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Exploring Life's Boundaries: Biosemiotics and the Challenge of Defining Life

Original Study

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Abstract: This article addresses the challenges of defining life by combining insights from biological and semiotic perspectives. It explores the lexicographic complexity of defining life, analysing how definitions vary across scientific and philosophical contexts and how these definitions are shaped by cultural and ideological influences. The study highlights the importance of semiosis as a fundamental characteristic of living organisms, positioning biosemiotics as a fundamental framework for understanding life beyond mechanistic models, but also semiotics as a tool for unravelling scientific narratives. Historical and contemporary intentions to define the minimum threshold of complexity for life, highlighting how these efforts have evolved over time and their implications for modern biology. By examining different perspectives on the phenomenon of life and its intermediate forms, the article offers a critical and interdisciplinary approach to understanding life as a semiotic and interpretive process.

> The fact that an everyday concept of life is richer than the biologic concept of life (in the sense of a greater semantic flexibility and its encompassing character of embracing normative, emotional, sacred, and other aspects of life) may lead us to pose a contra-factual question: Could other notions of life have become basic for biology had it not been developed in the shadow of a hegemony of a mechanicist ideal of science during the 19th and 20th centuries; i.e., could life have become conceived of as something different from merely complex organizations of material particles and their energetic relations? (Emmeche 1998: 4)

Key words: Biosemiotics; Complexity; Life; Threshold.

INTRODUCTION

The concept of life is ubiquitous in everyday discourse, yet its definition remains one of the most elusive and debated topics in both scientific and philosophical realms. From discussing our personal lives, life projects, and daily struggles, to the fight for the right to life and the care of animal and plant life, the term "life" encompasses a broad and diverse array of meanings. This semantic breadth poses significant challenges in arriving at a precise and universally accepted definition. Over the years, various types of definitions have been proposed to capture the essence of life, including lexical, stipulative, and operational definitions (Churchill 1986, 1990; Gupta 2015).

A lexical definition explains the meaning of a word as it is currently used and recorded in dictionaries. A stipulative definition assigns a specific meaning to a word within a particular context to clarify arguments or discussions, representing an explicit decision to use the term in a certain way. Stipulative definitions can be judged as more or less useful or clear but not as true or false. Operational definitions, commonly used in experimental sciences, establish the meaning of a term by linking its correct use to some observable condition. Scientific definitions of life are typically stipulative, with some extending lexical definitions by adding descriptions for use by specialists, while others aim to capture only the essential perceived characteristics of life. The most valuable definitions often strive to include the origins of life. Many definitions are a combination of these types.

In the broadest sense, life is the property or condition of material systems (living systems) characterized by a high degree of organization and complexity, with the cell being the fundamental unit. These systems, ranging from unicellular organisms to the most evolved multicellular organisms, consist of numerous subsystems or organs that function together to form a unique whole, referred to as a living individual or organism. Such systems exhibit capabilities for growth, development, autonomous movement, self-regulation, metabolism, adaptability, reactivity, and especially reproduction, whether asexual or via sexual cells (gametes). The concept of life has been unified by the theory of evolution through natural selection, originating from inanimate matter to form organized structures capable of development and reproduction, leading to the vast diversity of species observed today. The debate remains open, however, on whether entities like viruses, which cannot reproduce autonomously and depend on a host cell, should be considered living beings.

The apparent contradiction between the increasing organization and differentiation of living systems and the spontaneous tendency of physical-chemical systems towards disorder is resolved in modern thermodynamics of irreversible processes. Living systems are viewed as open systems, maintained far from equilibrium through continuous exchanges of energy and matter with the environment, where the growth in entropy of the surroundings compensates for the decrease in entropy within the system.

Starting from this discourse that use the everyday use of the reference to life as something self-evident and the scientific semantics that biologists and philosophers are looking for, we will propose a semiotic reading of the notion of life and its construction. The purpose is to show the difficulty in defining and interdefining[1] life based on its biological characteristics without considering the cultural and ideological ground. The first section will circumscribe the problem and challenge of defining life from a semantic perspective presenting a corpus of text about the definitions. By mapping the attempts, it will trace briefly the history of philosophy that has tried to create a discourse on life, moving from vitalism to mechanism to complexity theories. The idea is not to retrace the entire history of those who have tried to define life but to show the stratifications and discourses on life, illuminating the differences and difficulties. The second section will introduce the topic of the semiosis of life from a biosemiotic perspective. The challenge facing contemporary biosemiotics presents itself as one of the most profound and difficult challenges that the field of semiotics can investigate. It will be problematised that the idea of co-extension between life and semiosis only holds if one can understand how far what is called life by biosemioticians extends. This has pragmatic repercussions for what we consider living in today's discourses. The third section will investigate the minimum threshold of complexity, briefly interpreting one of the most fascinating stories that physicist Stuart Kauffmann has told us about the origin of life. In this short story, the discovery of DNA and the empirical experiments that tried to reproduce life will be retraced. This chapter it will emphasise how the notion of life is in fact a construct, a conceptual negotiation that emerges from a series of ideologies that underlie the discourses that seek to answer: "What is life?". In conclusion, the scope of the article is to show the difficulties and future challenges in trying to circumscribe life. This task now falls to biosemiotics, which, however, must keep a watchful eye on the construction of discourses about what is life and what is not. Only an attentive semiotic analysis can present itself as a serious critique of ideologies, showing what the limits of life and non-life discourses are.

