was led to suppose that new and simple forms are continually being produced by spontaneous generation ” (Darwin 1876, p. 98).

Lamarck still relied on the idea of “ prototype ”, which contrasted with a correct historical view of nature because it set an ideal (metaphysical) model of the organic body, from which all the others are generated. Darwin remarked :

7. On this point, see Hawking and Mlodinow 2010.

8. For a similar interpretation, see Young 1985, pp. 79-125. The problem is, how can we understand nature as ‘subject’ ? : “ Does Nature select ? ”. The use of an anthropocentric vocabulary to explain the phenomena of evolution is a thorny issue, especially in view of a new Darwinian “ common sense ” in the making. See the proposal (and the project) of a “ Darwinist education ” by Schwartz 2009.

9. This idea was expressed by Erasmus Darwin in *Zoonomia* (vol. I, 500-510) in 1794-1795, in line with Goethe’s *Metamorphosis of Plants* (1792).

> “ we may ask what advantage, as far as we can see, would it be to an infusorian animalcule – to an intestinal worm – or even to an earth-worm, to be highly organised. If there were no advantage, these forms would be left, by natural selection, unimproved or but little improved, and might remain for indefinite ages in their present lowly condition ” (Darwin 1876, p. 98).

Another important criticism on the part of Darwin was based on the case of neuter or sterile insects living fruitfully in community with others as ‘experts’ on particular and difficult tasks, thus achieving an admirable social-natural division of labour. Darwin used this fact as an argument against Lamarck’s theory :

> “ The case [...] is very interesting, as it proves that in animals, as with plants, any amount of modification may be effected by the accumulation of numerous, slight, *spontaneous variations*, which are in some way profitable, without exercise or habit having been brought into play. For peculiar habits confined to the workers or sterile females, however long they might be followed, could not possibly affect the males and fertile females, which alone leave descendants. I am surprised that no one has hitherto advanced this demonstrative case of neuter insects, against the well-known doctrine of inherited habit, as advanced by Lamarck ” (Darwin 1876, p. 233).

Even the concept of ‘transformation’, based on “ inherited habits ” consequent on the use of organs had to be faced head-on. Not only the conditions of life but also natural selection and the struggle for existence cooperate to produce the “ end ” which is associated with those conditions ; and in the same context spontaneous variability plays a key role, as demonstrated by neuter insects. Therefore, Darwin preferred to talk of “ conditions of life ” (rather than *milieu*) as causes of variability, whether acting directly on the body or indirectly through the reproductive system (Darwin 1876, p. 36). The Lamarckian notion of *milieu ambiant* (or *circonstances ambiantes*) did not do justice to the complexity of the evolutionary factors involved in specific organic changes. Darwin’s concept of conditions of life covered the entire set of causal agents, both endogenous and external, of change (Darwin 1876, pp. 5-6). Therefore, *Origin of Species* reconfigured the emphasis on transformation by means of use and disuse in evolutionary theory.

Finally, Darwin’s concept of conditions of life was very different from that of contemporary naturalists (especially French) who used the same phrase. According to Georges Cuvier (1769-1832) animal species did not undergo morphological transformations during their “ natural history ”. Species were fixed entities, and Cuvier missed no opportunity to emphasise his deep and substantial distance from Lamarck, his senior colleague (and adversary). A conservative scientist, to some extent Cuvier was inspired by Kant's *Kritik der Urteilskraft* (1790, Part II), according to which we can detect a substantial teleology in the morphological structure of organic beings, to wit, a tendency to obey internal and immutable laws of organic development, oriented to some “ purpose ”. According to Cuvier, it was necessary to postulate this tendency in living beings in order to understand their generation, development and corruption ; the tendency would depend on the conditions of existence (or life) that were typical for each species. In his first significant work (Cuvier 1798), these “ *conditions d’existence nécessaires* ” were related to the nature of different species and defined their laws of morphological development (that is, the laws of correlation of parts, according to objective purposes). Starting from the analysis of conditions of existence for different species, according to Cuvier we can understand and explain the genesis of organic functions without appealing to evolutionary transformation. Therefore Cuvier’s principle of conditions of existence had nothing to do with the Lamarckian notion of *milieu*, or with the Darwinian conditions of life or environment that biology would encounter in the late nineteenth century, in the immediate wake of Darwin.

