The Arrow of Time and the Historization of Nature

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Abstract
This paper discusses in a historical framework the conception of nature as subject to changes in time. The important reconceptualization of nature from a static to a dynamic dimension occurred in the late eighteenth century, but did not refer to the underlying causes, the laws of nature. A deeper understanding of the continual decay of nature over long spans of time was only obtained in the mid-nineteenth century, with the second law of thermodynamics. The concept of entropy offered a justification for the irreversible changes of nature, from more organized states to less organized, and for this reason it became controversial in some circles. One may imagine that nature is temporal on an even more fundamental level, namely in the sense that the laws of nature are themselves varying in time. Suggestions of this kind first appeared in the late nineteenth century, and more recently they have become quite popular in physics and cosmology. However, although nature is indeed changing in time, this does not mean that natural science has become truly historical.

Introduction
The concept of nature has many connotations, such as has the concept of history of nature. In many cases, "nature" refers to the perceptible objects and processes of the surface of the Earth, in so far that these are original and not "cultural", i.e. produced or influenced by humans. According to the philosopher Alfred Whitehead, "Nature is that which we observe in perception through the senses" (Whitehead 2004:3). This is of course a very broad and not entirely satisfactory definition, for other reasons because it does not distinguish between natural objects and artifacts made by humans. At any rate, it is largely in this sense we speak of "natural history", a term which is generally associated with the kingdoms of plants, animals and minerals. To speak in different terms, natural history comprises the sciences of botany, zoology and geology; or, from a more recent perspective, biology and the earth sciences. However, nature may also refer to much larger and more comprehensive entities, either to the Earth as a whole or, on an even grander scale, to the universe at large. It is in the latter sense that I speak of nature and its evolution in time, a concept which may be called "history of nature" in order to distinguish it from "natural history".

The subject of this paper is the temporal dimension of nature as seen from the perspective of the history of ideas, a topic covered in admirable breadth by Stephen Toulmin and June Goodfield (1982). I deal with some of the proposals made at different times that nature has a history and that her past can be investigated by basically the same methods as used in ordinary history. First I offer a very brief and highly selective review of a few of the early ideas of nature as evolving in time on a phenomenal level. I then proceed to some of the later attempts to account for the irreversibility of natural evolution in terms of fundamental processes as ultimately governed by natural laws. The relationship between the contrasting concepts of change and constancy is a classic theme in the history of ideas, where change has traditionally been explained epiphenomenally, on the background of fixed elements or constants. But what if these constants – the laws of nature and their associated constants of nature – are themselves changing in time? As we shall see, such ideas have been proposed for more than a century, although it is only relatively recently that they have been turned into testable scientific theories. As a kind of conclusion, I end with a few considerations concerning the meaning of the concept of "history of nature" and the relationship between history and the natural sciences.

From Steno to Herschel

During the later phase of the scientific revolution, in the second half of the seventeenth century, it became more common to think of nature as a historical product, rather than a fixed and immutable entity created at the origin of time. Nature was increasingly seen as something with a past that had shaped the present, but a past that was presumably very different from nature as presently observed. Such ideas, relating to the surface of the globe, were pioneered by the Danish natural philosopher Niels Stensen, better known as Steno, and also by his contemporary, Robert Hooke, in England (Rudwick 1985:49-80; Drake 1996).

It was generally agreed at the time that if the Earth changed as a whole, it was a change from the better to the worse, with the overall trend being one of decay or degeneration. The decay of nature manifested itself in particular in the rugged surface of the Earth, so obvious to any observer. God had of course created the Earth, and most philosophers thought that his creation was originally perfect in shape and had since deteriorated to its present form, marked by irregularities such as mountains, valleys and rivers. This theme was clearly stated by Hooke, who in a lecture of 1689 spoke of the "many Expressions that denote a continual decay, and a tendency to a final Dissolution; and this not only of Terrestrial Beings, but of Celestial, even of the Sun, Moon and Stars and of the Heavens themselves" (Drake 1996:319).

