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On the Definition of Life

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The definition of life is a very important issue in the philosophy of biology, but this issue has unfortunately been neglected by the mainstream philosopher of biology for many years. In this paper, the difficulties with and the reasons for defining life are illustrated, the characteristics of life on Earth are explored, ways of defining life are examined, the main definitions of life are explained and evaluated, and finally, a new information definition of life is proposed.

Keywords: definition of life, entity definition, functional definition, metabolism definition, autopoiesis definition, supple adaptation definition, information definition

What is life? Historically, philosophers have been very concerned about this question. Aristotle, I. Kant, and F. Engels each put forward his own views. However, for a long time after the revolution in molecular biology, philosophers and biologists seem to have completely ignored this problem. Originally, the revolution in biology advanced our understanding of life so much that we seemed to be able to say more precisely what life is, but unfortunately, from the 1950s to the 1980s, biologists and philosophers mostly avoided talking about the definition of life. Biologists often feel that the problem is too "philosophical" and therefore treat it as a philosophical rather than a scientific issue. On the other hand, philosophers may feel that the problem is "too scientific" and therefore treat it primarily as a scientific rather than a philosophical issue (Bedau, 1996). Therefore, some of today's major books in the philosophy of biology, such as Alex Rosenberg's *The Structure of Biological Science* (1985) and Elliott Sober's *Philosophy of Biology* (1993) do not take the nature of life as a major issue of study. In Chinese philosophy of science, the nature of life is seldom touched upon. Over the years, the major philosophical journals have published almost no research papers on the nature of life. With the rising of artificial life science, the situation changes a little bit. Some artificial life and related scientists and philosophers began talk about the definition of life. But as you can see, no consensus can be reached. In view of this situation, this paper discusses the various reasons life is difficult to define, explores in detail the two main methods of defining life—entity definitions and functional definitions, analyzes the advantages and problems of some of the main definitions of life, and finally puts forward and proves the information definition of life.

Difficulties in Defining Life

One important reason people seldom talk about the nature or definition of life is that the issue is too

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difficult to resolve. There are several reasons for the difficulties to define life:

First, we all have a common-sense view of and experience with life, and defining life requires generalizing the common characteristics of all life, including a large number of unfamiliar and extreme life characteristics. The definition of life thus may conflict with, or even contradict, common-sense. Our common-sense concept of life is generally related to the general characteristics of animals and plants, including growth, reproduction, the ability to self-sustain, and responding to external stimuli. However, when we define life, we need to consider the characteristics of all types of life, including microorganisms, such as bacteria and even viruses, viroids, and prions. The characteristics of these creatures are very different from those of more commonly conceived organisms.

Second, when people in different disciplines define life, they often start from their own disciplines, emphasizing one aspect of life and regarding it as definitive of the nature of life. Physiology, for example, often defines systems that perform functions, such as digestion, metabolism, excretion, respiration, movement, growth, development, and response to external stimuli as living systems. Biochemistry and molecular biology often regard living organisms as systems that can transmit genetic information encoded in Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA), which can control the synthesis of proteins, which determine the main properties of organisms. Evolutionary theory often regards a system that can evolve through natural selection as a living system. Thermodynamics regards life as an open system that exchanges matter and energy with its environment. Open systems can "eat" negative entropy, allowing the system to create order out of disorder, using this negative entropy to maintain and reconstruct its own organization. The differing perspectives of various disciplines also make people feel that a unified concept of life is difficult to obtain.

Third, there is continuity between life phenomena and non-life phenomena, and there is no clear-cut boundary between them. However, the purpose of our definition of life is to distinguish them clearly, which necessarily makes our definition of life either so broad as to include some nonliving phenomena or so narrow as to exclude some living phenomena. For example, although the definitions of life in the various disciplines above are meaningful, they all are logically unsatisfactory. These definitions of life either exclude some living systems or include some nonliving systems. Physiological definitions, for example, exclude dormant seeds, viruses, viroids, etc. from the set of life systems because they do not metabolize and include nonliving systems such as cars in the set of living systems because they do metabolize. Biochemical and molecular biological definitions exclude prions, the protein-like particles that cause pruritus, from the set of living systems.

Because of these difficulties, biologists often regard the question of the definition of life as having little influence on the development of biology. P. B. Medawar, the 1960 Nobel laureate and immunologist, was impatient to say that the discussions of what life is "are felt to mark a low level of biological conversation" (P. B. Medawar & J. S. Medawar 1977, p. 7). Biologists tend to think that our intuitive concept of life is enough for our study of biological phenomena. Lacking a clear concept of life will not adversely impact the study of biological structure, function, evolutionary processes, and so on. Some philosophers have therefore argued that a precise definition of the concept of life is not necessary for biological research. The philosopher John Searle (1992) once said, of course, biologists do not need to keep thinking about what life is, and indeed, most biological works do not even need to use the concept of life. However, no one in his sound mind would deny that the biological phenomena he studies are forms of life (Searle, 1992). Carol Cleland (2012) had claimed that any philosophical or scientific definition of life is doomed to fail because defining life may impede the exploration of others possibilities. Edouard Machery (2012) had claimed that whether the concept of life is based on folk intuition or theoretical science, in essence, there is no real definition of life. Kim Sterelny and Paul Griffiths (1999), in their book on the philosophy of biology, also said biologists do not need a definition of life to help them recognize what they are thinking.

