I. On the Concept of Evolution

The term "evolution" is universally recognized and used in both scientific and cultural fields. Because it is so largely used, however, further clarification is required in order to avoid any misconception. First of all, the notion of "evolution" originated in the domain of the natural sciences, with specific uses in the fields of zoology and biology, describing a scientific theory according to which the living species currently populating the world are the result of an ever-lasting process of transformation and diversification. Moreover, all the living beings contemporary to us derive from ancestors who were in their turn linked to one another through descent. Therefore, life may well be described as a single and strong family and descent relationship, that ties together all living beings. Strictly speaking, as a purely scientific term referring to a particular theory, "evolution" does not imply a "philosophic" vision of the world unless the theory is included in a further-reaching doctrine.

According to its first natural and scientific acceptance, in the past the term evolution was put in contrast with the term "fixism." The "fixist theory" suggests the different species -or at least groups of them-originated independently from one another, their characteristics persisting unaltered through time, so that no family relationships between the living beings could be established. In this perspective, the species could have originated in many different ways, even through spontaneous generation. Since any doubts about the alleged immutability of species have been dispelled, fixism is now considered as out of date.
However, the contrast between fixism and evolution, as opposed to each other, has exerted a major influence on philosophical thinking and on the corresponding theological debate.

Yet, the idea of evolution is to be found in diverse contexts. As far as biology is concerned, the study of the origins of life on earth or in the cosmos is usually referred to as the study of the "evolution of life". It focuses in particular on the idea of "transformation," a concept that evolution brings along with it—in this case, the process of transformation of simple, primordial elements into complex and organized structures. The same idea of "transformation" is also emphasized when we speak of "chemical evolution," referring to the synthesis of the various chemical elements and their compounds throughout the history of the cosmos. More than a relationship of descent, as occurs in the case of life, evolution here means the possibility of reconstructing the sequence of all chemical elements according to their increasing atomic number, since heavier chemical elements are generated from lighter ones through nuclear fusion occurring in the stars. It is in this context that the all-encompassing notion of "cosmic evolution" arises. By it we indicate the long *history the universe* [2] has gone through from a primitive, simple and poorly-diversified status, reaching its present complex structure, through the birth of the first elementary particles, the origin of the first chemical elements, up to the formation of galaxies, galaxy clusters, stars and planets. As far as physics is concerned, the notion of evolution always implies a time dimension. We speak for instance of the evolution of a dynamical system, indicating by this the study of the transformation undergone by a given material system according to the physical laws governing it.

Being the notion of evolution linked with the concepts of transformation and time [3], it was endowed in the last two centuries with a remarkable philosophical meaning, a one that it lacked at the beginning. By evolution, in fact, we come to express today also a global and all-encompassing philosophical view of nature, understood as an "evolving world," a continuously developing dynamic system. Such a view inherits the classical contents associated with the philosophical idea of "becoming" as opposed to being, taken as a philosophical perspective valid for reality as a whole, which dates back to Heraclitus. In these regards, the philosophical notion of evolution was crucially influenced by modern and contemporary science as the latter put forward the idea that the concept of "becoming" included not only growth and development (just as a seed grows into a plant), but also and foremost deep transformation and unpredictable consequences. Along this line of thought it was Bergson (1859-1941) who first introduced the idea of a "creative evolution," to which many authors, including not a few scientists, would implicitly resort to in order to underline the emerging of "novelties" in the history of biological and physical systems, that is, in their evolution. From a philosophical and theological point of view, the dialectics between being and becoming has been revived in modern times in terms of a comparison between *creation* [4] and evolution, leading to new synthesis built either on theistic or materialistic basis. The term "evolutionism" was introduced especially in the context of materialistic syntheses, and came to indicate mainly a "philosophical system". Syntheses on a theistic basis, which accepted transcendence of *spirit* [5] over *matter* [6], gradually interpreted -after due clarifications- the idea of evolution, both cosmic and biological, as a mode of God's creation.

A further clarification concerns the use of the term "theory" and its meanings. In the scientific field, whenever the expression "theory (or theories) of evolution" is employed, it usually refers to a framework capable of providing a reliable historical-scientific reconstruction. In such a framework further analysis is still certainly possible, but it is definitely more than a mere hypothesis, because it corresponds to a consistent and well-established picture. To make a comparison, we can say that the theory of evolution is the result of historical research as strongly supported by solid evidence as the Roman empire. Two interesting observations stem from this comparison. The first is that the theory of evolution is partly a historical event, and therefore it should also be investigated by means of historical research. Findings are analyzed dating from ancient times, namely fossils and the succession in time of the different species of
flora and fauna, and their present-day descendants, with particular attention to their geographical location as a visible consequence of that succession, as well as any possible connection between fossils and contemporary living species. All things considered, it is the same method followed to investigate the evolution of the Roman empire, whose relics have been studied along with the influence they exerted—the diffusion of Romance languages to mention one. The second observation is that whenever a probability of error is suspected, even very low, it would depend on an error of reconstruction. Should it be so, we may apply it to the Roman empire as well, that means it may be considered as a big interpretation mistake of Latin works of literature or of the numerous relics and findings dating from that period. We know, however, that such a remote probability of error is so low as to be considered in practice equal to 0. Likewise, we can reliably affirm that evolution is a historical process worthy being considered a part of our common knowledge, an outcome that both theology and philosophy must take into account.

Nonetheless, meanings overshadowing the empirical data have been added, more or less accurately, to the scientific notion of evolution, understood as a certain result of historical research. These further meanings must be discussed from a philosophical point of view, also in the perspective of a possible synthesis between science and faith. The present article aims at reviewing the main issues involved in the search for such a synthesis, focusing on the notion of evolution as it is used by biology, and by adopting a historical approach.