1. THE LEXICOGRAPHIC COMPLEXITY OF DEFINING LIFE: A SEMIOTIC PERSPECTIVE

The term "life" seems impossible to define without shifting from *what it is* to how it is composed and what it produces. Numerous definitions have been proposed over the years, with a notable collection of 95 definitions from 1855 to 2002 curated by Popa in 2004, and a more recent compilation of more 77 definitions from 1871 to 2002 by the same author in 2014. Additionally, a study by Pályi and colleagues in 2002 reported another 78 definitions from 1999 to 2000. Despite this extensive array of proposals, no definition has achieved universal consensus. Each definition captures some fundamental aspects of life but fails to encompass all its elements comprehensively. Attempts have been made to create minimalist definitions of life, as highlighted by Trifonov in 2011, and universal definitions applicable to extraterrestrial life, as proposed by Ruiz-Mirazo and collaborators in 2004. Many inclusive definitions describe the actions of life but do not precisely define what life itself is.

The ability to define life is closely tied to our understanding of its origins, a topic that remains controversial (Peretó 2005). There exists a philosophical puzzle regarding our insufficient knowledge of the theory of life to provide a definitive definition (Cleland & Chyba 2002, 2007). Currently, the most utilized definition is NASA's: "Life is a self-sustaining chemical system capable of undergoing Darwinian evolution" (definition by Gerald Joyce cited in Popa 2004, 2014). However, a comprehensive definition should also address borderline cases, such as viruses. Villarreal (2004) suggests that viruses occupy

1 The term "interdefining" in semiotics refers to the mutual definition of elements within a semiotic system. It implies that the meaning of each sign or element is defined in relation to the other elements in the system, creating a network of interdependent meanings. This concept aligns with the idea that signs do not exist in isolation but derive their meaning from their relationships to other signs within a particular context or framework.

a twilight zone of life, challenging the very boundaries of its definition.

In attempting to define life, scholars often focus on a set of common properties shared by all living beings, including chemical components, thermodynamic properties, metabolism, compartmentalization via a semi-permeable membrane, reproduction, and replication (Gayon 2010). These elements form a catalogue of fundamental characteristics present in all known forms of life, outlining a basic structure that defines the concept of "life". Identifying these shared characteristics is crucial for understanding the foundations of life and delineating the boundaries between what is living and what is not.

Historical conceptions of life significantly influence contemporary definitions. These include life as animation (Aristotle), life as mechanism (Descartes), and life as organization (Kant) (Gayon 2010). Contemporary definitions often reflect these historical perspectives. Philosophical views on life provide a broad and complex framework that deeply influences the process of defining it (Popa 2010, 2014; Švorcová 2024). Holism or generalism embraces the idea of life as a collective property, considering not only its tangible manifestations but also its deeper functions and purposes. Conversely, reductionism or minimalism seeks to explain life by reducing it to fundamental mechanisms and minimal forces, aiming to unravel the most basic functioning of what life is. Another perspective, vitalism and spiritualism, attributes life to esoteric forces or supernatural will, beyond empirical observation and rational understanding[2]. While contemporary science generally rejects these views, they sometimes subtly and indirectly influence modern thinking about life. For example, the concept of *élan vital* can be rephrased to avoid vitalistic connotations, such as the spontaneous emergence of organizational complexity[3]. This represents an attempt to adapt traditional philosophical concepts to the demands and sensitivities of modern science. Finally, mechanistic reductionism and dialectical materialism conceive of life as a phenomenon entirely determined by natural laws, with no room for supernatural forces or non-material elements. These conceptions, rooted in the logic of physical laws and the dialectic of evolution, also permeate scientific definitions of life, reflecting a rigorous and deterministic worldview.

Tsokolov's (2009) essay "Why Is the Definition of Life So Elusive? Epistemological Considerations" explores the conceptual labyrinth of defining life. Through meticulous analysis, the author highlights the intrinsic challenges and ambiguities in attempting to circumscribe the concept of life. One primary obstacle is the use of ambiguous or poorly defined terms in defining life. Concepts like "complexity" and "self-organization" may be intuitively understandable but remain elusive in precise definition, causing confusion and uncertainty in delineating the boundary between what is alive and what is not. Definitions of life often come in the form of lists of characteristics common to living beings. However, these descriptions can be limited and not always exhaustive (Capra, Luisi 2014). Characteristics such as nutrient and energy intake from the environment, metabolism, reproduction, and others may be included, but terms that are neither necessary nor sufficient to define life accurately can also be present.

Tsokolov also addresses the concept of "minimal life", imagining a living cell reduced to its essential properties for survival. If any of these properties are missing, the system is not considered living. However, as more properties emerge, the system becomes more complex and surpasses the threshold of minimal life. This concept presents an additional challenge in defining the boundaries between what is living and what is not, as these boundaries can be arbitrary in the evolutionary scale from inanimate matter to life. Tsokolov explores the notion of "arbitrarily alive life", applicable to borderline cases where it is difficult to determine whether a system is truly living. This notion further underscores the complexity and nuance inherent in defining life, highlighting the need for a prudent and aware approach in attempting to define one of the most fundamental and fascinating concepts in science and philosophy.

Vera M. Kolb (2019), in her chapter "Defining Life: Multiple Perspectives", offers a series of definitions that capture various aspects of life. For instance, a lexical definition from Merriam-Webster describes life as "the quality that distinguishes a vital and functional being from a dead body"[4], among other characteristics. Another definition views life as a system capable of self-organization, self-replication, and evolution through mutation, metabolism, and encapsulation. Other definitions highlight the thermodynamic and chemical requirements, the flow of energy, matter, and information, or the ability to undergo Darwinian evolution (as NASA's working definition).