However, not all biologists and philosophers agree with this view. The famous geneticist Joshua Lederberg (1960), the 1958 Nobel laureate, once said that "an important aim of theoretical biology is an abstract definition of life" (p. 394). In addition to theoretical biologists interested in the concept of life, biologists who study the origin of life, biologists who study extraterrestrial life, alifers who study artificial life and so on also think that the definition of life is very important because different definitions of life have a direct bearing on the content, scope and direction of their work.

"Life-as-We-Know-It" on Earth

Artificial life, the frontier science of the intersection of computer science and biology, emerged in the late 1980s, once described life on Earth as "life-as-we-know-it", while other possible forms of life, including digital life created in computers, were called "life-as-it-could-be". The definition of life should cover not only known life but also unknown or possible life. Here, we will start with what we know about the characteristics of life on Earth. Life on Earth, if viewed in terms of its composition, structure, and nature, has the following main characteristics:

First, in terms of the composition of life, all living things have essentially the same composition of matter. All life forms consist of carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, calcium, and other elements. These elements combine with each other to form small living molecules, such as amino acids, nucleotides, and glucose. These small molecules combine with each other in a special way to form biological macromolecules, such as proteins, nucleic acids, polysaccharides, and lipids. These molecules become the basic building blocks of life. Because all important bio-macromolecules contain carbon, artificial life researchers call this "life-as-we-know-it" "carbon-based life".

Structurally, life on Earth, which directly appears as living, is made up of cells. The cell is the basic structural unit of life; all lives are inseparable from the cell, the basic form of life. Although cells have various forms, they all have basically the same surface structure, which involves being surrounded by a semi-permeable membrane and selective material exchange with the outside world, and similar internal structures. The nucleus or nuclear region is responsible for the storage and expression of the information of life; the cytoplasm contains many organelles (such as mitochondria, endoplasmic reticulum, plastids, ribosomes, Golgi apparatus, etc.) that have different functions important for the life of the cell. Cells are also the basis for the activities of life. The activities of life, such as metabolism, growth, division and death, are all based on cell activity. Therefore, cells are the most basic form in the maintenance of life system functions. Without cells, living activity would stop. Viruses, viroids, and prions are marginal forms of life. They can show life activity only when they enter host cells. Without host cells, no matter how "superior" the environment may be, they can only remain quietly there without showing any signs of life (Chen, 1997).

The cell is the basic unit of life, but the cell is not the whole of life. Life is multi-layered. Except for some simple organisms, most organisms are made up of many cells. Multicellular organisms organize different types of cells in an orderly way by means of tissues, organs, and systems, forming a complex hierarchical structure and rich functions of biological individuals. Tissue is a collection of cells that are differentiated from other cells and have the same function. Organs are structures with specific functions that are formed by different tissues. A system is a structure formed by multiple organs to perform specific functions. Finally, a variety of systems combine to form a unified and orderly organism. Because multicellular organisms are cascaded structures formed by cell differentiation, the parts are closely linked and indivisible. Different kinds of multicellular organisms have different hierarchical structures, which makes living individuals look very different. Historically, due to natural selection, biological species evolve and develop gradually to differ greatly. In the long process of evolution, plants and animals evolved, and finally, intelligent organisms—human beings—emerged.

There is also a complex, dynamic, and stable ecosystem formed by interactions between the living things on Earth and the living environment. In this system, all living things restrict and depend on each other. Ecosystems also interact with other ecosystems to form a biosphere that includes all life, as well as the Earth's underlying atmospheric space, land surface, lithosphere, and hydrosphere. In the biosphere, organisms change themselves and evolve to adapt to changing natural and living environments. At the same time, living creatures also change their living environment through their activities.

The multi-level hierarchical structure of life makes us realize that life is a highly ordered phenomenon in nature. This kind of orderliness, from micro to macro and from the past to the present, is ubiquitous. This order is not only structural but also functional, both spatially and temporally. This structure also allows us to see that new attributes emerge at every level of life. In this way, when we study the phenomenon of life, we should not only see the correlation between the levels but also see the independence of the laws of each level.

Almost all life follows the same basic rules: All use the same genetic code and have the same replication, transcription, protein synthesis, and DNA repair mechanisms. The metabolic activities of life, including the generation, transformation, energy acquisition, and utilization of various major life materials, also have a high degree of consistency.

In nature, life on Earth has some of the following characteristics:

First, all life is constantly metabolizing matter and energy from the outside world. Substance metabolism and energy metabolism are actually two sides of the same coin. Life stores energy in the process of synthesizing its own matter and releases energy in the process of decomposing it. The key chemical processes in metabolism are the tricarboxylic acid cycle and oxidative phosphorylation. Metabolism is the foundation of the existence and activity of life.