II. From the Idea of Fixed Species to Evolutionary Thought: the Work of Jean-Baptist Lamarck

1. Two Different Visions of How Living Beings Adapted. We cannot talk about the evolution of living beings unless we consider it from a wider point of view, i.e. by taking biology into consideration and its birth as a science which studies living organisms. The first biological inquiry took place precisely when the first human beings started observing nature and noticing its regular cycles and changes. It is from this kind of observations that the concept of "species" first stemmed, since it was soon realized that all living creatures could be placed into different groups which could be named and distinguished by their morphological features. The features which identify each species persist unaltered through time and are handed down to their descendants through reproduction, i.e. each from their own semen. This was the very biological concept introduced both in Genesis and in the other books of the Old Testament to illustrate the world of the living, where the authors clearly referred to and made large use of the description of nature developed by science in their times. Since the origin of living beings appears to be the result of a single act of creation for every single species, the narrators seem to have based their story on an apparently fixistic framework. In fact, natural observations corresponding to science of that time proved that living species tended to preserve their features possibly unaltered, becoming therefore the premise on which the narrators based and diffused the theological teaching concerning the origin of the universe and of all living species as being created by God [7]. Paradoxically, such a fixistic framework divulged by the Bible overshadowed the meaning of history, that was indeed the great novelty of biblical theology. In fact, unlike other creation tales reported by extra-biblical religious traditions, the biblical account told in Israeli tradition contained a precise historical perspective, being a history of alliance, salvation, and redemption. It may well be an ante litteram example of how scientific paradigms sometimes influence the message of freedom and richness expressed in the theological message.

Also ancient Greek science and philosophy had to confront themselves with theology, that is, with the discourse about God [8] proper to their times. On one side, the natural observations adopted by the ancient Greeks did not conceive of time as a major factor of transformation, at least as far as living
organisms were concerned. However, Greek thought considered the problem of how to describe species and their adaptation, assuming that the species maintained their characteristics over the years, thanks to adaptations allowing them to survive and reproduce in an extremely efficient way. According to Aristotelian biology, living beings were complex systems, made up of various parts interacting with one another for a specific aim. Moreover, adaptations worked in such an effective way because, similar to the entire universe, they were the result of a Demiurge's farsightedness and providence, which, according to Plato, had oriented everything for the Good. On the other side, Empedocles' idea, splendidly popularised by Lucretius (98-54 B.C.), suggested that the living are nothing but systems made up of various parts randomly assembled. As a consequence, those who had the chance to be assembled in a way in which they could survive and reproduce had descendants, while all the others had to face a sure, more or less rapid extinction.

It is clear that adaptation used to be justified mainly by two contrasting hypotheses. One of them maintained that adaptation was the result of a rational plan and was much more inclusive and understandable than the other, according to which the right combinations were originated by chance, thus providing no rational reason to investigate animal structures thoroughly. Why, in fact, try to decipher the adaptive meaning of structures and organs when they were known to stem from a fortuitous union of different parts? Once the main reasons of adaptation have been explained, the rest is left to chance. On the contrary, every single action of a Demiurge had a precise meaning, which justified cognitive investigations as a means to understanding the role animal morphology and physiology played in adaptation. In writing one of the most complete pagan works on natural theology, Galen (129-210) took inspiration from the latter research program (cf. Hankinson, 1988).

It was Galen's opinion, in fact, that the plausibility of the theological hypothesis attributing a special aim to the various structures of living beings, thus justifying the analysis of their morphology and functions, rested on the assumption that they had been created by a clever and benevolent Maker. However, the existence of such a Maker implies that attached to every living thing there is a special aim, and that nature generates nothing superfluous. Otherwise the theological hypothesis loses its plausibility and the enquiry into the morphological-functional meaning of the structures of living beings makes sense no longer. It is thus evident that this form of natural theology -here intended as a simple form of teleology- stemmed neither from a Christian nor from a biblical theology. Basically, it aims at attaching a sort of "metaphysical substrate" to a scientific research program dealing fully with every single aspect of the morphological-functional description of the adaptation of living beings. To sum up, the theory on which Western biology was based until the development of the first evolutionary hypothesis, came out of a context which had little to do with both Jewish and Christian traditions.

The teleological perspective pervading Greek thought blended with the biblical notion of providence gave origin in this way to a solid paradigm unlikely to be altered. As a matter of fact, the God [7] of the Bible was the warrant for adaptation being suitable to the aims for which it had been thought, just as directly and immediately as Plato's Demiurge. Moreover, no evidence was found showing that adaptation could originate in a different way, mostly because observations did confirm its extreme accuracy and any alternative hypothesis implied chance, and thus being less favorable to scientific enquiry and clearly connected to the materialistic [9] and atheistic vision spread by Lucretius. Unlike rare exceptions, such as St. Augustine's thinking, the theological analysis appeared to be devoted to finding common traits between the biblical Creator and Plato's Demiurge, instead of highlighting the historical perspective brought about by Revelation. They were the first observations on nature carried out after Galileo's scientific revolution which raised awareness of the dramatic, far-reaching scope of the innumerable historical periods involved in natural history.
2. How the Evolutionary-Historical Perspective gained Ground. Niels Steensen (1638-1686), a Danish scientist who had been active in Tuscany for a long time, was the first to depict the idea of evolution of the geological landscape. He did so trying to explain how some marine fossils could have been stuck on the rock of a hill, undeniably rather a "strange place" for such remains. The key-concept in Steensen's hypothesis is that time influences the observation of nature because it actually brings along with it transformation and change. As pointed out by Barsanti (1979), the concept of natural history as "the story of nature" here develops into Lamarck's "history of nature," now understood as the transformation which natural events undergo in time. And that was the very moment when the idea of history, so deeply rooted in biblical theology, could begin to approach the natural sciences.

Yet, a key element is still missing in the plot of the first research program on evolution, that is, the possibility to extend the idea of "a change aimed at transforming nature." Such an extension was absolutely fundamental to allow the account of the scale of living beings (which had served as a basis on which scientists had developed the description of the living world from Aristotle onward) to now be proposed in terms of a real genealogical tree (cf. Barsanti, 1992). At this moment, the age of the Earth began to be determined through geological observations [10], and its overall time scale was extraordinarily expanded when compared with past calculations, relying on an extremely literal interpretation of the different biblical accounts on Creation [4]. Moreover, life too began to have its own history: animal fossils not only were found in anomalous locations, such as the shark teeth discovered on a hill by Steensen, but they were also recognized as belonging to living beings not directly connected to any living species known at those times. Had we to deal with the extinction of those species, or maybe with something completely different?