To overcome the “ natural infirmity of the imagination ”, the rhetorical use that Darwin made of the term *milieu* tended to displace and to incorporate the concepts of *milieu ambiant* and *transformation* (Sheldon Davies 2007, p. 137). In the psychology of common sense, life and human agency are notions that implicitly interact, when discussing environment and organic transformations. In the *Origin of Species*, Darwin was committed to ‘de-anthropomorphizing’ these theoretical concepts in natural science. Then he came to conditions of life, understood as the *total organic-historical system* in which (and by which) the developmental phenomena of organic growth take place and on which they depend : hence Darwin’s far greater sensitivity to the *ecological* dimension of nature and life.

So far, our analysis of the development of theoretical terms (at the heart of the emerging evolutionary science) has focussed on the importance and weight of changes in the lexicon and the historical view of nature and the environment. The great biologists of modern times gradually and progressively adapted the old ideas to new contexts, steadily renewing the vocabulary. The path followed – from ‘inside’ the living world to its ‘external’ dimension, through the notion of *milieu*, then *climat-ciel*, *milieu ambiant*, and *conditions of life* – reveals a vision of man as a natural being, living among other natural beings and the environment, as part of and in the context of, the great world of nature, as a *complex biological system*.

4. Evolution *versus* dissipation

In the sixth edition of *The Origin of Species* Darwin recognized that his theory had to counter a “ formidable argument ” : the Earth had not existed long enough to provide suitable living conditions (Darwin 1876, p. 286). This objection was raised mostly by Sir William Thomson, Baron Kelvin, whose estimated age of the solar system (later disproved) was incompatible with the very long time required by natural evolution. Beyond the specific issue (on which Darwin was right), this dispute originated from a very different attitude among physicists and biologists with respect to the relationship between natural systems and their environment and associated developments.

The birth of classical thermodynamics is customarily dated to 1824 when the twenty-eight-year-old Sadi Carnot published his little (and almost unnoticed) book *Réflexions sur la puissance du feu et sur les machines propres à développer cette puissance*. Eight years later the book fell into the hands of Émile Clapeyron who rewrote it. The laws of thermodynamics were firmly established over the next twenty years, thanks to the contribution made by British, French, and German scientists. These scholars were stimulated by very practical problems : the extent to which heat can be transformed into mechanical work and the efficiency of a heat engine. At the height of the first industrial revolution (the steam power revolution), the concerns of physicists such as Carnot, Clapeyron, James Prescott Joule, Hermann von Helmholtz, Rudolf Clausius, and William Thomson dealt largely with the *dissipation* of heat from engines into the environment, a negative factor for machine efficiency. The efforts of these scholars were designed to establish ideal conditions where the exchange between physical systems and their environment was minimal, negligible, or tending to zero. In this context, all the laws of classical thermodynamics assume *equilibrium* conditions and thermal *insulation*. For example, in all experiments to determine the mechanical equivalent of the calorie, it is essential that the calorimeters are adiabatic, that is, that they do not exchange heat with the outside. This means that the prototype of the container of a calorimeter is similar to the modern thermos flask (Dewar vessel), formed by a double-walled container, silver inside and with vacuum. Here, the separation between the physical system and the environment is *preset* as a specific experimental condition.

And yet, when it came to the limits that the laws of thermodynamics place on the existence and development of organic systems, Kelvin wrote in 1852 :

> “ Within a finite period of time past, the earth must have been, and within a finite period of time to come the earth must again be, unfit for the habitation of man as at present constituted, unless operations have been, or are to be performed, which are impossible under the laws to which the known operations going on at present in the material world are subject ” (Kelvin 1882, p. 511)[10].

Together with the idea that geological time is too short to ensure the likelihood of the formation and evolution of organic systems with a high level of structural complexity, there is the idea that natural processes spontaneously tend to disorder and maximum entropy. Therefore, instead of a ‘natural’ evolution, the harmonious relationships between organisms and their environment suggest the existence of a divine plan. Clausius stated the following some years later :

10. A similar idea – with a surplus of theological implications – was repeated two years later by Kelvin : “ purely mechanical reasoning shows us a time when the earth must have been tenantless ; and teaches us that our own bodies, as well as all living plants and animals, and all fossil organic remains, are organized forms of matter to which science can point no antecedent except the Will of a Creator, a truth amply confirmed by evidence of geological history ” (Kelvin 1854, p. 38).