Second, the metabolism of organisms is accompanied by growth, development, and aging processes. Single cells grow in the metabolic process, while multicellular organisms have a process of growth and development.

Third, organisms exhibit the phenomena of self-replication, reproduction, and variation (through reproduction). In the processes of replication and reproduction, organisms show highly genetic characteristics; that is, the genetic information of their parents and the structural characteristics determined by them are transmitted to the next generation with high accuracy. At the same time, in these processes, genetic information will also harbor a small number of errors, that is, exhibit variation, so that organisms have some differences from their offspring.

Fourth, organisms can respond to external stimuli to a certain extent, that is, the so-called stress response capacity. For example, the phototactic growth of the plant stem apex, the immune response of organisms, and the self-regulated homeostasis of organisms are manifestations of different stress abilities of organisms.

Fifth, life has the ability to evolve. Life on Earth began approximately 3.5 billion years ago. After a long evolutionary process, various biological species radiated from primitive single-celled organisms to form a variety of organisms adapted to various environmental conditions, culminating in the emergence of highly intelligent organisms.

Two Ways of Defining Life

There are currently two main ways to define life on Earth. One is from the point of view of the material that constitutes life and regards life as having a kind of special material structure or as being material with special structure. The other is from the basic characteristics of life and sees life as a special phenomenon. The former is an entity definition, and the latter is a function definition or an operation definition. However, it should be noted that since structure and function are closely related to each other, entity definitions and function definitions are often combined. The difference lies mainly in whether the definition focuses primarily on the structure or function of matter. Entity definitions emphasize the importance of the material composition of life, and functional definitions emphasize the importance of the function of life.

Entity Definition

There are currently two types of entity definitions. One defines life in terms of a specific macromolecule, including “life-protein identity theory” and “life-nucleic acid identity theory”; the other defines life in terms of a special material structure, especially a cellular structure, which can be called “life-cell identity theory”.

In the 19th century, Friedrich Engels (1987) defined life mainly in terms of macromolecules. In “Dialectics of Nature”, he said

> Life is the mode of existence of protein bodies, the essential element of which consists in continual metabolic interchange with the natural environment outside them, and which ceases with the cessation of this metabolism, bringing about the decomposition of the protein, (p. 578)

and “If success is ever attained in preparing protein bodies chemically, they will undoubtedly exhibit the phenomena of life and carry out metabolism, however weak and short-lived they may be” (p. 578). In “Anti-Dühring”, he stated that “life is the mode of existence of albuminous bodies, and this mode of existence essentially consists in the constant self-renewal of the chemical constituents of these bodies” (p. 76).

Engels’ definition was put forward on the basis of criticizing Herr Dühring’s definition of life. Dühring once defined life as the metabolic activity of cells. Engels claimed that advanced organisms consist of simple types of “cells” but that there are lower-level organisms that are associated with advanced organisms simply because their basic components are protein bodies so that they perform their functions: life and death. Engels’ definition of life is actually related to his thoughts on the form of the movement of matter. Engels thought that there are five kinds of movement in nature: mechanical movement, physical movement, chemical movement, life movement, and social movement. From a historical perspective, these five forms of motion reflect the evolution and development of nature, and each of the latter forms of motion is evolved from the former form of motion. Different forms of motion have different material bases and different laws of motion. The higher forms of motion include the lower forms of motion. Life movement is a kind of advanced movement that is developed from chemical movement. Its material base and its movement law are different from those of chemical movement, but life movement includes chemical movement. Engels emphasized the continuity of nature. It is difficult to explain the origin of life if it is defined as activity above the cellular structure. Engels paid special attention to the dialectical development process from the inorganic to organic world, so Engels chose protein bodies as the material base of life activities.

Engels' understanding of the albuminous body is different from what is now known as protein.

> The term albuminous body is used here in the sense in which it is employed in modern chemistry, which includes under this name all bodies constituted similarly to ordinary white of egg, otherwise also known as protein substances. The name is an unhappy one, because ordinary white of egg plays the most lifeless and passive role of all the substances related to it, since, together with the yolk, it is merely food for the developing embryo. But while so little is yet known of the chemical composition of albuminous bodies, this name is better than any other because it is more general. (Engels, 1987, p. 76)

Therefore, Engels refers to the protein body in a broad sense; it is not even a kind of polymer in the modern sense, but a material system. Engels used the word on various occasions, sometimes even calling cells "protein chunks". For example, he said, "All organic bodies, except the very lowest, consist of cells, small granules of albumen which are only visible when considerably magnified, with a nucleus inside" (Engels, 1987, p. 71).

In short, Engels equated life with protein bodies. Life is "a self-implementing process which is inherent in, native to, its bearer, albumen, without which the latter cannot exist" (Engels, 1987, p. 77). From Engels, it logically follows that "if chemistry ever succeeds in producing albumen artificially, this albumen must show the phenomena of life, however weak these may be" (Engels, 1987, p. 77). In the first half of the 20th century, with the development of biochemistry, the structure and function of proteins have been understood with increasing clarity. Proteins have complex morphology and various functions, so they play an important role in the process of life activities. All this makes many people more convinced that the molecular basis of life is protein.