The same theme can be found much earlier. One of the first advocates of the theory of decay was the English divine Francis Shakelton, who in a treatise of 1580, *A Blazyng Starre*, confidently stated that "this worlde shall perishe and passe awaie, if we doe but consider the partes whereof it doeth consist, for doe we not see the yearth to be changed and corrupted?" (Jones 1965:23-24). Shakelton found evidence of nature's decay all over, in mountains, earthquakes and floods, even in "the constitution of the celestiall worlde, [which] is not the same that it hath been in tymes paste, for so much as the Sunne, is not so farre distant from vs now, as it hath been heretofore." The world was surely approaching its end:

> Let this therefore be a forcible argument to proue, that the world shall haue an ende: for so muche as it doeth waxe old, and euery part thereof doeth feele some debilitie and weaknesse. For there is lesse vertue in Plantes hearbes than euer before. And more feeble strength in euery liuing creature than euer was before. And less age in men than euer was before. It remaineth therefore (of necessitie) that shortly there shall be an ende and consumation of the Worlde, because it is (as it were) subiecte to olde age, and therefore feeble in euery parte. (Jones 1965:24)

The early attempts of Steno, Hooke and their contemporaries to introduce a historical dimension in the science of the Earth were hampered by a much too narrow time-scale based on biblical chronology. In the seventeenth century everyone agreed that God had created the world about 4,000 years BC, and this authoritative time-scale effectively prevented a scientific reconstruction of how the present state of nature had gradually come into existence (Haber 1959). It was only during the era of the Enlightenment, in the second half of the eighteenth century, that the orthodox chronology was seriously questioned and it was argued that the world has a cosmic history immensely longer than the one traditionally adopted. This daring proposal appeared in different versions, first and most importantly suggested by a naturalist, a philosopher, and an astronomer.

The great French naturalist Georges Louis Leclerc, better known as Comte du Buffon, was the author of a vast work on natural history, the *Histoire naturelles* in an amazing 44 volumes. In a supplementary volume of 1778, entitled *Époques de la nature*, he reported how he had established a new age of the Earth, not from studies of the Bible, but experimentally. Assuming that the Earth was originally formed in a hot molten state, he estimated by means of model experiments and calculations the time it had taken to cool to the present temperature. He arrived at the staggering figure of 75,000 years, and privately he concluded that the age of the Earth was probably closer to a couple of million years (Albritton 2002:78-88).

Buffon's break with the biblical time-scale was important, and so was his recognition that the history of nature could be investigated by roughly the same methods as employed by historians and archaeologists. He held that the scientist should appeal only to those natural causes that are in operation today, namely by examining the relics which are still around us and which must be regarded as evidence of earlier eras. In this respect, he may be counted as a precursor of uniformitarian thought in geology. In the opening words of the *Époques de la nature*, Buffon stated his insight as follows:

> Just as in civil history we consult warrants, study medallions, and decipher ancient descriptions, in order to determine the epochs of the human revolutions and fix the dates of moral events, so in natural history one must dig through the archives of the world, extract ancient relics from the bowels of the Earth, gather together their fragments, and assemble again in a single body of proofs all those indications of the physical changes which can carry us back to the different ages of nature. (Toulmin and Goodfield 1982:244)

Whereas Buffon was mostly concerned with the history of the Earth, the great philosopher Immanuel Kant took an even grander view by extending the scope to cover the entire universe. This he did in a remarkable work published anonymously in 1755, aptly titled *Allgemeine Naturgeschichte und Theorie des Himmels*, a combined cosmogony and cosmology in which he presented for the first time a thoroughly naturalistic and evolutionary account of the universe in its totality (Kant 1981). Sure, God had created the universe, but the job of the Almighty was limited to the original creation, as the subsequent development was taken care of by the laws of nature. What is more, God had not created the universe in its present form, for it had slowly developed from the original primeval gaseous chaos and done so strictly in accordance with natural law.

