CHARACTERISTICS OF LIVING BEINGS

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Contents

1. Introduction
1.1.Epistemology of Biology
2. Former Conceptions of Life
2.1.The Birth of Biology
2.2.Metabolism, 'Irritability' and Cellular Organisation
2.3.The Becoming of Individuals and Species
2.4.Inadequacy of Mechanistic Interpretations and the Revival of Vitalism
2.5.The Gestation of the Concept of Biological Information
2.6.Information Flux is an Endowment of Every Living Being
2.7.First Conclusions on Living Beings
3. Current Conceptions About Living Beings
3.1.The Rise of Genetics
3.2.The Mighty Advance of Dynamic Biochemistry
3.3.The Sources of Information Flux and the Self-Control in Living Beings
3.4.Limits and Peculiarities of the Sensory Flux
3.5.Self Regulation of Genetic Information
3.6.Information and Needs
3.7.Death and Life
3.8.Ontogeny and Morphogenesis
4. Evolution
4.1.Is it Conceivable that a Living Being May Not Evolve?
4.2.The Darwinian Assumptions
4.3.The Subjects of Darwin's Evolution
5. Conclusion
5.1.Summary of the Properties of Living Beings
5.2.Final Definition
Acknowledgements
Glossary
Bibliography
Biographical Sketch

Summary

After a brief survey of the methodology adopted in the most advanced fields of biology, the progress of the ideas on living beings from the Renaissance onwards is illustrated. Along this historical itinerary, we find that the living beings, interpreted for a long time as something functioning thanks to their food intake, became conceived as subjects of

chemical processes (Paracelsus, J.B. van Helmont) and, later, as automata that must be studied with the methods of mechanics and hydraulics (R. Descartes, A. Borelli). At the beginning of the 19th century, M. J. Schleiden and T. Schwann attested that all living beings are formed by one or more cells. Toward the end of the century, it also became clear that each organism is the site of a flux of energy coming from an external source (the nourishment, or the sunlight), an energy that, variously transformed, sets the parts of the organism in operation (R. Mayer, H. Helmoltz). With these important additions, the conception of living beings appeared fairly well understood. However, the problems of physiological control and of ontogeny, as well as some problems of the emerging genetics, could not be explained by mechanistic or energetic interpretations. Later on, the physiological control was clarified thanks to the notions of steady state and homeostasis, but the other issues remained unsolved. Some authors utilized for this purpose the concept of 'memory', later replaced by that of 'order', but neither term appeared suitable to many. Happily enough, the progress in communication technology introduced the concept of information, enriched with a standard of measurement and some useful theorems. In light of the information theory, the relationships between molecular genetics, genomics and ontogeny acquired an unexpected intelligibility, and so did some questions concerning behavior and evolution, but above all, the living beings acquired, so to say, a new dimension, a new meaning for the site of a flux of information. This flux has a double source: the genome and the sensors, which abound in the interior and on the surface of the cells. By this new perspective, at the beginning of the 21st century, a living being may be defined in a more exhaustive manner as: a cellular, self-reproducible, open system with self-regulated fluxes of matter, energy and information passing through it, ensuring its growth and steady state. Because of its attributes, such a system is capable of evolution.

1. Introduction

For centuries, man has been wondering what the main features characterizing living beings might be. Some early conclusions were, and still remain, correct; some have been modified and improved; many others have been rejected. The never-ending quest has seen many protagonists, most of whom are now forgotten.

To offer a reasonably complete and consistent picture of the subject, it is worth tracing the main phases of the long historical process that has led to the many-faceted views of today.

Yet, since the method followed by naturalists and biologists has often been harshly criticized and disparaged, particularly so in the last fifty years, it may be convenient to introduce some concise preliminary notes concerning the way biologists work.

1.1. Epistemology of Biology

During the last five hundred years, the criterion of faithful and circumspect reports has prevailed, together with the use of inferences and generalizations. Generalizations were justified in the 16th century by the consideration that natural laws operate uniformly and that all living organisms appear to be reciprocally related, as they share many common properties like reproduction, growth, feeding, and death. Later, Francis Bacon justified this approach, which today is adopted even in the most advanced biological domains, on philosophical grounds. The force of the biological method resides in refusing to state principles of universal validity - those deriving from logical necessity excepted - and in formulating propositions open to correction and integration. For instance, the general validity of the genetic code was stated at a time when less than a millionth of possible cases had been tested, and its general validity is still maintained notwithstanding the recognition of a few exceptions. The same has happened for the cell membrane structure: its basic similarity in all cells was assumed as soon as a few cases had been investigated by electron microscopy: such uniformity of structure is still held as valid, even though a few exceptions are known that concern bacteria thriving at the temperature of boiling water. Notwithstanding their provisional nature, the propositions of biology can be safely utilized in the range experimentally established. For instance, the old proposition "all animals take issue from an egg" (approximately 1670), although a rough approximation, was very useful for organizing the protection of foodstuff from vermin, while the principle that "all living beings are engendered by living beings" (approximately 1860), so useful for the development of bacteriology and thus of asepsis and antisepsis (J. Lister, 1867), was not disaffirmed by the belief in the origin of life from abiotic matter, a belief that stimulated pertinent research during a whole century.

