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Time and Emergence in Victorian Scientific Theories:

Lyell, Darwin and Maxwell.

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ABSTRACT. The perception of time changed dramatically during the 19th century in both science and the social sphere. It is impossible to understand the revolution that was occurring in the concept of time without revealing its relationship with three central ideas that transformed Victorian science: emergence, directionality and probability. This paper maps the relationship between time and emergence in the works of Charles Lyell, Charles Darwin and James Clerk Maxwell, arguing that three of leading Victorian scientists laid the foundations for the concept of emergence by dividing nature into levels.

KEYWORDS: Victorian science, time, emergence.

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1. Introduction

The perception of time changed dramatically during the 19th century in both scientific and the social spheres. It is impossible to understand the transformation in the concept of time without revealing its relationship with at least three concepts that reshaped major areas of science: emergence, directionality and probability. Three leading theories, each in a separate discipline, are the focus of this research: Charles Lyell's Uniformitarian Geology, Charles Darwin's Theory of Evolution and James Clerk Maxwell's work on the Kinetic Theory of Gases.

Aspects of time and emergence which were closely related to the division of nature into distinct, separate levels are at the center of this paper. Lyell, Darwin and Maxwell each introduced a systematic approach of dividing nature into levels. Thus, they laid the foundations for the modern discourse regarding concepts of emergence and reduction. The separation of nature into levels revealed new kinds of conceptual "clocks". Each level was characterized by a unique "clock" that ticks with a distinctive rhythm. Lyell, Darwin and Maxwell had to cope with epistemological issues derived from the different rhythms as well as from the different scales of time that characterized each level. These differences in scale and pace make the notion of emergence even more salient.

2. Dividing Nature into levels

Victorian scholars were firmly educated in the Newtonian tradition and Newton's mechanics was an ideal model for the natural philosopher. One of Newton's major achievements was the derivation of universal laws: laws that are adequate for any scale; for falling apples as well as for rotating planets. Though Lyell, Darwin and Maxwell tried to maintain the high standards set by Newton, all three introduced and applied systematic approaches for dividing nature into levels, thereby challenging the Newtonian standard of universal laws.

Dividing nature into levels forced Lyell, Darwin and Maxwell to contemplate questions that are fundamental for the study of emergence and reduction, such as:
Is it possible to establish phenomena or qualities of higher levels on the basis of qualities of the fundamental levels? In other words: Is it possible to *reduce*

the higher levels to the fundamental levels?
Do new phenomena and qualities that do not exist in the fundamental levels *emerge* in the higher levels?

The division into levels took on a different shape in each of the theories under discussion. In his Uniformitarian Geology, Lyell made a clear distinction between local and global phenomena. According to Lyell's view the entire globe is in a steady state of climatic, geographic and biologic equilibrium. A violation of equilibrium is possible only locally. Darwin, in his Theory of Evolution, described the organic world as a complex system with several levels of organization, and differentiated the genetic level from the level of the organism; and the level of the organism from the levels of population and species. Maxwell, in his Kinetic Theory of Gases, refined the distinction between a gas and its atomic components and tried to establish the thermodynamical properties of matter on the properties of its components.
All three approaches resulted in distinctive levels characterized by a typical scale of time and a typical pace or rhythm: Stratification of a geological layer, which is a process slower and longer than the formation of rocks; creation of a new species by natural selection in a typical pace and scale of time of a geological scale unlike the shorter life cycle of an organism; and the relatively slow thermodynamical process at the macro level of matter versus the rapid motion of the minute atoms.

With such considerations all three moved on to analyze the causes of differences between the levels. They had two options to consider. The first was the possibility that differences between the levels were significant and actual. The second was the idea that the differences were merely epistemological.

3. Time, Emergence and Coping with the Unobservable

In their speculations on the characteristics of each level of nature, Lyell, Darwin and Maxwell took into consideration the limitations of the human senses: some natural events and entities are beyond the capability of human observations.
These unobservable can be two-dimensional: spatial or temporal. Furthermore, the unobservable were not the same in each theory. For the

spatial dimension we can point out processes that occur at the bottom of the ocean or deep down within the ground in the case of Lyell's Geology; at the genetic level and the mechanism responsible for creating genetic variations in the case of Darwin' s Theory of Evolution; and at the atomic level in the case of Maxwell's Kinetic theory of Gases. For the temporal dimension we have the history of earth and the history of the organic world in both Geology and Evolution Theory. Since the Kinetic Theory of Gases deals with equilibrium states and not with the dynamics that lead to those states, it does not have a temporal unobservable of the same kind as Geology or Evolution. Darwin and Lyell, however, had to contend with what seemed a contradiction between evidence of fossils and their theories.