The discussion, however, broke out in a favorable and extremely exciting period for science in Europe, thanks also to the geographic discoveries. Paris became one of the main centers of the debate. Georges Buffon (1707-1788) lived there, and it was one of the cities welcoming the ideas of the Enlightenment. Although Enlightenment stemmed from religious culture, soon dissociated itself from it, becoming a source of major trouble for Christian thought. The rift reached biological science later, when the new notion of progress [11] was added to the discussion about the long time scale and the question of the sense of the history of nature. History also means continuously moving towards better conditions of life. This "moving towards" concerned life as well, where other than mere transformation could be observed. Successfully investigated by sharp-witted scientists, the great laws of nature regulating the movements of celestial bodies were likely to be valid for life as well: at this stage, the hierarchical scale of the living could be interpreted as a sort of genealogical tree, where the (apparently) simplest life forms were in some way considered the ancestors of the most complex creatures. Therefore, the questions presented by the observations of fossils could finally be answered: they were not remains of species merely extinct, but remains of ancient species which had developed into the contemporary living species.

It was Jean-Baptiste Lamarck (1744-1829), working in France in the period straddling the 18th and the 19th centuries, and breathing the winds of the French revolution, who first put together the puzzle propounding a theory of the "transformation of the species." Supported by the social-political atmosphere of those times, the idea of progress played a crucial role in conceiving his scientific research program; the idea of life "moving towards" more and more specialized forms, towards increasing complexity, to use the current terminology. Lamarck's ideas are part of a deistic perspective: the Creator is the impersonal God proposed by the Age of Reason, the one who started the motion of the universe, but then stepped back and left it to its own rhythms, almost indifferent to what he had originated. What is presented here is a new version of Plato's Demiurge, whose primary task is to guarantee the existing order and assure the world will continue moving towards the future. When this perspective was applied to the history of life, an answer to the question of which mechanisms had caused transformation and adaptation was due. Here
the importance of Lamarck's work is emphasized, and its limits as well. The French scientist understood adaptation as an interaction between the environment and living beings. This was a great conceptual novelty, but his speculations were unfortunately limited by the mechanisms invoked, i.e. the use and misuse of the organs and the heredity of acquired properties. Leaving aside the development of Lamarck's proposal and the discussion which followed, here we will analyze the impact it had on theology and philosophy.

Strange but true, the most bitter confrontation arose in Paris, starting with the idea of progress. In the period of the Restoration, the idea of progress came to be considered dangerous again, and Georges Léopold Cuvier (1769-1832), another Parisian scientist, seized the chance to embody the alternative to Lamarck's progressive ideas by reproposing scientific fixism. He virtually broke that mechanistic view of living beings moving towards progress by declaring that the geological history of the Earth did show the presence of catastrophic events, which had led to the extinction of life forms in vast areas (catastrophism; see Geology [12]), subsequently repopulated by different animals and plants coming from different parts of the world. It is evident that the perfect mechanism created by the God proposed by the Age of Reason can no longer work here! Obviously, there were less dramatic and peremptory reactions to Lamarck's hypothesis other than Cuvier's. It is worth recalling that Lamarck and Cuvier both lectured and worked at the Museum of Natural History in Paris, and thus they had scientific, philosophical and also personal reasons to oppose each other. To top it all, both Cuvier's hypothesis and Napoleon's regime were detracting Lamarck's view of progress from the splendor it had experienced during the French revolution.

However, the immediate impact the debate had on theology, with particular reference to the Catholic milieu, were not completely negative. In 1835, before being appointed cardinal, Nicholas Wiseman held a theological course at the English College of Rome scheduling several lectures on "Science and theology," in which he presented transformist ideas. Although Wiseman was not enthusiastic about Lamarck's hypothesis, the only great obstacle he saw to compound trasformism and Catholic theology was the risk of endorsing a theory of the origin of human beings by various evolutionary branches, while the common origin of humankind ought to be considered a defined and unchanging teaching of theology. What is peculiar about him is that, in order to give an explanation to the differences of the various human populations without denying their common origin, Wiseman outlined a theory which sounded incredibly like Darwin's! He suggested, in fact, that the differences between human populations could be explained by assuming that hereditary varieties may have been produced accidentally and become fixed under favorable circumstances. "These examples [...] prove that sporadic, or accidental, varieties, may not only be produced, but what is much more to our purpose, may be propagated among animals. [...] Thus far then we have proved, both from analogy and from direct examples: first, that there is a perpetual tendency, I might say a striving, in nature, to raise up in our species varieties, often of a very extraordinary character. [...] and secondly, that these peculiarities may be communicated through successive generations, from father to son. A strong presumptive evidence is thus obtained, that the different families or races among men, may owe their origin to some similar occurrence; to the casual rise of a variety which, under the influence of favorable circumstances —the isolation, for instance, of the family in which it began, and its consequent intermarriages— became fixed and indelible in succeeding generations" (Wiseman, 1842, pp. 127 and 132).

After all, he was suggesting accidental hereditary varieties might have fixed in small isolated populations, which is exactly what "modern synthesis" catalogues as genetic drift. Neither transformism nor accidental fixation seemed to represent an obstacle for theologians: then, why did Darwin's works create so much friction?
III. The Confirmation and the Diffusion of the Evolutionary Hypothesis: Natural Selection according to C. Darwin and A. Wallace, and the corresponding Philosophical-Theological Debate

Leaving Darwin's biography and his acceptance of transformist ideas aside, we want here to investigate the reason why the Darwinian theory of evolution was an obstacle to theology, namely to its interpretation of the biblical account.