Of course, in biology no statement that infringes the laws and principles of physics and chemistry can be formulated; however, biology has its own methods and principles.
Other methodological principles of biology are related to some peculiarity of living beings. For instance, the fact that the organism's body appears to be functionally organized at any level of observation, i.e., macroscopic, microscopic, submicroscopic, molecular and submolecular, compels us to exclude that any of its properties should be attributed to some peculiar state of the protoplasm, or 'living matter'. The opinion, firmly held for half a century, that the colloidal state might be determinant for all phenomena of life, induced much valuable effort to be wasted in many laboratories around the world.

The ascertainment of numberless controlling devices acting at any level of physiological organization, and also in the behavior of any living being, as well as the ceaseless utilization of information, coming from both the genome and internal and external sensors, indicated that any metaphysical entity must be excluded when considering the functioning of organisms. Likewise it became reasonable to speak in terms of physiological functions directed to an aim and in terms of purposive behavior.

Other peculiarities of living beings having implications in biological epistemology will emerge in following sections (2.6, 3.6, 3.7).

2. Former Conceptions of Life

2.1. The Birth of Biology

We will begin our excursus from the first general conception of life in modern times. It was Paracelsus (1493-1541) who, drawing upon neo-Platonic sources, reopened the discourse claiming that man is a chemical compound and at the same time a microcosm enclosing a myriad of elements. The chemical transformations of the body are governed by an Alchemist, also known as *Archaeus*, an immaterial entity located in the vicinity of the diaphragm. The revolutionary novelty of Paracelsus' conception lies in having focused attention on the chemical processes that take place inside living beings. This aspect was to be extended subsequently by one of his followers, G. B. van Helmont (1577-1644), who industriously studied and described gases and attempted to unravel the chemistry of living bodies. He too concluded that vegetative life in every animate being can be personified in the form of an *Archaeus*, located at the centre of the organism, governing the various physiological functions of the body through subordinate *Archaei* who are its vassals. Thus this theory parallels that of Paracelsus although, in addition, it incorporates clever considerations on the use of scales and on fermentation.

The novelties introduced by van Helmont influenced the thinking of Descartes.

Descartes (1596-1650) stripped the living being of all its magic or metaphysical attributes. To him, an organism is an automaton governed by the laws of mechanics and driven by the 'obscure heat' developed by interaction of blood and air within the heart cavities. This heat triggers the process of fermentation and distillation, thus providing the automaton with driving force and 'vital spirits'. Only man has something non-material about him, a rational soul, quite distinct from his body.

The Cartesian interpretation of the living being was accepted amid much controversy, but in the meantime the discoveries by Harvey on blood circulation dismissed the role as central furnace that Descartes had assigned to the heart; thus depriving his automaton of any driving force. Nevertheless Linnaeus, a convinced Cartesian, in the 12th edition of his *Systema naturae* defines the animal as a "hydraulic machine driven by an ethereal-electric fire". This peculiar definition (perhaps suggested by the first thermal engine constructed at that time in Sweden) has greater stress on the hydraulic machine, which testifies that the importance of chemical explanation of the living beings was beginning to diminish. The chemical processes had been considered by G. E. Stahl (1660-1734), who vigorously emphasized their energetic aspects, especially in combustion, and also proposed a model of living being abounding in metaphysical connotations.

2.2. Metabolism, 'Irritability' and Cellular Organisation

The very old, intuitive conception of material metabolism has been clarified in modern terms by M. Malpighi (1628-1694), whereas Johann Bernoulli, early in the 18th century attempted to calculate the time required by each part of the human body to be completely renewed by assimilated food. At the time, scales were the most accurate instrument available to naturalists; however, since gases eluded weighing, the growth of plants accurately weighed by S. Hales continued to be shrouded in mystery.

The clarification of respiration and photosynthesis in terms of ponderal chemistry is due to the efforts of J. Priestley, A. L. Lavoisier and J. Senebier. By the end of the 18th century, these attainments had laid the basis for an understanding of energy metabolism, i.e., the premises that were later to give meaning and an operative value to Descartes' 'obscure heat' and Linnaeus' 'ethereal-electric fire'. However, the conception closest to energy that was available at the time, i.e., that of the caloric, drawn from the Stahlian chemistry, was used in a vague way by scholars, preventing correct conclusions from being reached. Thus vitalistic interpretations prevailed: for instance, some authors suggested that animals move because the principle of perpetual motion is inherent in them. Other authors resorted to a 'vital force'. This view was supported by eminent personages like E. Kant and J. F. Blumenbach and by the renowned medical school of Montpellier. Vitalistic conceptions got broader acceptance when animal and plant chemistry began to develop that ignored the energetic side of chemical reactions and catalysis. The illustrious T. Bergman, for instance, ignoring the energetic aspect of chemical reactions, stated that substances of the realm of organic chemistry could be synthesized by living organisms owing to a '*vis vitalis'* of immaterial nature. Such a belief was accepted by many chemists until 1828, when F. Wöhler accomplished the synthesis of urea, thus pulling down a stronghold of vitalism.