To map out the semantics of the various terms in 2011, Edward N. Trifonov published two tables (Fig. 1 and Fig. 2) within the article "Vocabulary of Definitions of Life Suggests a Definition", published in the *Journal of Biomolecular Structure & Dynamics*. Table I presents the vocabulary of words used in Barbieri's (2003) set of 60 definitions and Popa's (2004) collection of 90 definitions. The total non-redundant size of the two collections is 123 definitions. Words that appear more than 4 times in the collections are presented in Table I. "Life", as *definiendum*, is at the top of the list. Inspection of the list reveals that frequent words include those closely related to the group

2 Vitalism's research was not just the flawed version of adding a *plus* to the matter, which we often find in contemporary narratives, but an actual research program. Unlike Reviewer 2, who suggests that vitalism was a "fully fledged research program that failed because its explanations did not pass empirical testing", we strongly argue that vitalism is still very much alive in direct or indirect ways in many discourses. (See Magnus 2008; Donohue, Wolfe 2023).

3 As reviewer one correctly points out, the notion of "agency", especially in biosemiotics, also fulfils this role of avoiding vitalism while referring to the same concept.

4 Merriam-Webster's Collegiate® Dictionary, Tenth Edition, 1993, cited in (Kolb 2019: 59)

"life" (such as "living", "alive"). This suggests the combination of various words into groups based on their common meaning. Table II displays several such groups, at the top for their scores. Words from each group are present in at least 30% of the analysed definitions. The smaller groups (not shown) contain, essentially, only words with the same root (e.g. definition, defined, define, etc.). Therefore, the consensus on the definition of life derived from these nine definitions would be: Life is [System, Matter, Chemistry (Metabolism), Complexity (Information), (Self-) Reproduction, Evolution (Change), Environment, Energy, Ability] where the square brackets correspond to some compact expression containing the words listed within. The consensus derived from these definitions suggests that life is a system characterized by matter, chemistry (metabolism), complexity (information), self-reproduction, evolution (change), environment, energy, and certain abilities. This consensus provides a comprehensive and compact expression of the diverse terminologies used to define life, emphasizing the intricate and multifaceted nature of this fundamental concept.

In this context, we are not trying to investigate what the result of having a conceptual consensus is or where we find such a consensus in philosophy or linguistics. Instead, we are using the broad attempt to make use of the notion of life as a narrative instrument to show that when we talk about "life" we still do not know what we are talking about. Beyond these questions, we must assert that this perspective is situated in an attempt to universalise the experience of Western philosophy, always

Table I

List of most frequent words in the definitions of life.

Life	123	Organic	11	Internal	7	Capacity	5
Living	47	Alive	10	Replication	7	Different	5
System	43	Evolution	10	Being	6	Force	5
Matter	25	Materials	10	Change	6	Form	5
Systems	22	Reproduction	10	Characteristics	6	Functional	5
Environment	20	Existence	9	Entity	6	Highly	5
Energy	18	Defined	8	External	6	More	5
Chemical	17	Growth	8	Means	6	Mutation	5
Process	15	Information	8	Molecules	6	Necessary	5
Metabolism	14	Open	8	One	6	Network	5
Organism	14	Processes	8	Order	6	Objects	5
Organization	14	Properties	8	Organisms	6	Only	5
Complexity	13	Property	8	State	6	Organized	5
Ability	12	Reproduce	8	Things	6	Reactions	5
Itself	12	Through	8	Time	6	Self-reproduction	5
Able	11	Complex	7	Way	6	Some	5
Capable	11	Evolve	7	Based	5	Three	5
Definition	11	Genetic	7	Biological	5		

Fig. 1 *List of most frequent words in the definition of life (Trifonov 2011: 260)*

Table II

Groups of words with similar meaning.

LIFE	123	**COMPLEXITY**	13
living	47	information	8
alive	10	complex	7
being	6	other related words	46
biological	5	Sum	**74**
other related words	8	**REPRODUCTION**	10
Sum	**199**	reproduce	8
SYSTEM	43	replication	7
systems	22	self-reproduction	5
organization	14	other related words	33
organism	14	Sum	**63**
order	6	**EVOLUTION**	10
organisms	6	evolve	7
network	5	change	6
organized	5	mutation	5
other related words	40	other related words	20
Sum	**155**	Sum	**48**
MATTER	25	**ENVIRONMENT**	20
organic	11	external	6
materials	10	other related words	15
molecules	6	Sum	**41**
other related words	36	**ENERGY**	18
Sum	**88**	force	5
CHEMICAL	17	other related words	17
process	15	Sum	**40**
metabolism	14	**ABILITY**	12
processes	8	able	11
reactions	5	capable	11
other related words	26	capacity	5
Sum	**85**	other related words	1
		Sum	**40**

Fig. 2 *Groups of words with similar meanings (Trifonov 2011: 261)*

bearing in mind that numerous cultures define life and the living in other cosmological perspectives. Just think of the ontological turn in anthropology, where the living for multiple indigenous peoples can be subsumed in a stone, a mountain, a river, a sacred object (Descola 2013; Kohn 2013; Ingold 2018).

From a semiotic perspective, these attempts to clearly distinguish between what is living and what is not (Fig. 3) reveal, in fact, a strategic and narrative move that underscores how this distinction is not self-evident. As we have shown, the primary task of any scientific endeavor is the creation of a *taxonomic discourse* that defines and organizes the objects of knowledge within a given discipline (Latour, Woolgar 1986). For Greimas (1976), scientific discourse constructs its own objects – a semiotic objects – and it is this construction, along with the syntactic and semantic organization of these objects within a specific universe, that characterizes a field as a science. Thus, rather than being a given, the semantic universe is the very project of scientific practice.