1. The Assumptions of the Theory of Evolution through Natural Selection. In order to understand the basis of such a theory, we should start by considering the British scientific milieu, where two novel elements were being discussed alongside of Lamarck's hypothesis. In his *Principles of Geology* (1830-33, a three-volume work), Charles Lyell (1797-1875) questioned Cuvier's catastrophist view, keeping his distance from evolutionary ideas. According to his perspective, major geological changes were due to the sum of innumerable minor geological modifications observed and studied daily, such as erosion, sedimentation, rise, and subsidence, rather than to extraordinary, uncommon events which science had no means of investigating properly. This theory, known as "actualism" (see *Geology* [12]), provided a wider perspective: to understand evolutionary processes a daily study of the transformation of living being was needed. In this regards, cattle breeders definitely had a privileged position providing studies in artificial selection. Yet, how could one apply the mechanisms of artificial selection to understand the way selection works in nature?

A second element of interest was Thomas Malthus' *An Essay on the Principle of Population* (1798). In this work he presented a dynamic theory on human populations, which resulted in incredible support backing the development of the hypothesis on "natural selection." Malthus (1766-1834) claimed that any human populations having at their disposal unlimited resources reproduce in a geometrically increasing ratio, i.e. exponentially. As a matter of fact, when he formulated his theory he was thinking about the demographic boom occurring in North America, a land rich in resources where the English colonies were growing without real competitors —had he carried out a similar research on Native Americans, the results would obviously have been totally different! On the contrary, the European population was being kept constant by diseases, famine, and wars, in spite of a certain degree of fluctuation. The key concept, however, is that these disgraceful situations basically depended on a lack of resources: since they increase by an arithmetic ratio, a real struggle for life takes place, leaving the weakest and unfittest to their destiny of starvation, disease and death [13]. Undeniably, the human condition appears to be quite dramatic, and in fact Malthus used to define it by the term "misery," which was emblematic of a miserable state. The situation, though, is as terrible as it is inherent in human societies and consequently in humankind. Compared to the harmony and the order of nature, the miserable conditions of human beings could be easily interpreted as evidence of Adam's sin. After all, it was humankind who had sinned, not nature.

To sum up, Darwin's theory on natural selection was based on the following assumptions: on one side, actualism connected to gradualism, holding that evolution occurs through the accumulation of slight modifications originating major changes —e.g. the great diversification of living beings— over a long period; on the other side, the importance of the mechanism concerning the competition for resources and the selection of the fittest, which could be someway monitored through the studies on the process of artificial selection applied by cattle breeders. Times were ripe for the proposal of a novel theory on natural selection, to such an extent that two different authors came to it quite independently: Charles Robert Darwin (1809-1882) and Alfred Russel Wallace (1823-1913).
2. The Debate on Darwin's Theory: Scientific, Philosophical and Theological Perspectives. Leaving the historical implications of the issue aside for the moment, it is worth underlining that there has been no direct passage from the theory of natural selection to an atheistic vision of nature. As a matter of fact, although we may not define him as a believer, Wallace was not materialist at all: late in his life, he embraced a sort of muddled theosophism, claiming insight into natural selection through a universe of ghosts and spirits. Although superficially —his theological knowledge was rather poor and odd— he affirmed that his theory was acceptable for a Christian-inspired natural theology and justified it by claiming that natural selection may well be considered part of the harmony of the universe. In one of his works, he replied to the objections raised by the Duke of Argylls by including natural selection in a group of clear and simple laws governing and balancing nature (cf. Wallace, 1891). Yet, when summing up the main rules of the theory of the transformation of living organisms through natural selection, we notice that it posed serious problems, implying the failure of any attempt to maintain a "natural theology," that is, the undertaking of the demonstration of God's existence through the observation of the function and morphology of living beings. On the other hand, the criticisms to these forms of apologetics had indirectly fostered a new and more thriving era in which a more complete "theology of nature" would be proposed.

Julian Huxley (1887-1975) summed up the rules of natural selection in three observations and two deductions, the latter derived from the former. The first observation holds that the offspring of every species usually outnumber their parents; the second that the number of individuals in a species remains more or less constant over the generations. These observations led to the first deduction stemming from Malthus' hypothesis, i.e. the struggle for life is perceived when assessing the limited number of surviving offspring for every species. The problem, at that stage, was how to apply Malthus' hypothesis to humankind and to natural biological events, and here came the third observation, i.e. the individuals of a species are slightly different from one another, and those varieties are hereditary. The second deduction is that since individuals do show different features, those who exhibit the varieties guaranteeing better survival and reproduction are selected by environment or by any other external factors over the generations. This selection of some individuals instead of others is called "natural selection." All things considered, it is a question of applying the outcome of a daily study on the activity of cattle-breeders to the action of nature.

That is exactly the issue on which major and long-standing controversies centered. Natural selection itself was the core of the problem, more than the origin of humankind, and such a question could not be solved easily, by a generic reference to the harmony of nature as Wallace tried to do. The selection, in fact, could affect the existing varieties originated by internal mechanisms, but it presented no cause-effect relationship with the various factors interacting with it. The point was clarified and developed by Darwin through a metaphor representing natural selection as an architect who must build a house from the stones fallen during a landslide. Could we really say the land crumbled into those stones by chance? Of course not, because the stones originated through specific causes connected to the erosion forces exerted on the rock, the shocks they received during their fall, and finally their chemical compounds. Yet, no cause-effect relationship exists between the stones and the use the architect intends to make of them. Therefore, the chain of causes is interrupted and an element of uncertainty is introduced. Another key aspect of the issue is that nature sometimes seems to resort to violence —typical of cattle-breeders too- or at least to the same mechanisms Malthus defined by the term misery. The "distress" of the human condition now extended to the whole of creation. Hence, it is no surprise that new obstacles were posed to the philosophical and theological thought, even though authors who tackled them immediately and seriously were not lacking.