In the following I describe the different ways the three protagonists chose for coping with the unobservable.
Lyell used several illustrations and analogies in order to illuminate difficulties in coping with the gap between the observable and the unobservable. His rhetoric is well demonstrated with respect to metamorphic rocks. The location of the metamorphic rocks suggested that they belonged to a specific geological period, but according to their crystal structure they had started their formation much earlier:

> Suppose two months to be the usual time required for passing from some tropical country to our island…
> and that an annual importation takes place of a certain tropical species of insect, the ordinary term of whose life is two months, and which can only be reared in the climate of that equatorial country.
> It is evident that no living individuals could ever be seen in England except in extreme old age. The young may come annually into the world in great numbers, but in order to see them, we must travel to lands near the equator. Lyell 1830-33 pp. 379-380)

Similar to the tropical insects, metamorphic rocks can be created only in specific conditions. Since the time needed for the rocks to rise to the surface is very long, by the time they reach the surface they are already quite old. In order to become familiar with their young form we have to travel back in time and directly observe them. Lyell's lesson is that different time scales of separate processes might cause a misrepresentation of evidence. Hence, one cannot reach solid conclusions based on partial evidence. Unfortunately, the traces left during the formation of earth are always partial and a geologist must always bear that fact in mind.

Darwin differentiated the genetic level from the level of the organism, and the level of the organism from the level of population. We can learn about Darwin's thought by two examples. The first refers to the level of organism and the genetic level, and the second to the level of organism and the level of population. As for the first, Darwin believed that Natural Selection is a complex mechanism able to conduct change based on what we now call phenotype as well as on the genetic level. Darwin believed that although we are not familiar with the mechanism that creates the genetic variation, genetic variations are not random. He referred directly to this issue in the *Origin*:

> I HAVE hitherto sometimes spoken as if the variations … had been due to chance. This, of course, is a wholly incorrect expression, but it serves to acknowledge plainly our ignorance of the cause of each particular variation. (Darwin 1859, p. 131)

Thus, the seeming randomness of variations is due to our limited knowledge and faculties and not because a random nature of the way variations are produced.

The second example is the working ant. Darwin claimed that Natural Selection works also "upwards" in the organization of the biological world and can create a survival advantage not only for individuals but also for a whole community. The female working ant is sterile, but because of its crucial contribution to the survival of the colony her genotype is transferred to future generations by other members of the colony. Properties such as the benefit of the group have a major impact on the ability of the group to survive. Collective properties are meaningful only at the higher level of organization. Therefore, and colonies are an example for emergence of new properties at the higher level of organization.

Referring to the differences in time scale and pace, Darwin claimed that the time needed to change an existing species into a new one is much longer than that needed to produce a geological stratum. Thus, geological and evolutionary processes have different time scales.

Those differences in scale and pace might cause a misrepresentation of evidence:

> Although each formation may mark a very long lapse of years, each perhaps is short compared with the period requisite to change one species into another. … When we see a species first appearing in the middle of any formation, it would be rash in the extreme to infer that it had not elsewhere previously existed. So again when we find a species disappearing before the uppermost layers have been deposited, it would be equally rash to suppose that it then became wholly extinct. (Ibid, p. 293)

On several occasions Darwin used Lyell's illustrations in order to emphasize the lack of synchronization between the stratification of geological layers and fossilization, arguing that the incompatibility of fossils with his theory is not conclusive.

As mentioned, Kinetic Theory is a little different from Lyell's Geology and Darwin's Theory of Evolution since Maxwell had to cope with the unobservable only at the spatial dimension. But as we shall see Maxwell had to contend with the question of directionality of time.