Table 2.1. *The game of the two lists*

List of the living	List of the non-living
Fly	Radio
Tree	Automobile
Mule	Robot
Baby	Crystal
Mushroom	Moon
Amoeba	Computer
Coral	Paper

Question:
What discriminates the living from the non-living?

In other words:
What is the quality (or qualities) that is present in all members of the "living" list and that is not – and cannot be – present in any of the elements of the "non-living" list?

Fig. 3 *Approaches to the definition of life (Luisi 2006: 24)*

Tables and images in scientific texts serve as important visualization tools with two primary functions in argumentation (Bastide 1985). First, they provide *selection*, guiding the reader's focus toward specific aspects of the image or data, thereby directing attention and building competence through accompanying captions or visual aids. Second, they create *contrast*, differentiating relevant elements and highlighting key information through semi-symbolic systems, making the image or data more legible and comprehensible.

From a semiotic perspective, these tools act as strategic devices employed by the author-scientist (or *Enunciator*), forming part of a textual apparatus designed to communicate certain aspects of the scientific discourse to the reader-scientist (or *Enunciatee*). Specifically, in discussions about the concept of life, tables that distinguish between living and non-living entities play a narrative and enunciative role, helping structure the scientific argument by visually delineating categories and contributing to the overall interpretative process (Burgio, Raffaetà 2024). This dual role of tables as both narrative and semiotic devices underscores their importance in organizing and conveying complex scientific information efficiently.

2. LIFE AND SEMIOSIS: THE INTERSECTION OF BIOSEMIOTICS AND THE DEFINITION OF LIFE

The challenge of defining life has profound implications for contemporary biosemiotics, a field that posits life and semiosis as coextensive phenomena (Sebeok 1991)[5]. Biosemiotics explores the production, action, and interpretation of signs in biological contexts, suggesting that semiosis – or the process of meaning-making – is intrinsic to all living systems. This perspective introduces a new dimension to the longstanding debate on the definition of life, proposing that understanding the boundaries of life is inherently tied to understanding the boundaries of semiosis.

Biosemiotics, drawing on the semiotic theories inaugurated by Charles Peirce, extends the concept of sign processes to the biological realm through Jakob von Uexküll's theory of the umwelt, with a Peircean interpretation through the sign-vehicle. It posits that life itself can be viewed as a complex system of sign relations, where living organisms continuously interpret and respond to environmental cues. According to biosemiotic theory, all living systems – from the simplest bacteria to complex human beings – engage in semiosis. This implies that semiosis is not just a characteristic of life but a defining feature. However, this raises a significant epistemological question: if semiosis is coextensive with life, how do we determine where life – and consequently, semiosis – begins and ends? Traditional definitions of life, as discussed previously, struggle to provide a comprehensive and universally accepted boundary. This ambiguity extends to the realm of biosemiotics (Zengiaro 2024), complicating efforts to delineate the scope of semiosis.

The biosemiotician Claus Emmeche (1998) presents in the article "Defining life as a semiotic phenomenon" several key ideas about the concept of life and its scientific interpretation:

1. Unity of knowledge: the concept of life in biology might support the principle of unity of knowledge, suggesting that a general understanding of science is essential.
2. Artificial Life and biosemiotics: artificial life aims to make theoretical biology universal by explaining life in any form.

5 According to my historiographical research, the proposition "life and semiosis are coextensive" does not appear in any of Sebeok's official writings. It seems to be an adaptation of one of his remarks during a conference held on October 1, 1990, at the Hungarian Academy of Sciences in Budapest (Deely 2006: 22), or possibly a synthesis by an author based on his earlier propositions.

Biosemiotics, on the other hand, proposes viewing life as a semiotic phenomenon, based on the interpretation of signs, where a sign can be a physical entity representing something in a living context.

3. Interdisciplinarity: analyzing life as the functional interpretation of signs in self-organized material systems supports the idea that biology can benefit from interdisciplinarity and the search for universal principles through computational models and semiotic approaches.
4. Origin of order and conceptual autonomy of biology: understanding the origin of order in the universe and the emergence of biological organization requires a unified approach that integrates historical and physical causality. Special principles of organization, like the genetic code, can give biology conceptual autonomy and grant organisms a unique mode of existence.
5. Pursuit of a unified narrative: science should aim for a unified narrative of the evolution of the universe, life, and mind, informed by semiotics and philosophy. Discovering new laws of self-organization and evolution could reshape our view of the cosmos in a more "organic" direction.
6. Normativity and semiotics: the quest for a unified understanding of the world is a normative pursuit. If a coherent worldview is to be evolutionary, then understanding the emergence of normativity and normative concepts of life among humans should be achievable, even if imperfect.

The idea that life and semiosis are coextensive suggests that wherever there is life, there is semiosis, and vice versa. This perspective aligns with the view that life is characterized by the capacity for information processing, communication, and interpretation – core elements of semiosis. Biosemioticians argue that living organisms, at every level of complexity, engage in sign processes essential for survival and adaptation but also choice and subjective present (Kull 2018; Favareau, Kull 2024). For example, cellular processes such as gene expression can be viewed through a semiotic lens, in which DNA sequences act as signs interpreted by the cellular machinery to produce specific proteins (Barbieri 2024). This view, which is not shared by all biosemioticians, challenges traditional definitions of life that focus exclusively on physical and chemical properties such as metabolism, growth, reproduction and homeostasis. Paradoxically, by incorporating semiosis, biosemiotics provides a more nuanced understanding of life that encompasses the informational and interpretive dimensions essential to living systems.