A zoologist of Anglican origins, George Mivart (1827-1900) played a crucial role in the debate. He
embraced Roman Catholicism in a way similar to John Henry Newman and accepted evolution as a historical fact, even though he declared he was not completely satisfied with its alleged mechanisms -thus raising doubts among the most orthodox Darwinians, such as Thomas Huxley. Never the less, he tried to investigate, more closely than Wallace, the relationships between natural selection and the theological perspective on life on Earth. In 1871, Mivart published *On the Genesis of Species*, in the main part displaying a critical acceptance of natural selection. He underlines the explanatory limits related to the historical process of the evolution of living beings and, therefore, holds that natural selection should be considered alongside other equally scientifically founded processes. And yet the last chapter of his work analyses the serious theological implications raised by the rules of natural selection. Even though he was a zoologist, he had wider knowledge on the matter than Wallace, as his references to outstanding British authors such as Baden Powell and John Henry Newman clearly show, the latter being deeply involved in the debate instigated by Darwinism.

First Mivart distinguishes the different meanings of the term "creation," by stating that, when it refers to the absolute origin of something from nothing, it is a supernatural act, completely external to the field of natural science. He even suggests another possible meaning, referring to the power God gives to matter and to nature to evolve (this is already an evolutionary perspective). It is clear that, within this second meaning, the evolutionary mechanisms appeal to theology, for they present themselves as ways or patterns in which creation takes place, operating at the level of secondary causes. Therefore, Mivart was right when he raised the question of the metaphysical value of natural selection, which should be enough to stress how significant his work was.

As we have already seen, the concept of evolution was accepted by theology as long as it was intended as the transformation of the living creatures in time, transformation that could always occur according to a plan. The same is to be said for the concept of chance and the interruption of an orderly chain of causes. After all, this could more easily question the watchmaker God of the natural theology of the classic period (the metaphor of the watchmaker God already existed in Cicero's *De Natura Deorum*) or the God of the Age of Reason of the Enlightenment. Also chance, considered from a scientific and not from a philosophical point of view, did not represent a problem for the theological analysis: the existence of events that are not easily or immediately referable to precise deterministic laws, seemed in some debates even more in keeping with God's free action and the existence of a Providence freely directing history. The historical dimension of evolutionary phenomena, strictly connected with the uncertainty of its corresponding mechanisms, could always be related to the action of a God, precisely characterized as being the God of history: "What seems the effect of chance to the eye of the non-believer, is to the believer the sign of Providence, acting freely and with no necessity so that nature can take the needed steps to reach the human being" (Galleni, 1992, p. 104).

Regarding this subject, it may be interesting to remember that the encounter of Christian philosophy with the laws of Greek science and philosophy had already run the risk of leading to a vision of Nature where the events are governed by conditions so strict and necessary, so binding and definitive that not even God could alter them. This brought the Archbishop of Paris, Etienne Tempier, to condemn, in 1277, along with other statements of the Latin Averroism, the proposition according to which chance does not exist, but everything that happens, happens by necessity ("quod nihil fit a casu, sed omnia de necessitate eveniunt": P. Mandonnet, *Sigier de Brabant et l'averroïsme latin au XIII e siècle*, Louvain 1908, vol. II, p. 183, n. 102). As a matter of fact, natural laws have never been identified by Christian thinking with strict determinism [14]: such a conception would have meant limiting God's powers within natural laws discovered by science (cf. Galleni, 1992, pp. 172-173). The problem of the uncertainty of the evolutionary mechanisms could have been solved without many difficulties, even though this would have required a new and deeper theological analysis, sometimes unavailable due to a certain intellectual
laziness, aimed more at defending positions than dialoguing and trying to seek for syntheses.

If the above perspective was quite conceivable, the idea of natural selection as a violent, harmful event, was—and still is—an open matter of more difficult solution. In this case, Malthus' definition of the human condition as misery is to be extended to nature as a whole; as a result, the contrast between the biblical goodness of creation and the suffering, harm and death caused by a time-evolving world, was difficult to reconcile. Working on a solution to this problem, Mivart retraced several issues Leibniz had discussed in his Theodicy (1710), with reference to the presence of evil in the world (LEIBNIZ, II-III). He gave a clear and lucid account, pointing out that, from a scientific point of view, natural selection is only one of the numerous mechanisms contributing to evolution. However, since God's plan is so far from our comprehension, we might take it as disgraceful and dramatic when it could be perfectly explained in the light of a Creator's global vision. Although it was rather an interesting attempt, it still lacked some points.

IV. Confirmations and Novelties in the 20th Century

Resuming the thread of the scientific debate, it is possible to observe that, at the end of the 19th century, there was an open and lively discussion about the potentialities of natural selection to explain the world of living beings. The mechanisms controlling the appearance and the heredity of variations were not yet clear because the proper experimental approach was still lacking. That approach, at least as far as the heredity of variability is concerned, had already cleverly been proposed by Gregor Mendel (1822-1884) right after the publishing of Darwin's On the Origin of Species (1859), but, paradoxically, his works remained practically unknown.

1. The Reductionist Approach, the "Modern Synthesis" and Molecular Biology. Mendel managed to apply a mathematical statistical approach to the analysis of the heredity mechanisms. Such approach was based on the regularities deriving from dealing with large numbers and he could do that thanks to a methodology that was definitely reductionist [15]. In fact, he analyzed the hereditary mechanisms of evident and qualitative characteristics (green or yellow, smooth or wrinkled, white or red) in an experimental system, which allowed him to obtain a vast number of crossbreeds, and in a controlled way, so that the experimenter could be certain about the precision of the crossbreeds that he was planning (i.e. the pollen of a certain plant was to fertilize the ovule of another). Moreover, he could monitor a high number of crossbreeds and extend his experiments over time. This way, Mendel noted the presence of statistical regularities in the transmission of genetic characteristics, getting to understand that each individual possesses two "determinants" for the same characteristic, one deriving from the father and one from the mother. Such determinants do not blend, but they maintain their own individuality and then migrate in the gametes in a stochastic way, so that the new gametes have only one per genetic characteristic.