In Kant's vision – and it was more a vision than a scientific theory – creation took place at all time and simultaneously with destructive processes. "Creation is never completed," he wrote. "It is always busy in bringing forth more scenes of nature, new things and new worlds." Kant's universe was dynamic and evolutionary, but it did not evolve teleologically, towards some future state or goal. It should rather be characterized as a steady-state universe, infinite in space as well as in time. The great cycles of creation and destruction might occur endlessly. He eloquently wrote about "this phoenix of nature, which burns itself out only to revive from its ashes rejuvenated, across all infinity of times and spaces."

If Kant's view of the heavens was speculative, the cosmology of the great British astronomer William Herschel was to a considerable extent based on his careful observations of stars and nebulae. Although he was unaware of Kant's work, he arrived at a picture of the cosmos which had several features in common with the one proposed by the philosopher from Königsberg, including that it was dynamic and evolutionary. In an important series of papers from the 1780s, collectively entitled *The Construction of the Heavens*, Herschel concluded that creative processes still took place and that the distant star clusters were, as he said, "the laboratories of the universe" in which new stars were continually made (Hoskin 1963). Furthermore, he realized that when astronomers look into the depths of space, they look at the same time back in cosmic history, which is a consequence of the finite velocity of light. They will even be able to see distant celestial bodies which no longer exist. "I have looked further into space than ever human being did before me," Herschel wrote. "If those distant bodies had ceased to exist millions of years ago, we should still see them, as the light did travel after the body was gone" (Lubbock 1933:36).

According to Herschel, the heavenly bodies were in a state of evolution, from birth to death, but how could this slow evolution possibly be recognized empirically? Evidently, the astronomer could not focus on a single nebula or star and follow its development over time. But he could nonetheless form an evolutionary picture of the cosmos, namely by collecting data from different parts of it, some far away and some closer to Earth. Herschel expressed this method by way of an analogy. Imagine, he wrote, a garden with a variety of flowers, some young and some old: "Is it not almost the same thing, whether we live succesively to witness the germination, blooming, foliage, fecundity, fading, withering, and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view?" (Hoskin 1963:115).

Irreversibility and entropy

In the dynamical conception of the cosmos, such as expounded in different versions by Kant and Herschel, creative processes coexisted with those of a destructive nature. There was no overall direction of evolution, neither towards progress nor towards decay. But processes in nature, such as we observe them and are familiar with them, normally proceed in a definite direction. The acorn may evolve into an oak tree, but there has never been an instance of an oak tree which develops the opposite way, ending up as an acorn. In other words, natural processes are irreversible, and it is this irreversibility that allow us to distinguish the past from the present and the future, to use the terms "before" and "after" correctly. Of course, if no such distinction existed, neither would history be possible.

This existence of an "arrow in time" in natural phenomena could not be explained by the laws of mechanical physics, which were largely the only laws of nature known in the early nineteenth century. These laws are ahistorical in the sense that they are symmetric in time and thus do not distinguish between past and future. Technically speaking, the equations of motion are unaffected if the symbol t, denoting the time parameter, is replaced by $-t$. If a motion is time-reversed, it is described by the same mechanical equations as the original motion. What was needed was a natural law with the property that it was as unidirectional as history itself, a law which accounted for the irreversible changes from one state to another. Since the dominance of christianity, European history had been based on a linear conception of time rather than the cyclic or recurrent conceptions favoured by many earlier cultures. In order to "historicize" nature on a fundamental level there ought to exist a law of nature with features corresponding to those found in human history, an arrow of time corresponding to the unidirectionality found in natural processes.

Such a law, a candidate for a time's arrow, was discovered in the 1850s in the form of what is known as the second law of thermodynamics. This is still the only law of physics which is inherently evolutionary and offers a kind of explanation of the direction of time. The essence of this law, formulated independently by Rudolf Clausius in Germany and William Thomson (the later Lord Kelvin) in Scotland, is that any closed physical system will spontaneously evolve in such a way that it becomes ever more disordered, ever less structured and less organized. Thomson spoke of dissipation of energy, while Clausius introduced the concept of *entropy*, a measure of the disorder of a system or its content of waste energy. According to Clausius' law, the entropy of a system must necessarily increase, in the end leading to a state with no life, no order and no activity, a state known as the "heat death" or the *Wärmetod* (Brush 1978; Kragh 2008).