> " […] we can express the fundamental laws of the universe which correspond to the two fundamental laws of the mechanical theory of heat in the following simple form.
>
> 1. The energy of the universe is constant.
>
> 2. The entropy of the universe tends toward a maximum " (Clausius 1935, p. 236).

In these terms, the environment appears as a *dissipative* factor which tends to destroy the stability of systems. The objection raised by some scientists in Darwin's time against the likelihood of natural evolution, and especially against the idea that ordered life could have originated from inert matter, is understandable. For many writers at the time, everything in the natural world seemed to suggest that the forerunner of life might simply be life itself. Once life had begun, its origin should not be sought in nature but in something completely different. According to tradition, this origin should be attributed to the Creator (see, for example, Stewart and Tait 1895, pp. 165-166).

5. Priorities of objects over substratum

The approach of the founders of thermodynamics was inclined to establish a clear separation between the systems and the 'rest of the world' (that is, against all other physical entities that populate the surrounding regions of space and time), but this was after all a characteristic of Newtonian mechanics. Enunciating the " first law of motion " in around 1632, Descartes argued that every part of matter remains in the same state until the clash with other parts forces it to change (AT XI, p. 38)· And in 1687 Isaac Newton stated : " Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon " (Newton 2002, p. 11).

The idea that the rest of the world, with respect to the original state of a body, always manifests itself as a *perturbation* is thus a precondition of the principle of inertia (and, consequently, of all mechanics). Moreover, the idea that *things* have a special status – a sort of epistemological priority, with respect to the whole of which they are part – is a recurrent idea in Kantian thought, already expressed in the *Prolegomena* (Kant 1783, § 16) and confirmed in the *Opus postumum* :

> " The object of the science of nature is either matter in general (formless) or body. A matter which, by its internally and externally moving forces restricts itself in texture and figure, and resists all alteration of its figure, is called a physical body " (Kant 1993, p. 67).

Indeed, in important domains of classical physics, there is a prevailing attitude that basically considers *individual entities* as the specific object of scientific inquiry and conceives the relationships with the rest of the world as factors of change or perturbation.

Recent studies of developmental psychology (see, for example, Spelke 1990) have shown that the recognition of objects (namely their separation/identification with regard to the context) could be a specific and innate cognitive ability of human beings : an adaptive trait, based on principles of spatio-temporal *cohesion* (objects move as a whole, cohesive and limited), *continuity* (objects move along paths connected without gaps or interruptions), and *contact* (objects do not interact at a distance). Skills of this kind give human babies (and even other animals) the ability to recognize the external surfaces of bodies, to represent their shape, and to make predictions about their behaviour ; hence the spontaneous tendency to segment the world into different objects, which is typical of our 'naïve physics'. By contrast – even though in today's conception, the *objects* of physics tend to become entire *regions of space* with specific distributions of matter and energy – the fact remains that every investigator cannot avoid a reference to the tools and indicators that he uses, that is, to a language that mainly refers to *things*, even when faced with mere *distributions*[11]. To some extent, this is an inevitable aspect of scientific work, related to the specific scale of *Homo sapiens* and its perceptual abilities.

6. Hierarchies of systems

For many decades, the belief that the world was inevitably doomed to disorder and inertia led many physicists to believe that the evolution described by the biological and social sciences was incompatible with the laws of physics. In the late 1970s Ilya Prigogine and Isabelle Stengers (1978, chapter 5) described the process by which this prejudice was overcome with the formula of " the three stages of thermodynamics ". The first stage, that of classical studies, relates to systems in thermodynamic *equilibrium* : in this case, entropy remains at a minimum, and evolution cannot occur. The second stage, posited by Lars Osager in the 1930s, concerns systems *close to equilibrium* : in this case, the increase of entropy produced by irreversible processes is compensated by the negative flow of entropy that comes from the environment (in the form of matter and energy) ; however, the linear nature of the exchange does not allow the construction of new organized structures. The third stage concerns the " dissipative structures " *far from equilibrium* : in this case, the exchanges between systems and their environment are no longer linear ; here, the dissipation of energy and matter can, under certain conditions, be the source of a new order.

> " In far-from-equilibrium conditions we may have transformation from disorder, from thermal chaos, into order. New dynamic states of matter may originate, states that reflect the interaction of a given system with its surrounding " (Prigogine and Stengers 1984, p. 12).