At the basis of such results there was a reductionist formulation [15]: each visible feature was related to a genetic characteristic by a linear relation and the organism was formed by the addition of the characteristics that were inherited through simple rules, namely Mendel's laws. As a paradox, it was the clearness of Mendel's reductionist approach that restarted the experimental and theoretical work on natural selection. In fact, by developing the mathematical-statistical formulation, it was possible to create a model for the behavior of genes over time and to define the reasons that balanced their frequencies. Moreover, it was possible to define the factors that, interrupting the balance in the frequencies of genes, allowed evolution. The creation of models opened also other perspectives: the reductionist approach inaugurated by Mendel let scholars think that, when all the mechanisms of the evolution of the genes over time were understood, it would be possible to also understand the richness of the transformations of living
organisms. A population of living beings could be brought back to the simple addition of its genes and then modelled as a cloud of genes and alleles (forms of a single gene that are different from the molecular point of view) in which forces such as selection and mutation intervene. Therefore, it was possible to adopt the same techniques belonging to statistical mechanics that were used to create a model for the behavior of a gas cloud.

Another concept of "chance" appears here, to be added to the Darwinian one. In fact, while the "Darwinian chance" was related, as we have seen, to the existing disconnectedness between the emergence of variability and the natural selection that would have acted on it, in genetic terms chance is related to the stochastic mechanisms of heredity: therefore, it is not possible to predict how a certain population will develop, but it is possible to create a model of a system displaying the probabilities that certain combinations of alleles will form and get inherited.

However, the inventiveness of Mendel's work is not only due to the introduction of models. The fact that genes behave like chromosomes led to the idea according to which the physical structure supporting the genes was made of chromosomes. The birth of cytology and karyology (the study of the reproduction of cells and of the duplication of their nucleus) and the studies of the so-called Drosophila group (from the name of the fruit fly, Drosophila melanogaster, which was found to be the perfect animal to analyse for such studies) ascertained that genes are placed on chromosomes in a linear sequence and clarified the nature of mutations. In fact, since mutations have a precise physical support, such support could change in various ways and the corresponding variation could affect the action of the gene on the phenotype and then be inherited. Moreover, the variation had no cause-and-effect relationship with the selection that was to operate on it: mutations occurring after exposing animals to ultraviolet rays, for instance, did not make them more resistant to such rays. Hence, this important part of the Darwinian theory seemed to be confirmed. This leads to the so-called "modern synthesis," which takes Mendel's notion of heredity and natural selection as the core reference for all the biological discoveries occurring during the first half of the 20th century (cf. Huxley, 1942).

The discoveries of contemporary molecular biology seem to further confirm the picture given by modern synthesis. In fact, genes are formed by a sequence of nitrogenous bases, which, in codons, codify the corresponding amino acids and proteins. The double helix of the DNA can open up allowing the "reading" of the code corresponding to a gene and can double allowing the transmission of the genetic information from cell to cell and, thus, its hereditary transmission. Moreover, a change in the base sequence leads to mutation. Finally, the information can be transmitted from the DNA to proteins, but not the other way round. Therefore, molecular biology confirms the non-directionality of the mutation and the hereditary mechanism through which selection can operate. Moreover, the reductionist approach, summed up in the statement: "a gene, a protein," seems to be confirmed. Once the genes of an organism are known, also its proteins are known and thus all the information necessary to create its biological identity: what applies to the bacterium applies also to the elephant, except that the elephant needs a few more proteins...

The aforementioned two meanings of "chance": the Darwinian one, maintaining the disconnection between cause and effect (and interruption in the chain of chance), and Mendel's, displaying a stochastic fluctuation, are fully accepted by molecular biology. In fact, molecular biology explored the structure of the gene in various ways, with direct experiences. These two concepts of chance inspired the famous theory expressed by Jacques Monod in Chance and Necessity (1970), a clear example of interpretation of evolution according to a precise philosophical structure. However, it is only from the philosophical point of view that it can be subject to criticism, because the author maintains he proposed the sole "scientifically possible" interpretation. In order to draw universal conclusions starting from the scientific
description of molecular biology, it is always necessary to adopt a scheme of interpretation, which should be correctly defined and should not be based solely on experimental sciences. In fact, it is necessary to adopt global philosophical considerations. Monod drew his conclusions from his existentialist and atheist perspective. Thus, it should be clearly stated that Monod's considerations were philosophical, clarifying and discussing all the passages, but Monod did not do it. Moreover, Monod's theological inferences are quite superficial, because they enter the discussion without using the appropriate methodological instruments. It may be interesting to observe that his position corresponds exactly to what Archbishop Tempier wanted to defend! Nevertheless, Monod radicalized the notion of chance as the ultimate, global answer, while in Tempier's remarks the existence of chance was aimed at depriving nature of the attributes of absolute necessity belonging to God only.

2. The Biology of Complexity and the "Global Vision." It is now necessary to analyze what the approaches are, but also the problems, related to the interpretation of what is commonly known as the "modern synthesis" of Darwinian evolution. In the first place, it should be borne in mind that this is a reductionist approach: it considers a single problem, analyses it in the most convenient way and then tries to provide a global overview of living organisms by summing up the results of the surveys carried out on the single parts. Obviously, it is a definite methodological approach and, as such, its first point of reference is epistemology [16], not theology. It can be incidentally remarked that, analyzing the three figures who revolutionized 19th-century biology, Darwin, Wallace and Mendel: the first was an agnostic who approached clearly atheist positions in his late life; the second had always maintained wider views from the religious point of view (even though they were confusing and led him to theosophy); the third, Mendel, was a saintly monk, as far as we can see. On the other hand, the method employed by these scholars was extremely important because it led to the birth of the various disciplines forming contemporary biology: from cytology to physiology and morphology. Nowadays, however, this approach shows its limits. In order to understand the problem better, it is necessary to reconsider the discussion related to the current status of evolutionary mechanisms, when they are reconsidered in the light of complexity and following a global approach.