After the 1950s, the discovery of the double helix structure of DNA and its genetic function changed people's view that the nature of life is protein. Since then, many people have turned their attention to nucleic acids and began to regard the molecular basis of life as nucleic acids with self-replication and genetic information. Therefore, the definition of life has changed from emphasizing protein and its metabolic function to emphasizing the function of nucleic acid and its genetic carrier. The origin of life is reduced to the origin of oligonucleotides and polynucleotides capable of self-replication. This view can be called "life-nucleic acid identity theory".

Defining life in terms of the nature and function of a macromolecule inevitably raises the following question: Is there life in the form of acellular organisms? Can the basic characteristics of life be reflected in the molecular state?

It is now known that there are indeed acellular forms of life: the virus, which consists of a protein shell and a core of DNA or RNA; the viroid, which is a naked RNA molecule without a protein coat; and the protein-infectant, or prion, which consists of only protein molecules but contains codons that replicate themselves. In other words, the protein itself is a carrier of genetic information. However, little is known about this very special form of protein life.

However, these three types of acellular life can show the characteristics of life only when infecting a living cell. They cannot independently replicate themselves. Therefore, the above three kinds of acellular life are not complete life forms and are unable to be used as a model of primitive life (Zhang, 1998).

Given that viruses, viroids, and prions are not complete forms of life, can we say that there are no cell-free "macromolecular states" of life in the early stages of Earth's chemical evolution? Is it possible to produce life forms consisting solely of protein molecules or nucleic acid molecules in the chemical evolutionary stages leading up to the advent of cellular life? Because abiotic organic molecules may have existed in large quantities on early Earth as an external condition for the replication of macromolecules themselves, macromolecular forms of life were likely to have existed in the early stages of Earth, just as acellular life forms can now exist in test tubes.

If we agree that there are indeed life forms consisting of protein or nucleic acid molecules in the chemical evolutionary stages leading up to the advent of cellular life, the next question is as follows: During the origin of life, did proteins or nucleic acids occur first? This question has been hotly debated. The “RNA world” theory holds that nucleic acids came first. In the early 1980s, it was found that RNA functions as an enzyme under certain conditions: RNA itself plays a catalytic role in the cleavage of RNA molecules. This finding provides evidence that nucleic acid came first. However, the discovery of prions led to the belief that proteins evolved first. Prions themselves carry genetic information and control their own replication. Therefore, the question of which evolved first remains unanswered.

In today’s life forms, nucleic acids and proteins are inextricably linked. Protein is synthesized under the guidance of nucleic acid information, and nucleic acid is replicated and transcribed under the catalysis of protein. Therefore, it is likely that the primitive life form of early procells is neither RNA nor protein but a macromolecular system of nucleic acids and proteins (and perhaps lipids). In this macromolecular system, the relationship between amino acids and nucleotides is gradually established through interaction; that is, the genetic code is generated in this interaction.

There is another entity definition of life, i.e., life-cell identity theory. This theory holds that there is no molecular life and that all life is cellular. Once produced, proteins and nucleic acids must be contained within lipid-forming membrane structures to form independent life forms. Viruses, viroids, and prions all lack membrane separation and therefore cannot perform a variety of biochemical reactions outside the host cell. So they are not independent living beings.

Functional Definition

Contrary to entity definitions that emphasize the material base or the structural characteristics of life, function definitions mainly defines life in terms of the nature and function of life. There are also two kinds of functional definitions: “Cluster definitions” emphasize that life is a collection of various properties, and “fundamental property definitions” emphasize that a few or one of the properties is essential to life.

“Cluster definitions” often define life by enumerating a series of characteristics of life. For example, in his famous book *Chance and Necessity* (1971), Jacques Monod listed three characteristics as definitive of life: purposiveness, autonomous morphogenesis, and reproductive invariance. Crick (1981) defined life according to the following characteristics: self-reproduction, heredity, evolution, and metabolism. General biology textbooks enumerate more properties, such as metabolism, growth, development, genetics, evolution, stress, homeostasis, and self-organization. Well-known biologist Ernst Mayr (1982) once made a longer list of the nature of life:

(1) Life systems at all levels have a very complex and adaptive organization.

(2) A living organism is composed of a group of chemically distinct polymers.

(3) The important phenomena in the life system are mainly qualitative rather than quantitative.

(4) Life systems at all levels consist of a highly variable population of unique individuals.

(5) All organisms have historically evolved genetic programs that enable them to participate in purposeful processes and activities.

(6) The categories of living organisms are defined by the historical connections of a common family.

(7) Organisms are the product of natural selection.

(8) The course of life is particularly unpredictable.

J. Doyne Farmer and Aletta d'A Belin (1991) had enumerated the following set of properties as typical features of life:

(1) Life is a pattern in space-time, not a special material object. What matters to life is the set of patterns and relationships, not the particular atomic entity.