The prospect of a dying Earth and Sun was a theme that both frightened and fascinated the Victorian mind, and it was taken up by several authors and poets, one of the first being Algernon Charles Swinburne, who in his poem of 1866, "The Garden of Proserpine", expressed the consequence of the second law as follows:

Then star nor sun shall waken,
Nor any change of light:
Nor sound of waters shaken,
Nor any sound or sight:
Nor wintry leaves nor vernal,
Nor days nor things diurnal.
Only the sleep eternal
In an eternal night.

This is quite a precise description of the heat death of the universe.

Although the second law of thermodynamics offered an explanation of the direction of time, and thus provided a link between physics and history, it was controversial for a number of reasons and the subject of much discussion during the last decades of the nineteenth century. Among these reasons was that the law, if applied to the universe at large, predicted that in the far future all life and activity would cease. The universe would end in an equilibrium state where nothing happened or could happen, and there was no way to escape from this pessimistic scenario of what was effectively a dead cosmos. Although the law of entropy was a law of evolution, it differed fundamentally from evolutionary natural history by being more properly a law of devolution and decay. According to Oswald Spengler, the author of the highly influential *Untergang des Abendlandes*, it heralded an end to the world, as in the non-scientific world views of ancient cultures: "What the myth of *Götterdämmerung* signified of old, the irreligious form of it, the theory of Entropy, signifies to-day – world's end as completion of an inwardly necessary evolution" (Spengler 1980:424).

It is no wonder that many naturalists considered the law of entropy increase to be contrary to the more progressive Darwinian evolution theory. Charles Darwin, for one, found it intolerable that the second law challenged his optimistic belief in greater perfection obtained through the slow evolutionary process. In his autobiography, begun in 1876 but only published posthumously, he referred to "the view now held by most physicists, namely, that the Sun with all the planets will in time grow too cold for life, unless indeed some great body dashes into the sun and thus gives it fresh life." It is, he continued, "an intolerable thought that he [man] and all other sentient beings are doomed to complete annihilation after such long-continued slow progress" (Darwin 1958:67). A few other evolutionists went to the extreme of denying altogether the validity of the second law, such as did Ernst Haeckel, the German zoologist and self-styled prophet of Darwinian evolutionism. As Haeckel saw it, and spelled it out in detail in his best-selling *Die Welträtsel* from 1900, nature was eternal and ever-progressive. It added to his dissatisfaction with the second law that it could be used, and in fact was used, as an argument for a divinely created universe, a notion he detested (Kragh 2008:122-127).

But there were also those who welcomed the message of the second law and saw in it a model, or an inspiration, for cultural and social history. This was the opinion of the American Henry Adams, an author and professor of history at Harvard. About the turn of the century, Adam argued that a science of history could be based on the general properties of energy and entropy as discovered by the physical sciences. He believed that it followed from the second law, not only that the physical universe, but also human society, must end in degradation and death, even though this prophecy would be distasteful to the evolutionists who preached nothing but eternal progress (Brush 1978:125-127). Also some theologians and Christian writers found the second law of thermodynamics to be appealing, primarily because it indicated that the world was of finite age and on its way toward dissolution. As they pointed out, this pessimistic scenario was in basic agreement with the Bible and the Christian tradition (Kragh 2008).