Despite its integrative approach, biosemiotics faces the same fundamental challenge as other definitions of life: determining the precise boundaries of what constitutes life (Hoffmeyer 1996, 2008; Kull 2007a, 2007b). The problem of defining life is not merely academic but has practical implications for various fields, including astrobiology, synthetic biology, nanotechnology, and medicine. If we cannot definitively circumscribe what is alive (which is at the same time a different issue from what is life), we also cannot determine where semiosis begins and ends. This challenge is exemplified in the case of viruses. Viruses exhibit some characteristics of living organisms, such as the ability to evolve and replicate, but lack others, like autonomous metabolism and cellular structure. In biosemiotic terms, viruses participate in semiosis by encoding genetic information and interacting with host cells. However, their dependency on host machinery for replication raises questions about their status as autonomous living entities. Consequently, the inclusion or exclusion of viruses from the realm of life affects our understanding of where semiosis occurs.

The unresolved issue of defining life has significant implications for biosemiotic theory. If the boundaries of life remain ambiguous, so too do the boundaries of semiosis. This uncertainty necessitates a flexible and inclusive approach in biosemiotics, acknowledging that our current understanding of life and semiosis may evolve with new scientific discoveries. Furthermore, biosemiotics must grapple with the philosophical implications of its claims. If life and semiosis are truly coextensive, this suggests that the emergence of life is inherently tied to the emergence of sign processes. This perspective invites further exploration into the origins of life and the nature of semiosis, potentially reshaping our understanding of both phenomena.

In a recent interview between Kalevi Kull and Winfried Nöth (2020), fascinating ideas about the semiotics of viruses emerged in which Kull proposed an important conclusion: the behaviour of viruses is based on habits, these habits are forms of semiosis and viruses, within cells, participate in semiosis processes. These observations lead us to revise our understanding of the lower threshold of semiotics (Rodríguez Higuera, Kull 2017; Lacková, Faltýnek 2021), as formulated by Umberto Eco (1976). Eco introduced a useful concept, but did not analyse organic systems in detail, as he was not a biologist. Consequently, he could not determine whether neural, immunological or simple organic systems are above or below the semiotic threshold. He remained open-minded on this point, finding Giorgio Prodi's (2021) approach worthy of discussion. However, if talking about the "lower threshold of semiotics" still makes sense, it is necessary to do so by thinking of it as a political limit that the tools of the discipline do not yet have the maturity to move without threatening the specificity of its domain.

Today, we understand that the lower threshold should not be seen as a sharp dividing line, but as a boundary zone (Kull 2009). Semiosis appears and disappears, while cells (the minimal organism) maintain the conditions for the reappearance of semiosis. Only for the permanence of semiosis, i.e. consciousness, might a brain be necessary. It is important to note that the definition of semiosis used by Kull differs slightly from that of Charles S. Peirce. Contemporary biosemiotics draws many ideas from Peirce, but they are not always in perfect agreement with this model (Japply 2023; Lacková 2023; Švorcová, Lacková, Fulínová 2023). One of the main claims of biosemiotics is the connection of semiosis with life, which in its radical form suggests that semiosis is co-extensive with life and implies that the lower threshold of semiosis is life. This directly contradicts Peirce's universal synechism since despite possible gradualism there is no ultimate term in the chain of meanings expressed in the universe. Indeed, many biosemioticians suggest that semiosis is an emergent process (Kull 2024). By adopting a biological approach, however, this threshold becomes evident again.

This difference is crucial to understanding the virus ability to induce their own reproduction making them potentially dangerous, especially when conditions change. However, it is possible for viruses to learn something new through semiosis, but this can only happen within a living cell. This learning process could contribute to uncontrolled outbreaks. Ultimately, the discussion between Kull and Nöth invites to rethink the semiotics of viruses, not only in terms of logic and computation, following Peirce's ideas, but also considering biological and existential aspects. This holistic approach helps us to better understand the complexity of viruses and their potential impact on life. The problem of defining life is intricately linked to the biosemiotic view that life and semiosis are coextensive. As long as the boundaries of life remain indeterminate, the question of when and where semiosis begins and ends will also remain unresolved, if not understood as zones that amplify and overlap (Zengiaro 2023). This interplay between life and semiosis underscores the complexity of these fundamental concepts and highlights the need for ongoing interdisciplinary research to refine our understanding of the living world.

3. THE MINIMUM COMPLEXITY THRESHOLD OF LIFE: THE BRIEF HISTORY OF ATTEMPTS TO DETERMINE LIFE

When exploring the origins of life, it is crucial to recognize that every experiment and hypothesis in this field relies on a narrative framework, which contains both consistencies and inconsistencies. These narratives are constructed through a process of fitting pieces together and making adjustments. Authors who claim with certainty that life began 3.45 billion years ago in a searing world are essentially telling a story that relies on the trust of their audience – similar to many scientific narratives. Currently, it is important to acknowledge that no one can reconstruct with absolute certainty the historical sequence of events that allowed early molecular systems to evolve and self-replicate three billion years ago. However, this does not imply that we should abandon the attempt to trace a historical pathway, despite its mysterious nature. The theory of the origin of life, although still open, has made significant strides in developing structured theories and experiments aimed at demonstrating how life could have originated.