(2) Life has the ability to reproduce itself or at least to be reproduced. A mule, for example, is sterile, but it is also produced by breeding.

(3) Life stores information that represents itself. For example, organisms in nature store descriptions of themselves in DNA molecules that can be translated into proteins by the organisms themselves.

(4) Life has the ability to metabolize and constantly transform matter and energy in the environment.

(5) Life can functionally interact with its environment. That is to say, organisms can respond selectively to external stimuli and adapt to the environment, and they can create and control their corresponding environment.

(6) The components of life are interdependent. This interdependence maintains the unity of the organism.

(7) Life can maintain stability in the face of disturbances or can maintain its own shape and organization in a noisy environment, playing its normal function.

(8) Life has the ability to evolve. This ability to evolve is not the property of the individual organism but the property of the spectrum of the organic system.

Farmer thought that this list is far from perfect. Some organisms, such as viruses, are between living and nonliving in many ways. The "primitive organism" in some models of the origin of life is also such a "semi-active" entity. According to this list, we may also think of ecosystems and social systems as living systems. Thus, Farmer says that there is no clear-cut line between life and non-life. It is appropriate to view life in terms of a continuous pattern of organization, some of which are more or less active than others.

Cluster definitions help us distinguish between life and non-life by complementing each other with properties, which allows us to avoid over-simplifying the determination of whether a property is an essential attribute of life. However, this ability is both an advantage and a disadvantage. Because there is no unified criterion for which properties are definitive of life, the cluster definition can seem rather arbitrary. The list of properties of such definitions constantly changes, with some people having a longer list and others having a shorter one. Different people always enumerate different properties according to their own understanding.

"Fundamental property definitions" define life in terms of functional properties and primarily in terms of a few fundamental properties. Life has many properties; however, what causes these properties to come together to form the unique phenomenon of life? Cluster definitions are not particularly concerned with the relationships between properties, and do not explain why a particular set of properties should come together to produce entities such as life. The fundamental property definition attempts to overcome these defects of cluster definitions.

At present, there are four main fundamental property definitions: metabolism theory, autopoiesis theory, supple adaptation theory, and information theory.

Fundamental Property Definitions of Life

Metabolism Definition

Metabolism definition of life is a product of the application of physics and chemistry in biology. In the 19th century, with the development of physics, chemistry, and physiology, people began to regard life as a metabolic activity that can exchange matter and energy with the environment through physical and chemical means, that is, a continuous assimilation and dissimilation process of invisible components in the life system. Metabolism can now be defined as the sum of the chemical and energy conversion networks of the life system mediated by enzymes. Metabolism includes material metabolism and energy metabolism. Metabolism involves changes in the substances in organisms, including assimilation and dissimilation. Assimilation is the process by which organisms combine substances absorbed from the outside world into their own; dissimilation is the process by which organisms decompose, expel, or reuse their own substances. Energy metabolism includes two aspects: storing energy and releasing energy. Substance metabolism and energy metabolism are two different manifestations of one process. Organisms store energy in the process of assimilation and release energy in the process of dissimilation. The renewal of organic matter, the generation of physiological functions and the maintenance of ordered structures all depend on energy metabolism. A basic manifestation of living life is that its body has been engaged in material metabolism and energy metabolism. Once this activity ceases, life ceases to exist. Therefore, many people regard metabolism as the nature of life.

In the 1940s, Erwin Schrödinger (1944) further developed this viewpoint of metabolism and proposed the "negative entropy" definition of life. He believed that life is a system that relies on metabolism to face the second law of thermodynamics. His views are summarized in the following words:

> What is the characteristic feature of life? When is a piece of matter said to be alive? … It is by avoiding the rapid decay into the inert state of "equilibrium" that an organism appears so enigmatic; … How does the living organism avoid decay? The obvious answer is: By eating, drinking, breathing and (in the case of plants) assimilating. The technical term is metabolism…. [T]he essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive. (Schrödinger, 1944, pp. 74-76)

With the development of modern physics, chemistry, biology, and system science, this negative entropy theory was developed into "autopoiesis theory" in the 1970s.

Autopoiesis Definition

The autopoiesis definition of life was proposed by Humberto Maturana and Francisco Varela in 1974. This definition is a combination of the metabolic definition and the self-organization theory of systems in physical science. This definition was further developed and concretized by Gail Raney Fleischaker in 1990. "Autopoiesis" is composed of the Greek words "auto", that is, "self" and "poiesis", that is, "producing" or "making". The autopoietic system has three characteristics: self-delimitation, that is, the life system sets its own boundaries to distinguish itself from the environment or other living things; self-producing, that is, all the components of life, including its internal matter and boundaries, are transformed by the system itself; and self-sustaining, that is, the internal activities of life are continuous over time. Maturana and Varela coined the term "autopoiesis" to describe the dynamic self-sustaining and self-creating nature of life. According to Maturana and Varela (1974), and Fleischaker (1990), life needs to take in and convert energy from the outside environment to drive and sustain its own production process and keep itself out of equilibrium. The characteristic of a life system is that it can couple the internal processes of energy conversion and matter interaction and organize them into a complete process network. In this process network, all the components of the system, including the boundary membrane structure itself, can be reproduced automatically and continuously.