Varying laws of nature

The second law of thermodynamics deals with the development of nature over time, but it does not itself depend on time. The classical notion of the laws of nature was of course that they were permanent and immutable, valid for all places and at all times. They were believed to be islands of constancy in an ocean of phenomenal change. To speak of a law of nature, or its corresponding constant of nature, as varying in time may seem to border on a contradiction in terms (Balashov 1992). Still, such heretical ideas were suggested by a few thinkers in the late nineteenth century. The first to do so was possibly the American scientist and philosopher Charles Sander Peirce according to whom everything in nature, including the laws of nature, were characterized by an element of chance. The laws shared the evolutionary feature of the material world in the sense that they varied in time, although Peirce did not say how and only discussed the possibility in a very general way.

A few decades later a somewhat similar line of thought was defended by the British-American mathematician and philosopher Alfred North Whitehead, who made it part of his general process philosophy. In his main work of 1929, *Process and Reality*, Whitehead argued for a world view where processes were of higher ontological status than objects and where everything was in a state of flux, including the laws of nature. A few years later he elaborated:

> Since the laws of nature depend on the individual characters of the things constituting nature, as the things change, then correspondingly the laws will change. ... The modern evolutionary view of the physical Universe should conceive of the laws of nature as evolving concurrently with the things constituting the environment. Thus the conception of the Universe, as evolving subject to fixed laws regulating all behaviour should be abandoned (Whitehead 1933:143).

To Whitehead, a thorough-going process philosophy must also include a new picture of God, a process theology. The God of Whitehead and later process theologians (such as Charles Hartshorne and John Cobb) shares with the physical world a measure of temporality. He is influenced by events in nature, and “It is as true to say that God creates the World, as that the World creates God” (Whitehead 1929: 528).

The unorthodox ideas of Peirce and Whitehead are of great philosophical – and theological – interest, but they were foreign to science as usually conceived. For this reason they made almost no impact at all on the physicists and other scientists, who felt no need to introduce a temporal perspective on the laws of nature.

In a scientific context this idea was first introduced by the British theoretical physicist Paul Dirac, a Nobel laureate of 1933. In a paper of 1936, he suggested that the gravitational constant appearing in Newton’s universal law of gravity might be slowly decreasing in cosmic time. Generalizing the hypothesis, he explained in a lecture three years later that the laws of nature were evolutionary rather than fixed once and for all: "At the beginning of time the laws of Nature were probably very different from what they are now. Thus we should consider the laws of Nature as continually changing with the epoch, instead of as holding throughout all space-time" (Dirac 1939:139; Kragh 1990:227-239).

Although Dirac's heterodox idea was pretty much ignored at the time, more recently the general hypothesis of varying constants of nature – and hence of varying laws of nature – has aroused considerable attention and is nowadays seriously investigated by many physicists and cosmologists. The shift in attitude appeared in the late 1990s, after a team of physicists and astronomers announced that analysis of spectroscopic data from distant quasars indicated that one or more of the fundamental constants of physics had been smaller in the cosmological past (Barrow 2002). Although these results were contradicted by other experiments, they had the effect of highlighting the question of varying natural constants. Not only was the possible variation of the gravitational constant reconsidered, so was the possible change of other constants, such as the elementary electrical charge and the speed of light. The outcome of this line of research is still uncertain and so far there is no strong empirical evidence for constants of nature changing in time. On the other hand, neither can the case be ruled out. The present situation is that it remains a possibility that one or more of the constants do vary in time and in this sense reflect the history of the universe.

If the hypothesis of evolutionary features in the theories and laws of nature is uncertain, and to some extent speculative, this is not the case on the ontological level, when it comes to understand the constituents of nature, the atoms and subatomic particles of which ordinary matter is made up. Indeed, atomic and particle physics has long ago acquired a historical dimension, at least in the limited sense that atomic particles are now recognized to be historical products, formed in the past and destined to disappear in the future.

This insight stands in stark contrast to the classical notion of atomism, according to which atoms are permanent and immutable bodies – unhistorical, so to speak. Although the idea was only substantiated and turned into a viable physical theory in the 1930s, it can be found half a century earlier. During the Victorian era a few chemists and physicists speculated that the atoms of the chemical elements were the products of what they called "inorganic Darwinism".