In fact, the study of complexity has shown, also in physics, the difficulty related to a purely Galilean approach, based on the mathematical reduction of natural phenomena. Complex systems are sensitive to initial conditions and their behavior is unpredictable in the medium-long range. Moreover, the unpredictability of the system depends on the number of objects interacting and on their relationships. Fortunately, it is possible to reverse the apparent difficulty of biology, which was said to be traced to the Galilean scientific paradigm only with great difficulty, and thus described as "weak science." Biology is now defined as the "strong science" because it has been considered closer to the complexity of the real world, so much so that it is proposed as the guiding science in the new approach based on the complexity method. A perspective of this kind should lead to the conclusion that living beings (being objects formed by a large number of parts having a great number of relationships among themselves) should be highly unpredictable and highly "unstable". However, even though this could be easily proved by adopting a reductionist approach in analyzing a living being, the result would be very different by employing a "global" approach. In fact, it would be easily seen that the parts interact keeping the system stable. The complexity applied to a living being leads to the emergence of unpredictable features on the basis of the analysis of the single components, and such properties tend to maintain the system itself stable.

This is particularly interesting if considering that the end of the reductionist program was marked by the branch of biology that seemed to have hallowed its success, that is molecular biology. In fact, in the organisms with complex cells (eukaryotes), a great quantity of DNA escaped the simple "one gene, one protein" scheme, because this had structural functions. This could be explained only by considering DNA inside the complex structure where it was found, that is the cell nucleus, and the functions that it had, that
is the maintenance of the stability in the organism. This introduces the biggest innovation in evolutionary mechanisms, related to the most interesting novelty in the last decades: a theoretical pluralism that can no longer be eluded. We will try to briefly sum up the main theories contained in this pluralist vision, and will then discuss the diversity of their impact on the relationship between science and theology.

V. The Contemporary Debate on the Plurality of Evolutionary Mechanisms

From an epistemological point of view, the existence of different evolutionary theories is quite interesting. They can coexist without being replaced in time by one another. One of the most effective epistemological clarifications of that is represented by the so-called triangle of evolution (see Galleni, 1998, 2001), where each apex accounts for an evolutionary theory: a) gene-centered theory or the theory of disconnections; b) organism-centered theory or the theory of self-organization; and c) biosphere-centered theory or the theory of connections. The area of the triangle is formed by dots whose different distance from the three apexes measures the interconnection of the theories, none of which could operate "purely," that is, could ever give a complete and satisfactory explanation of a real event without taking the others into consideration. Any interpretation of evolutionary events is to be found within the area of the triangle, in the very place where its distance from the apexes accounts for the different contribution given by each theory. Individual authors, though, tend to find their own position within the triangle according to their own philosophical ideas. In principle, this kind of visual representation allows one to figure out the role to be given to each theory separately, though in practice, in the ordinary work of biologists, they usually coexist both at a theoretical and at a practical level, precisely because they are part of the same triangle.

The gene-centered theory is the closest to Darwinism and to the modern notion of evolution. What is noteworthy is that genes change and are handed down through their own rules, representing the rough basis where natural selection intervenes as an organizing factor. Richard Dawkins, who supports atheistic philosophical ideas actively, is currently the most representative follower of a gene-centered theory. It is undeniable that this theory is in accord with most of the classical Darwinian hypotheses, including the impossibility to support a naïve apologetics based on a chain of causes mechanistically conceived. This is why a philosophical transposition of the theory ends by eliminating the idea of God [7] as a watchmaker or as it was presented by Enlightenment thinkers (cf. Dawkins, 1996), although it does not make atheism sound plausible, as Dawkins would claim. Yet, it makes the notion of a provident and benevolent Creator quite problematic by removing the idea of a project or, at least, by making it hard to understand.

Concerning the emergence of the organized structures characterizing the morphology of living beings, the organism-centered theory, or theory of self-organization, refers to the ability to create organized structures interacting with one another in objects occupying the same level of a hierarchical scale, in a way more efficient than how natural selection would have done. The almost perfect geometrical structures characterizing many living beings —phyllotaxis and flat spiral shells, just to name a few— are likely to originate from the phenomena of organization connected to the relationships between molecules or cells, just as the perfect geometrical shape of snowflakes and crystals is the result of specific relationships between their atoms. Another crucial matter at stake connected to the former question is the emergence of new features. Although they have their limitations, the high number of simulations carried out on relationships between objects —from Conway's straightforward game of life to the most sophisticated NK systems by Kauffman— seem to show that, in particular situations, organized structures are due to emerge from objects showing basic patterns of interactions, and sometimes even find their own balance. Organization appears to be self-generated, with no need of intervention for natural selection and its
organizing forces. Yet, it is only a geometrical organization. Despite some clearly finalist interpretations stemming from Kauffman's philosophical considerations (1995) holding that human beings may be the logical result of the processes through which the universe can self-organize, the existence of a plan in creation was excluded from Western cultural tradition by natural selection, and even the theory of self-organization could not include it again. Indeed, it is worth noticing that a non-reductionist vision, based on the observation of nature, has come to philosophical conclusions that are diametrically opposed to those maintained by Jacques Monod.

The biosphere-centered theory offers wider perspectives of a positive interaction with theology. Pierre Teilhard de Chardin (1881-1955) was one of the outstanding mentors of such a theory, which is the most valiant attempt to develop a global approach to the question of evolution. If analyzed from the point of view of complexity, the crisis of the reductionist program stemmed from the impossibility to understand certain characteristics of the whole by analyzing its parts individually. On the contrary, a non-reductionist evolutionary program was due to suggest different research methods dealing with evolution as a whole, in order to monitor the emergence of any new feature overlooked by population biology. From this point of view, a large-scale approach is absolutely essential. A mention goes to Teilhard de Chardin's dual work on the evolution of the continent, and of the biosphere as a whole by means of geobiology. When interpreting the evolutionary genealogical trees according to his view, the observed emergence of new features evolving in parallel demonstrate the effectiveness of his method. When studying the evolution of the biosphere as a single, complex, evolving entity, he focuses on the channel driven patterns and parallelisms that a reductionist perspective would never detect. And this is quite crucial when tackling the theological question.

The theory of the global approach has been recently given a new interpretation by James Lovelock, which he calls "Gaia Hypothesis" (cf. Lovelock, 1990). Apart from some simplistic explanations, Lovelock's is a scientific hypothesis predicting that all the living and non-living beings on Earth, considering the whole biosphere, are connected to one another through negative feedback relationships, resulting in a balance of the survival parameters of the biosphere itself. Therefore, the biosphere monitors and assures the survival of the world as a single entity by balancing external, changing factors with its constant basic parameters, such as the temperature of the atmosphere, the level of salinity of sea waters, and the concentration of oxygen and carbon dioxide. That is, life evolves to survive.