11. On this point see Carnap 1932.

Possibilities of this kind led to the idea of " assisted bifurcations ". Far from equilibrium, the possible states of a thermodynamic system may lead to multiple and relatively stable conditions (provided that an appropriate reserve of matter and energy is available in the environment). In these cases, the selection between the different evolutionary paths (theoretically allowable) can be decided by very small differences in environmental conditions (not significant for a thermodynamic system in equilibrium but decisive in far-from-equilibrium conditions) (Prigogine and Stengers 1984, chapter 6). At this point, the dichotomy between system and environment appears to be too elementary to account for the complex relationships that exist in the real world and that science tries to describe and represent.

In the general systems theory that Ludwig von Bertalanffy developed in the 1920s, the term 'system' initially denoted any finite region of a generic space (physical or formal) separated from its environment by a suitable interface (actual or conventional), and characterized by well-defined *composition*, *state*, and *structure*. Here, the term 'structure' only indicates the way in which the system is composed, and perhaps divided into discrete parts (Bertalanffy 1969, Introduction).

There are three kinds of system : *isolated* (no exchange with the environment) ; *closed* (only energy exchanged) ; and *open* (matter and energy exchanged). The concept of isolated system (as noted above) is a mere abstraction : all real physical systems are indeed *open* systems, described by the thermodynamics of *irreversible processes*. In this context, 'process' means any systemic change, in terms of its composition, its structure, and its state. The concept of reversible process, invoked in classical thermodynamics, is also an abstraction. A reversible process should be infinitely slow and infinitely long, and it should be able to move precisely backwards through the states of equilibrium which it has already passed through. All the processes that occur in a finite time are by their very nature irreversible. Spontaneously, all open systems tend to transfer the excess of internal energy accumulated. When a system transfers its energy to the environment, an adjacent system can absorb a part, store it, and then yield the excess energy (not used to change or to perform work). Continuous exchange of energy and matter in the universe – directly between systems or through the environment – characterize what we call 'nature'.

Once we admit that the distinction between system and environment can be fixed by convention, we understand that a certain population of systems can in turn be considered as a specific section of the environment of *another* system. And we also understand that the 'parts' of a certain system that make up its structure can in turn be considered as *subsystems*, whose environment includes other parts of the system.

In the late 1960s it was considerations of this kind that encouraged James Grier Miller to propose a *general theory of living systems*. For Miller (1978, p. 17) : " A *concrete*, *real*, or *veridical system* is a non-random accumulation of matter-energy, in a region in physical space-time, which is organized into interacting interrelated subsystems or components ”. In such a picture there are systems and subsystems. Moreover, it is assumed that the universe contains a *hierarchy* of systems and that any system of a ‘high’ level is decomposable (in principle) in systems belonging to a ‘lower’ level. Each subsystem is characterized by the function it plays within its system. But the same function in a given system may be performed by structurally different subsystems. Thus, within this hierarchical organization there is no one-to-one relationship between processes and structures. Finally, according to Miller, each *suprasystem* of a certain subsystem does not coincide with the environment of that same subsystem : in order to coincide, the latter must be removed from the overall system (immediately above). The overall environment of a subsystem consists of the entire hierarchical organization of the higher systems that contain the subsystem involved. In this framework, the ecological relationships between systems and the environment constitute a complex network of mutual interactions : “ In order to survive, the system must interact with and adjust to its environment, the other parts of the suprasystem. These processes alter both the system and its environment ” (Miller 1978, p. 29).

7. Autopoietic systems, ecosystems

In the theoretical framework described above we can say that a system is a *set of functions* (determined by the structure), thanks to which the values of some quantities (*inputs*) are matched against the values of other quantities (*outputs*). Each characteristic function of a system may therefore be taken as a set of input-output pairs, the inputs and output indicating the relationships that the system has with its environment.

The systems capable of self-organization, autopoiesis, reproduction, and evolution are of great interest for scholars of social organizations and living beings. Yet under what conditions can an autopoietic system be constituted, survive, and evolve ? This broad question about the relationship between systems and their environment can be formulated more precisely : what aspects of this relationship must be taken into consideration to guarantee the origin of a species and its evolution ? After the controversy over the “ operational closure ” of autopoietic systems[12], the contemporary debate has become progressively polarized into two different positions : *adaptationism* (the traits of organisms and species are the result of natural selection, which is capable of optimizing functions), and *pluralism* (or *evolutionary structuralism*, according to which the mechanisms of selection are dependent on contingent histories and structural constraints so that many