As Stuart Kauffmann recounts in his book *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*, life emerged on Earth as soon as the meteoric masses forming the proto-Earth began to settle, allowing the surface to cool enough for liquid water to be present. It is from this liquid water that chemicals combined to produce organisms with metabolic activity. The question of the origin of life has undergone substantial transformations over the centuries due to the historically situated interpretation of scientific and philosophical discoveries. Initially, in the West, most scientific thinkers believed that life formed spontaneously from inanimate material. This belief stemmed from observations that life seemed to appear from nowhere in decaying organic matter, such as fruit, rotten wood, and mould.

Modern theories of the origin of life began to take shape over a century ago, starting with Louis Pasteur. He demonstrated that bacterial populations could grow in seemingly sterile solutions. Through experiments with closed and open containers filled with culture medium, Pasteur observed that bacteria only grew in the open containers, leading him to hypothesize that bacteria were airborne. He concluded that life arises from existing life. However, this raised a crucial question: if life only comes from other life, where did the first life originate? Pasteur's experiments marked the beginning of a complex series of scientific and philosophical debates. The scientific impasse can be divided into two main issues. Firstly, Pasteur's experiments in the 1860s, which argued against spontaneous generation and supported the idea that life comes from pre-existing life. Secondly, Charles Darwin's *The Origin of Species*, published in 1859, indirectly challenged Pasteur's conclusions by implying that life must have originated at some point from non-living matter.

In his narration of the history of life, Kauffman explains that alchemy led to chemistry, which in turn led to the analysis of atoms and inorganic molecules such as lead, copper salts, gold, oxygen, and hydrogen. However, organisms contained organic molecules not found in non-living materials. For a long time, it was thought that the difference between living and non-living matter lay in the types of molecules they contained. The gap between the two seemed unbridgeable until the mid-19th century when Emil Fischer synthesized urea, an organic compound, from inorganic chemicals. This demonstrated that life was composed of the same material as the non-living world.

In response to the crisis in understanding the origin of life from the non-life, a "neo-vitalist" trend emerged, rejecting attempts to explain biological phenomena solely in terms of physics and chemistry. Instead, they postulated a special active "living force". Others subscribed to panspermia, the idea that germs of life are everywhere. Panspermia suggests that life is eternal in the universe and arrived on Earth from space. Hermann von Helmholtz supported this theory due to the perceived impossibility of scientifically explaining the origin of life in any other way.

Philosopher Henri Bergson proposed the concept of an *élan vital*, an intangible essence that animated inanimate matter, suggesting that this vital force permeated inorganic molecules to give them life. This idea was supported by discoveries showing that frog muscles exhibited animal magnetism (electric potential) and that

James Clerk Maxwell's magnetic field could move matter. Thus, the idea of an additional element to animate the inanimate didn't seem so extraordinary. Hans Dreisch, through his experiments on bicellular frog embryos, concluded that each fertilized cell could produce a complete frog. This suggested that each part of an embryo contained the information needed to create the whole organism, but it was unclear where this information came from. Dreisch proposed the notion of entelechy, an immaterial force directing the development of the embryo.

However, theories on the origin of life stagnated by the late 19th century, considered scientifically unfeasible or premature. Attention shifted to the Earth's primitive atmosphere and its role in producing the chemical molecules necessary for life. In 1924, Alexander Oparin challenged dualistic views of life and matter, suggesting a natural origin of life in his pamphlet *The Origin of Life*, expanded into a book in 1936. Independently, J.B.S. Haldane published a similar paper in 1929. Both argued that an abundant synthesis of organic compounds was crucial for the emergence of life on ancient Earth, forming a "primordial soup" in the oceans where chemical evolution led to the formation of complex organic structures and primitive living systems. Oparin and Haldane's theory of heterotrophic origin, which proposed that organic compounds synthesized from inorganic molecules served as building blocks for primitive organisms, differed from the autotrophic conception that early organisms produced their organic material through photosynthesis. In his 1924 pamphlet, Oparin's materialism opposed neo-vitalism and panspermia, aligning with the social and political climate of the Soviet Union. By 1936, Oparin embraced dialectical materialism, arguing that matter evolves from one level of organization to another, each with specific laws, including biological ones. Oparin's association with the Communist Party and Trofim Lysenko led some to view his Marxist jargon as political opportunism, but historian Loren Graham (1987) argued that Oparin genuinely incorporated dialectical materialism into his scientific views.

It is important[6] to note that many of those who contributed to the early 20th century philosophical breakthrough in the study of the origin of life were Marxists: notably Oparin, Haldane, the virologist N.W. Pirie and the Irish physical chemist J.D. Bernal. Haldane joined the Communist Party in 1936, soon after the outbreak of the Spanish Civil War, and was chairman of the editorial board of the party organ, the Daily Worker. As noted by Podolsky (1996), in the 1930s many left-wing scientists supported socialism or Marxism politically and dialectical materialism epistemologically. The significance of the Marxist philosophical-ideological commitment can be grasped from Oparin's comment: dialectical materialism makes it possible to accept the material basis of life without having to consider every phenomenon not included in physics and chemistry as "vitalistic or super-natural" (Fry 2006).

The story of the origin of life is complex and non-linear, involving jumps, spirals, and backtracks. In *Origins: A Skeptic's Guide to the Creation of Life on Earth*, Robert Shapiro points out that even if scientists can synthesize life's ingredients, assembling them into a coherent narrative remains challenging. This search for narrative coherence is fascinating from a semiotic perspective. The origin of life involves numerous small steps, often requiring abrupt leaps and sometimes metaphysical considerations. The quest for a consistent origin and development has long frustrated researchers. Shapiro likens the origin of life to a theatre without a stage director, making the narrative logically incomprehensible or non-linear.