Specifically, the main points of the autopoiesis definition of life are as follows:

(1) The basic components of life are related biochemical processes.

(2) Each related biochemical process is organized into a network system through coupling.

(3) The network-coupled biochemical process requires a compact structure in space, i.e., enclosed within a boundary membrane structure and selectively separated within it, so that it can have integrity and individuality and can maintain itself.

(4) Within the boundary membrane structure, the biochemical process network reproduces itself through the utilization and conversion of energy and the exchange of internal and external materials.

The “auto” in “autopoiesis” refers to the biochemical process network system, that is, the whole rather than the part of the system. The realization of autopoiesis depends on the overall operation. Autopoietic systems can be metabolized in a biological sense but not in a non-autopoietic system. Proteins, viruses, cytoplasms, and genes are all part of the substance of life. When they are in animals, plants, or other cells, they may be used to maintain the autopoietic behavior of cells or tissues; however, proteins, viruses, cytoplasms, and genes themselves cannot be metabolized, and they can never be autopoietic in isolation. Metabolism involves the exchange of inorganic and organic matter (e.g., breathing, eating, and excreting) and associated energy conversion, which is a visible manifestation of autopoiesis. Autopoiesis determines the physiological process, so it is necessary for all living matter. Autopoieticentities—what we call life—must be metabolized. The exchange of substances is a necessary condition for an autopoietic system, whatever it may be.

In other words, the autopoiesis theory holds that life is a self-sustaining and self-creating production organization. This organization is holistic and indivisible in space and is continuously operated in time. A living system is a self-organizing system that can continuously self-produce its own structure.

Fleischaker (1990) argued that autopoiesis does not in principle depend on any particular material. Life may need not consist of water or proteins containing carbon, nitrogen, and hydrogen, let alone amino acids or any other particular compound. However, since all life on Earth came from a common ancestor, all life is a water-protein-nucleic acid chemical system, which has existed for more than three billion years. In this way, the autopoiesis chemical knowledge of life on Earth provides a framework for evaluating the study of life, especially the origin and evolution of life.

Supple Adaptation Theory

The supple adaptation definition of life was proposed by Mark Bedau, a professor of philosophy at Reed College in the United States. Bedau believes that in the past, we defined life in an attempt to give a consistent interpretation of our daily ideas of life, but this undertaking is not only very difficult but also doomed to failure. Because the true nature of life is just the opposite of our intuition in many ways, Bedau believes, in defining life, we should make a one hundred and eighty degree change in our thinking (Bedau, 1996; 1998).

First, the goal of the definition of life is to unify the diverse nature of existing life and solve various problems that face people when defining life. Life has diverse properties, and a good definition of life should be able to provide a unified explanation for the diverse nature of life. In addition, there are many difficult problems in defining life, and a good definition must be able to solve these problems. These problems have four main aspects: (1) There is the boundary case problem, for example, whether viruses are living systems? Are there acellular forms of life in pre-chemical soup? (2) There is the level problem, i.e., what is the highest level at which the concept of life can be applied? We can undoubtedly consider cells, tissues, organs, and organisms to be living systems, but are ecosystems and biosphere also living systems? (3) Is the nature of life material or formal? On the one hand, all life on Earth is related to organic molecules containing carbon; on the other hand, the nature of life seems to lie primarily in processes and properties rather than in matter. So, which is the most fundamental? (4) There is a problem with the relationship between life and mind or intelligence. In the real world, different animals, their intellectual levels and their complexity have a certain correspondence. What is the relationship between life and mind? Must mind be based on life? Bedau (1998) believed that a good definition of life should solve all these proposed problems.

Second, Bedau believes that the definition of life should focus on the phenomenon of life, not on our intuitive knowledge of life; attention should be paid to the process of life phenomena rather than to individual living organisms. The process of life phenomena is at the center of focus. Process provides a unified explanation of the phenomena of life. Based on this consideration, Bedau argues that definitions of life should focus on a group of organisms rather than on the individual organism. That is to say, the starting point to defining life should not be the nature of individual life but the system of organism.