Towards the middle of the 18th century, physiologists had reconsidered animal 'irritability', i.e., the aptitude of animals to react to stimuli. Two eminent scholars, A. von Haller and G. G. Zimmermann, dealt with this topic exactingly, establishing by vivisection that there is a connection between irritability and innervation of anatomical parts. Such views were before long integrated with the new ideas that had ensued from the experiments of Galvani on animal electricity and gave origin to the first intuitions on electrophysiology.
In the 19th century, the rhythm accelerated: M. J. Schleiden in 1838 and T. Schwann in 1839 asserted that plants and animals are composed of cells. This fundamental concept of biology was, however, weakened by their credence that cells could arise spontaneously from rough organic matter. It was the great merit of R. Remak and R. H. Virchow to assert, a score of years later: *omnis cellula e cellula*, i.e., every cell is produced by a cell.

In 1841 J. R. Mayer and in 1847 H. Helmholz, two scholars who came to physics from physiology, and in 1843 the physicist J.P. Joule, developed the ideas of the transformation of mechanical work into heat, the concept of energy and the first principle of thermodynamics. It was the need to understand the functioning of the animal machine that led to ideas that are central to the whole of science.

Thanks to these developments, in the second half of the 19th century the living being was conceived as an organism made of cells, composed of proteins, fats and carbohydrates and having a flux of materials and energy passing through it. In animals, energy is bound to the organic substances on which they feed, while in photosynthetic plants, energy enters the metabolic pathways in the form of light, quite independently of the simple substances absorbed by them. Thanks to this metabolism of matter and energy, living beings grow and reproduce.

To the above properties was added that of responding to stimuli. This property, more developed in animals than in plants, was not easy to define at the time.

2.3. The Becoming of Individuals and Species

Two more problems were then open to discussion, related to the transformations that organisms undergo during embryonic development and during the succession of generations in an ever-changing milieu.

At the end of the 17th century, some philosophers and naturalists formulated the theory of 'emboîtement', a theory which holds that at the moment of Creation all individuals of coming generations were miniaturized and enclosed in the first egg (or in the first spermatozoon) of each first couple. The organism's development was postulated to consist merely of an 'evolution', i.e., an unfolding from the primeval envelopes. The theory was lively debated and one century later was definitely discredited. Among the opponents was Caspar F. Wolff who assailed the 'preformation', not on the basis of factual evidence, but for purely theoretical reasons. And for purely theoretical reasons he proposed a new view of the gradual becoming of plant and animal embryos. The gradual development from the unstructured mass of the seed or of the egg, was conceived by him as following Aristotelian epigenesis, and the process was believed to be driven by a *vis vitalis*, i.e., an intrinsic force, the nature of which he did not attempt to identify.

This rupture with the past was received coldly in Germany, so that Wolff moved to St. Petersburg. In the new milieu his scientific program met with success and descriptive embryology became a leading biological discipline and as such lasted for a whole century.

During the 18th century an old dispute about creation had revived: whether Creation had occurred *in actu* or *per causis*, i.e., whether the cosmos was built from the beginning as we behold it today, or underwent transformation according to the causes set up at the time of Creation. The development of geology and paleontology lent credence to the latter thesis, but zoologists and botanists with Linnaeus as their leader preferred the former. The dispute soon extended to the primitive condition of human kind and to the origin of man: with the arrival of specimens of great apes in Europe some authors ventured to suggest their kinship with man. Thus, the first hypothesis on the transformation of species was formulated by anthropologists and philosophers.

Right at the beginning of the 19th century, J.B. Lamarck (1744-1829) asserted the universal kinship of all living beings, both plants and animals, and thus the uniqueness of the phenomenon of life. He also criticized the static concept of species and attempted to define the relations between the most important taxonomic groups.

The historical view of biology, closely following the onset of a historical view in cosmology, geology and paleontology, continued to spread slowly, until Charles Darwin came up with his model of natural selection with a strong accent on heredity, to explain how the tree of life kept on producing new trunks, new branches and new buds (also see section 4).