In a visionary address of 1886, the British chemist William Crookes suggested that the elements were "the gradual outcome of a process of development, possibly even of a 'struggle for existence'" (Crookes 1886:568). He likened the method of the chemist to that of the archaeologist or ancient historian, in the sense that both groups needed to rely on relics in order to understand the past. This was the same point that Buffon had made more than a century earlier, but Crookes was apparently unaware of his French precursor. Referring to the spectra from the stars and those produced in the laboratory, he called them "autograph inscriptions from the molecular world". But the inscriptions were written in a strange and baffling tongue which had to be deciphered, just as the strange hieroglyphic language of the ancient Egyptians had been deciphered by means of the Rosetta Stone.

Crookes' ideas were bold and speculative, but in the twentieth century they were vindicated and turned into a quantitative theory of how the elements had come into existence in the cosmic past and can now be considered fossils from which this past can be reconstructed. Today it fully accepted that the material constituents of nature are historical products and that they continue to take part in the history of the universe. This line of reasoning, sometimes known as "nuclear archaeology", has been of singular importance in the development of modern cosmology (Kragh 2007:161-163).

Is nature truly historical?

I have been concerned with the temporal evolution of nature, both with regard to its laws and its constituents, and I have considered the analogy between history and the temporal change of nature which was first highlighted by Buffon more than 200 years ago. Although the analogy is of considerable interest, it should not be adopted uncritically. Nature has a history, but from this fact it does not follow that the history of nature is just another branch of ordinary history. In which sense, more precisely, is it justified to speak of nature in historical terms?

From a methodological point of view the methods of the historian do not differ fundamentally from the methods of the scientist concerned with the past of nature, whether this past is related to the organic or the inorganic realms. In both cases the crucial element is the present existence of sources or documents from the past, relics that properly interpreted can tell us about conditions that no longer exist and cannot be recovered. Whereas explanations in the physical sciences are normally causal, inferences from a cause to a future effect, in the history of nature the relevant argument is not so much prediction as it is *retrodiction*, that is, to start with observed effects and then to infer from them the causes in the past that shaped them.

But one should beware not to exaggerate the similarity between the history of nature and the history of human societies, for there are also historical methods that we cannot adopt in the study of nature's past. Because the historian is a human being he can mentally move back to the past and try to identify himself with the historical actors – he can imagine himself as one of those actors and in this way obtain a kind of empathic understanding or feeling of what they thought and did. This is obviously not a possibility for the scientist trying to understand the past of nature. It is just not possible to imagine being a dinosaur and even less imagining being a molecule.

The French historian Marc Bloch was aware of the analogy between scientific inference and historical method, but he also noted the differences. In a discussion of the legitimacy of speaking of the possibility of past events, he wrote: "When the historian asks himself about the probability of a past event, he actually attempts to transport himself, by a bold exercise of the mind, to the time before the event itself, in order to gauge its chances, as they appeared upon the eve of its realization" (Bloch 1953:125). Such mental transportation is outside the possibility of the scientist, but then it is not necessary either. For the scientist can and will rely on the laws of nature and methods of science, which in many ways is a superior approach and one that the historian cannot follow to any extent.

To express the matter in a slightly different way, it is only in the case of history of nature that developments are law-governed or nomological. Predictions as well as retrodictions depend on phenomena following laws or regularities, and whereas this is the case in nature it is generally not the case with the human actions and thoughts that to a large extent constitute ordinary, civic or cultural, history. To put it differently, we can explain the past of nature by referring to causes and laws, but the human actors of history are not bound in a similar way; they can act freely, and often do so, they have motives and intentions for doing as they do. Intentionality is basically restricted to human actors and is not to be found in nature. There are processes and changes in nature, just as there are in the human world, but they are much less contingent and they occur because they must occur under the circumstances, not because nature wants them to occur of because they fulfill a purpose.

In brief, and to conclude, to speak of the historicity of nature is really only to say that nature is subject to evolution and change in time. It is only historical in a limited sense, not in the full and genuine sense that we know from the history of culture and human societies.

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