VI. Philosophical and Theological Reflections

The existence of three different theories on evolution has encouraged the debate concerning the relationship between evolution and theology.

In this context, a gene-centered theory may be the closest to Darwinism. Not only does natural selection interrupt the chain of causes which refer mechanically to a Plan, but it also extends to the whole of creation, through the idea of the struggle for life, the problem of suffering, pain, and death (DARWIN, VII). In this light, it is more difficult to understand how the biblical account can insist on the fact that God rejoices when seeing the goodness of creation. It is worth remembering that it is not so much a matter of an apparent lack of teleologism or the presence of casual genetic variations in evolutionary mechanisms, as the fact that these mechanisms are often responsible for suffering -e.g. in the case of beta-thalassaemia, where refined adaptive mechanisms resulted in a boost for the species but revealed to be lethal to humankind because of the high mortality they cause (cf. Galleni, 1995). Darwin's Creator of the universe is one who actually dismisses the single creatures and their suffering. George Mivart's emphasis on the "metaphysical" value of Darwin's theory is openly recognized. The natural philosophy stemming from it,
further described and supported by Monod, holds that life evolves, from the simplest forms to human beings, casually and with no fixed plan, while the only aim of humankind is to experience loneliness—all individual human being facing the supreme, existential indifference of the universe. From this point of view, the organism-centered theory is of no help. If Kauffman's interpretation does introduce finalist elements in the motion of life towards complexity, his theory includes the gene-centered theory instead of replacing it, and thus he does not propose any final solution to the drama of the evolutionary mechanisms.

On the contrary, the perspective provided by the biosphere-centered theory, or theory of the connections, seems to hold a different view. Although it does not eliminate the main problem, at least it tries to solve it within a global vision and a global scientific method, partially resorting to Mivart's ideas. The biosphere-centered theory leads to remarkable philosophical considerations: besides confirming, as a general feature of life, that evolution is a time-irreversible transformation, it adds the interpretation of evolution as a "motion towards." When analyzed from a global perspective, even though they partially depend on chance, evolutionary mechanisms proved to follow a given direction, a motion towards specialized life forms and towards awareness, emphasized by specific parallel and channel-driven patterns detectable by scientific trials.

Therefore, a need for an aim, i.e. a finalist perspective [17], is being reintroduced as far as rational beings are concerned, despite a non-deterministic pattern leading to the appearance of humankind. As a matter of fact, the biosphere-centered theory suggests a third characteristic of evolution, alongside transformation and motion towards, i.e. that of being a path towards freedom. In this view, the casual, and sometimes tragic evolutionary mechanisms are the result of processes which cannot follow a merely deterministic plot, otherwise free human beings could never have been born and lived according to their free will. The same is to be said for the Creator: should he intervene in the processes of nature and eliminate the causes of human physical suffering, he would restrict their freedom. God will intervene only after the emergence of rational beings and thus of the noösphere, thanks to an alliance the creation has freely accepted through the free thinking creatures. The noösphere provides the means by which the whole biosphere becomes the Creator's allie. Thus, it is not the presence of a deterministic evolutionary pattern that demonstrates the existence of a plan for creation, but rather the opposite, since the appearance of rational free creatures was possible thanks to a non-deterministic process. The real value of creation is freedom. Events which happen by "chance," sometimes even tragic when analyzed from a perspective similar to that provided by a Leibnitzian theodicy, are the only ones which maximize freedom. And the very goodness of the created world resides precisely in that it leads to the emergence of free, thinking creatures.

The relationship between theology and the evolutionary perspective might imply a review of the contents associated with original sin (cf. Gaudium et spes, n. 13), particularly the connection between the sin and the natural world. At times, the doctrine on sin may have been seen as a sort of "way out" to forgive God for the evils we see in the creation: within a harmonious universe organized by a provident Creator, evil might be only due to a mistake, a sin committed by rational creatures. After all, the question of evil has always been in contrast with the goodness of the laws of nature [18]. Whereas, before Darwin, the "miserable state" of humankind was still due to human sin, once that state was extended to the whole of creation, the meaning of the evolutionary perspective would become that of providing a pattern to follow in the preparation of a new order. Therefore, order and harmony must not be considered in connection with the past but as conditions to be realized in the future. As Karl Schmitz Moormann (1995) remarked, the classical idea of id verius quod prius was replaced by the evolutionary view of id verius quod posterius, which resulted in important consequences for theology. On the other hand, it must not be forgotten that the biblical Revelation differs from both ancient classical tradition (order and truth set at the beginning of time) and modern, idealistic historicism (truth and meaning set at the end of time). In fact, the Word of God, Logos Creator [19], is the subject of an extensive cosmic mediation at the
beginning as well as at the end of time. However, a God creating an evolving world, a world characterized by the emergence of ever new capacities, coincides well with the historical perspective of the biblical Revelation. A God granting his creatures total freedom, up to consenting to be crucified by them, is the God of history, alliance and redemption. He is the God, making use of Teilhard de Chardin's famous expression, whose creation is approaching the Omega point. Furthermore, the evolutionary perspective matches the concept of alliance as well: God wants to intervene in the world only through his gratuitous alliance with his free creatures, in order to let the Earth and history be open towards future.

To conclude, apart from the acceptance of the evolutionary scientific perspective, theology must also develop its knowledge of God's plan for the created world, a knowledge that, according to Galileo's remark, also derives from the scientific study of the Book of Nature. Taking this matter into consideration means assuming a future-oriented theology, with a view to explaining God's "proposals of alliance" which he continuously offers to humankind, helping us to face and accept new and unpredictable events, because novelty and unpredictability are inherent in the world he created and in which we have to live. Indeed, it is only by accepting the alliance with its Creator that the noösphere can continue its own path, also ensuring the integrity of the biosphere, to which it is symbiotically linked (cf. Galleni, 2001).

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