Ernst Haeckel endeavored to give concrete form to this new way of conceiving both the branching out of the tree of life and the history of single individuals by interpreting everything in terms of his monistic materialism, and Wilhelm Roux accentuated the materialistic approach in embryology by introducing the more alarming concept of *Entwickelungsmechanik*. The mechanistic and the monistic approaches, however, were not suited to such problems. Furthermore, the causes of hereditary variations, on which Darwin had insisted, remained unknown. Thus these difficulties produced a sudden breakdown of evolutionary concepts.

2.4. Inadequacy of Mechanistic Interpretations and the Revival of Vitalism

The vitalists, who had been keeping a low profile, reacted with loud pronouncements. The first of these was H. Driesch who explained ontogenesis by once again attributing its cause to Aristotelian entelechy, while H. Bergson, who explained evolution in terms of a metaphysical 'élan vital', obtained durable success, especially in France.

It is not surprising that the crisis in ontogenetic concepts should accompany the crisis in phylogenetic concepts. Many 19th century naturalists were aware of the links between the two, thus succeeding in drawing attention to the fact that something fundamental was missing from the complete picture of the historical development of living beings.

This is quite apparent in the passages in which Lamarck, in hypothesizing that a physical principle exists in living beings which leads them to increasing complexity, and claims that the same principle guides the embryonic development of organisms.

Similar assertions may be found in the writings of K. E. von Baer, J. F. Meckel, F. Müller, and later in those of Ernst Haeckel, who formulated the 'fundamental biogenetic law', according to which ontogeny (the individual's developmental history) recapitulates phylogeny (the taxon's history from its most remote ancestors up to present time). Nearly one century after Lamarck, Daniele Rosa again took up the idea that the forces directing the evolution of living beings must be interpreted using a materialistic key, just like the forces directing the development of single individuals.

Many critics did not accept as bona fide the philosophic declarations of these authors, and judged their ideas as ineffectual travesties of vitalistic conceptions. Similar criticism was even leveled at the leading theoretician of the experimental method in biology, Claude Bernard. This great physiologist does in fact show a tendency to acknowledge the existence in living beings of a principle directing the processes of repair and development, and controlling the various physiological functions.

"The vital phenomena.…are repeated eternally in an orderly, regular and constant way and are harmonized in order to achieve the result of the individual's organization and growth. There is a sort of pre-established pattern for each being and each organ". "While……each phenomenon in the economy of the organism is dependent on the general forces of nature, in its relations with other phenomena it displays a special bond, and appears to be directed by some invisible guide along the path it is treading, to be led to the place it subsequently occupies. The simplest reflection enables us to perceive the existence in this pre-established vital order of a primary character, a “quid proprium".

Now, after more than one century of biological breakthroughs, the problems that Lamarck, Haeckel and Bernard had to face do not appear so abstruse, nor do the theoretical positions of Lamarck and Bernard appear to be self-contradictory. We have no difficulty in concluding today that what was missing in the 19th and early 20th century theory was the modern concept of information with all that this entails.

2.5. The Gestation of the Concept of Biological Information

Of considerable significance in this connection is a paper written by E. Hering in 1870 entitled *On memory as a general function of organic matter*. This was followed in 1904 by a longer work by R. Semon: *The* '*Mneme*' *as a conservation principle in the changing world of organic matter*. According to Semon, memory is inscribed in the organism as an engram. Some engrams are inherited, and others are acquired by the individual. If needed, the engrams are recovered by reminiscence, a process he calls '*Ekphorie*'. The basic framework of Semon's theory is acceptable even today. However, even though his ideas met with popular acclaim, they got a cold reception in the scientific milieu at the beginning of the century, partly because he handled his ideas very clumsily. It would not be out of place to remark that the term 'engram', subsequently retained in biology, can be likened to that of 'program', a very old term used to denote what is written before in order to direct a performance.

In 1922, E. Rignano stressed that memory is a central phenomenon "to be placed at the basis of all biological phenomena in order to shed light on the great mystery of life". He relates memory to assimilation, to ontogenesis, to the control of the steady state. However, his bold effort unfortunately contains some obscure points, that lead to confusion.

The validity of these works was compromised by dilettantism. The authors, however, had two merits: the first consisted in drawing biologists to the study of memory, a faculty which in some fashion concerns all organisms, and the most advanced ones in a special way. The second merit is to have acknowledged that the solution of some biological problems requires resorting to concepts that are unrelated to mechanism, even though they necessarily rely on a material basis. Later, in the 1930s, the concept of memory was abandoned and the concept of 'order' was introduced in its place. The change was not for the better, because the concept of order is a static one (and corresponds to that of 'information content'), whereas a dynamic conception is needed to cope with the problems of ontogeny and evolution.

The concept of program, stripped of all its esoteric overtones, was introduced into physiology by W. B. Cannon in 1929. He combined it with the concept of homeostasis, or self-regulation, whose fundamental mechanism he clarified in a way that was acknowledged to be universally valid.

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Biographical Sketch

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