According to the Kinetic Theory of Gases a gas is an assemblage of a large number of atoms which are unobservable. One of the basic hypotheses of the Kinetic theory was that atoms move at a very high velocity, thus having a more rapid pace of motion than the gas itself. In his first model developed in 1860 Maxwell assumed that the atomic motion is Newtonian and he calculated by applying statistical methods the properties of gases, such as temperature, as averages of the properties of the atoms. Maxwell's model, as well as Clausius' work in the field of Kinetic Theory, gave successful predictions regarding the properties of gases; hence the concept of atoms as real entities gained credibility. Yet, at an early stage, the Kinetic Theory had to cope with criticisms and to explain how it is possible that the atoms move so rapidly while smoke moves so slowly. In order to overcome this criticism Maxwell and Clausius calculated, independently, the mean free path of an atom and showed that due to the frequent collisions of the atoms the assemblage fails to achieve a considerable linear propagation.

Another gap between the atomic level and the level of gas is the direction of time. According to Maxwell's model the atomic motion is Newtonian, and therefore symmetric in time. But according to the second law of thermodynamics, phrased by Thomson and Clausius less than a decade before Maxwell introduced his first model, heat can transfer spontaneously only in one direction, from a cold body to a hot one. Contemplating the issue, Maxwell introduced his famous demon who can sort molecules according to their velocities without investing work, violating the second law of Thermodynamics by reversing the spontaneous direction of heat transfer. A short while after it was introduced; the universality of the second law was questioned, thus the Newtonian standard of universal laws was clearly challenged.

At an early stage of his work Maxwell believed that the need of statistical tools for calculating gas properties is an epistemological need: If we had the faculty of observing atoms we would not need statistics because we could track their exact dynamics. Maxwell took atoms to be the internal unchangeable building blocks of nature. Changes occur only at the macro level and statistics provides us with the tools needed to represent new regularities: regularities of averages. The new regularities are achieved only at the macro level, whereas the typical time scale is much longer than the typical pace of events at the micro levels (see Maxwell 1873 p. 374-377).

Later, Maxwell became very troubled by the idea that the atomic level is symmetric in time while there are irreversible, and thus asymmetric in time, thermodynamical processes. This quandary caused him to change his views about atomic motion. In 1875 Maxwell presented a new assumption about the "kind of motion we call heat":

> In the next place, we learn how to distinguish that kind of motion which we call heat... The peculiarity of the motion called heat is that it is perfectly irregular… the direction and magnitude of the velocity of a molecule at a given time cannot be expressed as depending on the present position of the molecule and the time. (Maxwell 1875 p. 436)

By assuming that the atomic motion is "perfectly irregular" Maxwell attempted to reduce the irreversibility of thermodynamical processes at the macro level to asymmetry of time at the micro level. In fact, Maxwell's

hypothesis does not solve the problem since the perfect irregularity he described is symmetric in time: Not correlated to the past, nor to the future. On the one hand Maxwell's irregularity hypothesis deepens the gap between the macro and the micro level. On the other hand one can understand Maxwell's attempt to cope with the problem of directionality of time as an attempt to "save" the continuity between the levels, or, in other words, to set a strong basis for reduction of the macro level to the behaviour of the micro level.
The following quote reinforces this line of interpretation:

> If we go on to consider a finite number of molecule… the average properties of this group… are still every now and then deviating very considerably from the theoretical mean of the whole system, because the molecules … do not submit their procedure as individual to the laws which prescribe the behaviour of the average or mean molecule.(Maxwell 1878 p. 670)

Individuals, according to Maxwell, do not "obey" statistical rules. Deviation from the theoretical mean of the system decreases as the number of individuals increases. Maxwell put the two levels, macro and micro, on a continuous scale; the location of the observer on the scale determines the nature of the observation.

4. Concluding Remarks

Lyell, Darwin and Maxwell introduced systematic approaches of dividing nature into levels, yielding basic questions of reduction and emergence and giving rise to further questions about time scales, pace and rhythm. All three protagonists had to cope with the limits of human senses and with the gap between observable and unobservable. Maxwell withdrew his initial stand regarding the regular Newtonian motion of atoms, while Darwin did not lose his faith in the causal mechanism at the genetic level, although genetic variations look random to us. In addition, Maxwell significantly deviated from the standard of universal laws when he described the second law of Thermodynamics as a statistical law that is constantly violated by individual atoms.

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