From the perspective of organism groups, Bedau (1996) argued that the underlying principle for explaining the unity of diversity of life seems to be the flexibility of adaptive process of life: its enduring ability to produce novel solutions to problems of survival, reproduction, or, more generally, unforeseen changes for prosperity (p. 338). In other words, the essential characteristics of life are revealed in the process of evolution. Bedau says that this view was advocated before him, but these advocates did not make it clear that this definition of life was new. For example, the famous evolutionary biologist Maynard Smith (1975) once said:

> We shall regard as alive any population of entities which has the properties of multiplication, heredity and variation. The justification for this definition is as follows: any population with these properties will evolve by natural selection so as to become better adapted to its environment. Given time, any degree of adaptive complexity can be generated by natural selection. (p. 96)

Cairns-Smith (1985), who also stressed the role of adaptation in evolution, said: Without natural selection,

> living things could not even stay adapted to a given set of circumstances, never mind become adapted to new ones.… That kind of in-built ingenuity that we call "life" is easily placed in the context of evolution: life is a product of evolution. (p. 3)

On the basis of these people, Bedau clearly regards this infinite and constant adaptation of biological communities to new circumstances as the nature of life. Living systems in group can always respond to new types of environmental challenges with new adaptations. An evolutionary arms race is a simple and supple adaptation. However, if an adaptation is a fixed adaptation, then it is not a supple adaptation because it can adapt to only the old environment; in the face of a new unprecedented environment, it cannot adapt to change. The adaptive challenges of supple adaptation are often open, unforeseen and novel.

Bedau believes that there are two types of life forms: basic life forms, which are supple adaptation systems and derived or subordinate life forms, which are living primarily because they have an appropriate relationship with the first form of life. Thus, Bedau defined living systems as follows:

X is a living system if and only if:

(1) X is a supple adaptation system;

(2) X is associated with supple adaptation systems in an appropriate manner (Bedau, 1998).

According to this definition, the basic form of life is an evolutionary population of organisms, a number of populations of all evolutionary ecosystems, or, in the final analysis, an entire evolutionary biosphere of many interacting ecosystems, which is a basic supple adaptation system. Individual living systems, organs, cells, and so on are regarded as living because they are related to the supple adaptation system in an appropriate way. They are dependent forms of life that are generated and supported by supple adaptation systems.

Bedau believes that his definition has several advantages. First, this definition provides a unified interpretation of the diversity of life. For example, because living systems are supple adaptive systems, in the course of history they have produced very complex adaptive organizations, historically interrelated organisms with genetic programs. Random changes in supple adaptation explain why biological processes are particularly unpredictable and why life systems are made up of highly variable distinct groups of individuals.

Second, Bedau believes that his definition of life can solve various historical problems facing the concept of life. For example, with regard to the continuity between life and non-life, previous definitions required us to make either-or choices between life and non-life. Supple adaptation theory can avoid this dichotomy. Because of the varying degrees of suppleness, there is no clear-cut line between life and non-life. Different systems can show different supple adaptations, and the supple adaptation level of a given system can also change with time. Because the supple adaptation level of a system is measurable, we can judge whether a system is alive and how much it lives according to the supple adaptation level. Viruses, frozen sperm, dormant seeds, and so on can be regarded as straddling the boundary between life and non-life. When they are isolated, they lose contact with supple adaptation systems and are therefore inanimate; however, when their connection to supple adaptation systems is re-established, they return to the “kingdom” of life. For the hierarchy of life, according to the basic forms of life and derived forms of life, this is inevitable; that is to say, life can appear at different levels, and different levels contain different but related forms of life. Ecosystems and economic systems can be regarded as living systems. For the question of whether the nature of life is material or formal, Bedau’s answer is that it is form. Supple adaptation can be realized in multiple ways; that is, a given adaptation can be realized via different material bases. Therefore, for life, what is important is form. Regarding the relationship between life and mind, Bedau believes that the flexible and adaptive concept of life reveals the unity between them in a deeper sense. All forms of life must cope with the complex, dynamic and unpredictable environment, as do all forms of mind. Therefore, the nature of life and mind is supple adaptation, but the latter is a much higher form of life than the former.

Bedau provides an influential theory of the nature of life. However, the athor thinks Bedau’s definition is flawed. First, Bedau’s definition of life is obviously counterintuitive. Bedau asked people to change their minds, to see the group as the basic form of life, and to see the individual as a subordinate form of life. This reversal is simply unacceptable to many. Generally speaking, individual life is the basic form of living systems, and group life is based on individual life. Although we can say that social and economic systems have “vitality”, the claim is merely metaphorical. We cannot therefore regard these systems as living in and of themselves, let alone as a more fundamental form of life. Even if Bedau is right and group life is the basic form of life, because groups vary from small to large, which group is the most basic form of life? Bedau did not answer this question but rather vaguely claimed that supple group systems are the basic forms of life and did not explain which level constitutes the most basic forms of life. It is not enough for us to say in general that supple adaptive systems are basic forms of life.

Second, Bedau said that life arise via a proper relationship with a supple adaptation system. What kind of relationship is "appropriate"? Bedau did not answer. He only generally claimed that a "proper relationship" with a supple adaptation system is required but did not provide a clear picture of that relationship. Bedau's answers to certain questions were casual. Individual living systems, such as mules, arise from mating relationships within supple groups: horses and donkeys. Obviously, this relationship is reproductive, although the mule itself will not reproduce in the future. The top-level ecosystem is no longer a supple adaptive system by Bedau's definition, but Bedau argues that we cannot say it is inanimate; because they evolved from supple adaptation systems, they are alive. Here, the ecosystem, which should have been the basic form of life, has become a derived form of life. Since we cannot clearly determine what kind of relationship is "appropriate", Bedau's definition becomes arbitrary. Different people may tell different relationship stories in claiming something to be alive.