The discovery of the DNA double helix by James Watson and Francis Crick in 1953 renewed interest in the origin of life. The molecular structure of genes seemed poised to explain the transmission of heritable genetic information. Debates focused on DNA's ability to encode information, positioning it as the most crucial molecule of life. The double helix's replication mechanism suggested DNA might be the first living molecule, carrying the genetic blueprint for life from a fertilized egg.

Contemporary analyses highlight the complexity of living systems. As Kauffman (1995) notes, living organisms seem to require a minimum complexity below which life cannot exist. This criterion of minimum complexity is essential for investigating life. Complexity in living systems appears above a certain threshold, and investigating life involves understanding this complexity. Observing and describing complexity is influenced by human cognitive processes and technological tools. Evolutionary narratives, while plausible, often lack evidence and should not be over-relied upon. Understanding life and its semiotic regimes requires exploring these complexities and imagining new regimes of meaning that bridge the gap between what exists and what can be considered alive.

In *Science in Action*, Latour's concept of the "black box" refers to how scientific facts, once contested and

6 In response to reviewer 2, who asks: "what is the exact point being made by mentioning that many scientists were Marxists in this context? [...] To put it another way, would history change much if some of these authors adhered to Bakunin's collective anarchism instead of Marxism?", one has to admit something that semiotics has explained in several situations. The cultural context, the ideology of the scientists, and political orientations are all part of scientific theories. Such theories are narrative constructions that do not come from 'facts' but from negotiations between one's own ideologies and the adaptation of certain results that come from experiments that have already been prepared on the basis of previous ideologies. This was the theme of Rossi-Landi, Bakhtin, Barthes, Petrilli, Ponzio and other scholars of ideology. As was clear in more recent times to Fabbri, Latour, Bastide, Haraway, Braidotti, whose analysis shows that scientific production is articulated between something that is seen and something that is believed, connected in a process of negotiation (Latour 2009). In order to be published and understood by readers, every paper must go through semiotic processing. So, the answer is that if the political orientation of scholars had been different, the narrative and construction of scientific 'facts' would certainly be different, as would the definitions of life and living. Each definition is culturally, historically, geographically situated.

negotiated, become stabilized and taken for granted. These "black boxes" are the accepted truths that no longer require further questioning unless new evidence disrupts them. The structure of DNA, for example, became a black box after Watson and Crick's discovery, moving from a state of scientific debate to a fundamental, unquestioned fact in biology. The notion of life can similarly be understood as a black box in the modern scientific discourse. In fact, initially, the boundary between life and non-life was highly contested, with theories from vitalism to mechanism offering competing views. However, as biology and biochemistry progressed, certain aspects of life – such as cellular functions, genetic coding (DNA), and metabolic processes – became "black-boxed," i.e., widely accepted as fundamental features of living organisms. The definition of life, like the structure of DNA, from a semiotic perspective involves complex layers of scientific, philosophical, and cultural debates; and political: who funds the research? How should projects be sold so that funding is granted? How much does one have to narrow or broaden the notion of life in order to find funds to go to other planets? How many scientific publications must be written before new instruments are obtained in the laboratory?

Yet, the definition of life remains partially open to interpretation and revision. For instance, questions about artificial life, viruses (which challenge the traditional definitions of living and non-living), and life's origin still keep this black box from being entirely closed. Latour's framework suggests that while parts of the concept of life have been stabilized through scientific consensus, ongoing debates in astrobiology, synthetic biology, and biosemiotics indicate that the "black box" of life might still be reopened as new evidence or perspectives arise. The notion of life, like DNA, has elements that have been "black-boxed" through scientific processes, but it remains subject to challenges that could shift its accepted boundaries.

3. 1 A PARTIAL HISTORY: INTERMEDIATE ENTITIES

In the article "The Definition of Life: A Brief History of an Elusive Scientific Endeavour", Stephan Tirad, Michel Morange and Antonio Lazcano in the conclusion strongly affirm the new view of sciences with respect to the notion of life. In this sense, we feel akin to their conclusion, which with extreme lucidity traces an innovative research in this field from a complex and systemic point of view. In a sense, those who have attempted to define life from a single perspective, the authors argue, may have grasped an aspect that is true, but only in part. Life is, without a doubt, a complex, thermodynamically open, autopoietic system capable of undergoing Darwinian evolution; however, it is essential to understand the origin and coupling of these distinctive features. Over the past fifty years, a remarkable change has taken place; the question of life is no longer configured as the search for fundamental principles, but has acquired a historical dimension. As Lazcano (2010a, 2010b) pointed out, the recognition that life is the result of an evolutionary process subject to the laws of physics and chemistry can lead to the acceptance that many properties typical of living systems, such as replication, self-assembly or catalysis, are also found in non-living entities. Some of these systems may not be "semi-living", but nevertheless exhibit some of the properties associated with life, such as self-organisation, replication or Darwinian evolution. In the context of the origin of life as an evolutionary transition between the non-living and the living, the idea of drawing a clear line between these two worlds is meaningless (Lazcano 2010c). The appearance of life on Earth must therefore be interpreted as an evolutionary continuum, in which prebiotic synthesis and the accumulation of organic molecules in the primordial environment intersect seamlessly, with the emergence of self-sufficient and replicative chemical systems capable of Darwinian evolution.