12. Maturana and Varela (1973) have particularly insisted on the following idea : the systems capable of reproducing would be completely autonomous from the external environment because the flow of input and output would be filtered in an extremely strict manner thanks to the structural characteristics of these systems. Over the years, the discussion has softened, reduced to a matter of emphasis, underlining the subjective properties of systems capable of reproduction rather than the general conditions that allow life and change.

traits are not adaptations in the true sense of the word). The first position (once radicalized) leads to the idea that the natural environment only plays the role of filtering (negative) mutations that occur elsewhere ; the *active* role of evolution is instead reserved for genetic mutations able to produce alternatives. By contrast, the position that insists on contingent histories and structural constraints (once radicalized) can lead to the idea that, within specific ecological niches, the distinction between the role of the environment and the specific system is quite nuanced.

In reality the positions at stake are not particularly radical. The tone of the debate is also due to the personal characteristics and expertise of the main protagonists : Richard Dawkins, a geneticist and ethologist, and hence inclined to identify the units of selection with genes and to emphasise adaptation as the specific object of his profession ; and a palaeontologist (Stephen Jay Gould), inclined to identify the unit of selection in the species and to investigate the modes of their origin and extinction[13]. In short, Dawkins stresses the unlikehood of life, the most complicated form of natural organisation : if you reject the idea that the origin of complex structures is attributable to a divine plan, the only factor that can explain their complexity is the very protracted process of natural selection from random mutations. On the other hand, Gould addresses the extinction of species. He is attracted by the conservative aspects of life and consequently interested in the *constraints* that the structure of organisms and their environment impose on mutations. Gould is also concerned with *speciation*, which is determined by conditions that may be random, so that it is not necessarily (and exclusively) linked to adaptive problems. After all, an environment can change more rapidly than the adaptive responses to change. For this reason, the story of an environment tells us great deal about the extinction of some species and the origin of new ones.

In terms of cultural history the discussion of non-selective factors in the history of natural evolution received considerable attention in the 1970s with the greater awareness of the impact of human activities in the biosphere. However, from a strictly epistemological point of view, it is unlikely that the contrast between *adaptationism* and *evolutionary structuralism* constitutes a real difference in paradigm. Indeed, from a strictly formal point of view, the structural constraints that the pluralists have highlighted can be seen as *implicit premises of the adaptive model* : " A developmental constraint is a bias on the production of variant phenotypes or a limitation on phenotypic variability caused by the structure, character, composition, or dynamics of the developmental system " (Maynard Smith 1985, p. 266). In this perspective, a constraint imposed on a change does not play the effective role of a cause, but is only a *logical premise* of adaptation (to wit, the role of a 'formal antecedent') ; given certain structural constraints, only a few phenotypic variants are possible. In a given environment (which may evolve more or less independently from the organisms that inhabit it), some phe-

13. On this controversy see Sterelny 2001.

notypic variants provide a selective advantage. In short, adaptation occurs downstream of the constraints, and is not, strictly speaking, influenced by them.

8. Conclusions

As with all theoretical definitions the distinction between systems and their environments has some conventional aspects. In our current experience the distinction is presumably activated by natural characteristics of our cognitive system. In certain conditions these allow us to distinguish between objects and agents with respect to their substrata. Everything occurs in an automatic and mandatory way, even before our cognitive system is aware of it. Not all aggregates constitute systems. For physical aggregates that constitute a system, the substratum is not, strictly speaking, an environment. To ensure that the ‘neighbourhood’ of a system constitutes its environment, there must be appropriate relationships. Each system generally has a structure and can be part of more complex structures, making the organization of the system hierarchical. No real system is isolated. Systems that are able to reproduce and evolve are generally dissipative systems (open, far from equilibrium) that exchange a big amount of matter and energy with their environment. When a dissipative system reaches a state of thermodynamic equilibrium within a finite neighbourhood, the system and its neighbourhood constitute an ecological niche, or ecosystem. The equilibrium of an ecosystem depends on the behaviour of its components ; the niche may evolve, but it can also shrink. Indeed, in natural history some dissipative systems (belonging to the species *Homo sapiens*) have reached a sufficiently high level of complexity to enable them, within limits, to calculate the necessary conditions, to prevent their ecological niche from being eroded, and hence to prevent the extinction of their species[14].

14. On this point, which opens up fundamental questions, see Giannoli 2003, par. 3.6 and 3.7.