Information Definition of Life

The author intends to propose an information definition of life, as it emphasizes the role of information transmission in the process of living and reproduction. An entity is alive if it has an autopoietic ability to sustain, develop and/or reproduce itself under the control of information stored in it. Maturana and Varela (1974) rightly emphasized the autopoietic characteristics of life, but wrongly neglected and even negated the information characteristic of life. The author combines these two characteristics together and believes that living systems are autopoietic information systems that can maintain, develop, and/or reproduce themselves under certain environment. For every individual life, self-sustaining and developing are important for living. Some lives cannot reproduce themselves, but can maintain and develop themselves; examples are mules and sterile animals. But as we can see, self-reproduction is most important for the continuing of life. Without self-reproduction, life will stop. Self-reproduction allows entities to reproduce themselves. As John von Neumann (1966) had shown, self-reproduction systems are information systems. On the one hand, the self-reproduction information contained in this system can play a role similar to that of a computer program. During the production of the next generation, its expression results in a new but basically identical individual. On the other hand, it can also play the role of passive data, which can be transmitted to the next generation almost invariably during reproduction.

The discovery of the double helix structure of DNA in the 1950s and the subsequent understanding of its mechanism of action have deepened people's understanding of the informational nature of life. Many phenomena in life are related to the double helix structure of DNA molecules. DNA has just two functions: carrying biological information in that it contains a basic description of the structure of life, and its expression produces various properties of organisms; serving as a template for gene replication in that it can produce a copy identical to itself and pass it on to the next generation.

In the past, when people talked about the nature of life, they paid attention to only the source of the "aliveness" of life, so they often emphasized changes in the matter and energy of life because these lead to the expression of the aliveness of life. However, without the guidance of information, the metabolism of life will soon stop. For example, assimilation and dissimilation of living organisms is guided by genetic information. Different organisms may be engaged in material and energy metabolism, but each organism can orderly produce its own unique life matter. Cows eat grass to produce cow's milk, sheep eat grass to produce sheep's milk, and there will be no cow's milk from sheep or sheep's milk from cows unless people genetically engineer cows or sheep's gene. Why does this happen? The discovery of the genetic code led people to realize the different genetic information contained in different organisms is the cause of their difference.

Nucleic acid, the carrier of genetic information, and protein, the basic component of biological characters, have corresponding relationships in structure. This correspondence is shown in the fact that the nucleotides of each of the three nucleic acids can correspondingly determine the amino acids of the structural units of a protein. The triplet structure of this nucleotide is called a genetic code or codon for short. There are 64 codons in biology. They are start codons or stop codons or they determine one of the 20 amino acids that make up the protein. In the process of development and heredity, parents replicate their own DNA and pass it on to their offspring intact. The progeny uses the same DNA as the parent as the template to synthesize protein so that the characters of the progeny are consistent with those of the parent. Progeny do not obtain traits directly from their parents but rather obtain signals that control development, i.e., genetic information.

Biogenetic information guides metabolism, and many processes in life are now found to be essentially information processes, such as the processes of biological growth and development, biological immune response, biological response to external stimuli, neural signal transduction, biological variation and evolution, etc. Although the external process involves a change in matter or energy, the essence is under the guidance of the information process.

Evolution is actually the change of biological genetic information. There are three basic conditions for the genesis of evolution: heredity, variation, and natural selection. Heredity involves the transmission of parental information to offspring during reproduction. Variation involves accidental changes in genetic information during the process of inheritance, resulting in differences in traits between offspring and their parents. It has long been known that there is excessive multiplication in the biological world; that is, every organism reproduces very efficiently if it is not controlled. Every living thing needs to obtain all its requisite resources from the environment. Nature's resources are limited. When a large number of breeding organisms appear in the same geographical region, due to limited natural resources, these organisms must compete for survival. Because there are variations (heritable variations) in the process of inheritance, each organism's chance of survival varies. Competitive organisms will be preserved by natural selection, while disadvantaged organisms will be eliminated by natural selection. Such a process continues in nature, leading to greater numbers of well adapted and highly integrated organisms and evolution occurs. The evolution of living things would have been impossible without heritable variations. Heritable variation is essentially an information process, so the essence of evolution is actually the change of biological genetic information under the action of natural selection.

In demonstrating the advantages of Bedau's definition of life, an important argument is that it can offer a unified explanation of the pluralistic characteristics of living phenomena, but the cost of this unity is that individual living systems are considered subordinate to basic group adaptation systems. As has already been analyzed, this counterintuitive definition makes it possible to view many systems, and even works of art constructed by people, as primary living systems because we can construct artistic works, such as fiction, through a supple system of adaptation. Therefore, Bedau's definition of life is ultimately absurd. However, the information definition of life can also explain the pluralistic characteristics of life in a unified way and can provide a more natural explanation of the pluralistic characteristics of life.

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