The intellectual dichotomy between those who advocate the idea that the first living beings originated from informative oligomeric compounds, following the genetic approach, and those who argue that the origin is based on autocatalytic metabolic cycles, has turned into a seemingly incomprehensible dialogue. Instead of falling into sterile arguments about when exactly life began, it is more fruitful to recognise that it is the result of an evolutionary process bound by the laws of physics and chemistry. Such an awareness may lead to the acceptance that many properties associated with living systems, such as replication, self-assembly or catalysis, also occur in non-living entities. Some systems may not be completely "alive", but are capable of exhibiting some of the characteristics associated with living organisms (Lazcano 2010c).

In the broader context of evolutionary biology, answers to questions about the origin and nature of the first living beings must be regarded as investigative and explanatory, rather than as definitive conclusions. This does not imply that all theories and explanations of the origin of life should be discarded as pure speculation, but it does suggest that the question should be approached in a conjectural manner, attempting to construct not only a chronology, but also a coherent historical narrative, weaving together a wide range of various observational findings and experimental results, as pointed out by Kamminga in 1986.

The existence of intermediate entities is the result of the presence of two well-defined categories, and does not eliminate their existence: the demonstration of such intermediate entities will help to delineate these two categories more precisely. This allows us, for example, to explore the question of whether viruses are considered alive from a new perspective. This question posed by the authors has recently re-emerged with the isolation of giant viruses and the accumulation of data highlighting the richness and diversity of the viral world. Viruses most likely played a crucial role in evolution, especially in the early stages, transferring genes from one organism to another. However, they lack metabolism and synthetic capabilities. Labelling them as "alive" is confusing; it is clear that they stand on the inanimate side of the barrier between life and non-life. Francis Crick and Jacques Monod were not wrong in claiming that the secret of life has been unlocked and the molecular characteristics of organisms have been explained (Morange 2008, 2010). The question of life is no longer an enigma in some respects. The question one has to answer when exploring the nature of life is no longer "What characteristics are found in organisms but not in inanimate objects?" but "How have these characteristics been progressively associated in the objects we call organisms?". While we still lack a precise definition of life, it is essential to recognise that, in the scientific context, the most challenging questions are often those that remain unanswered.

For this reason, semiotic analysis and biosemiotic expertise become crucial in understanding life. Indeed, on the one hand, semiotic methodology challenges the factuality of data and reorganises the structures of meaning from a stratification of cultural narratives that mesh humans, technologies, scientific objects, non-human entities, institutions, politics, etc. On the other hand, biosemiotics, with its attentive gaze at the edges of life and lower threshold zones, can activate a competent analysis of what happens in the interaction and relationship between biological entities, natural contexts, and general species-specific functionalities. Thus, if biology, physics, and chemistry remain stuck today in the definition of life and the search for universal patterns, semiotics and biosemiotics can cooperate to restore an honest and accurate meaning in circumscribing the object and the problems related to it. So, nature and culture, life and non-life, from obvious data become matters whose boundaries are not known a priori, becoming universes to interrogate. It is not a matter of presenting a naive relativism, but rather of enforcing relativity, moving up the chain of delegations that connect what we are used to calling life with many other complex instances that are not living, or perhaps they are.

CONCLUSION

This article explores the complex task of defining life by merging biological and semiotic perspectives, aiming to offer a nuanced and critical view. Through a comparison between intuitive perceptions and scientific definitions, it becomes evident that defining life purely based on biological traits is insufficient, as these definitions are inevitably shaped by cultural and ideological influences.

In the first section, we reviewed various philosophical and scientific works, tracing the evolution of ideas from vitalism to mechanism and complexity theories. This historical overview showed the challenges involved in drawing clear boundaries between life and non-life, highlighting how both scientific and philosophical definitions of life are deeply intertwined with conceptual and ideological assumptions. The difficulty in defining life arises from the layered and complex nature of the concept.

The second section introduced the idea of life's semiosis from a biosemiotic perspective, arguing that life cannot be fully understood without considering its semiotic dimension. Organisms engage in meaning-making through biochemical, behavioral, and environmental signals, which are essential for survival, reproduction, and adaptation. Therefore, semiosis is crucial in studying life because it reveals that living processes are inherently interpretative. This means that life operates through the creation and interpretation of signs, making semiosis central to understanding both biology and semiotics.

The third section discussed the minimum complexity required for life, examining Kauffman's narration on the origin of life and the discovery of DNA. It emphasized how experiments and theoretical models shape our understanding of life. This analysis showed that the definition of life is not purely empirical but shaped by conceptual negotiations and ideological frameworks. These negotiations "black-box" the concept of life, stabilizing it through scientific consensus, much like how the structure of DNA became a scientific "fact," as Latour describes in his concept of the "black box".

In this viewpoint biosemiotics, by integrating semiosis into the study of life, provides a broader and more critical understanding of living processes. Recognizing that life involves not only biological mechanisms but also interpretative and cultural processes opens new paths for interdisciplinary research. The challenge for future research lies in applying rigorous semiotic analysis to biology, not just as a descriptive tool but as a method to question the cultural and ideological assumptions embedded in scientific discourses about life. In doing so, biosemiotics can critically assess the boundaries between life and non-life, offering insights that enrich both biological and semiotic research. This article reaffirms the importance of a semiotic and biosemiotic approach to understanding life, challenging purely mechanistic models and advocating for a perspective that recognizes the interpretative and sign-making nature of living beings in a *natureculture* landscape.

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