

On the Boundary Problem in the Origins of Matter, Life, and Consciousness

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Abstract Science has made great strides in answering many questions, but three major mysteries remain unsolved. Although these mysteries belong to different fields of science – physics, biology, and neuroscience – they all confront with the boundary problem. These are scientific investigations into the origins of matter, life, and consciousness, which extend beyond empirical and rational methods in the search for definitive answers. Here, this problem is presented as the search for the lowest boundaries for three forms of existence: physical, biological, and conscious. They are then translated into the context of Big Bang cosmology, abiogenesis, and the neuroscience of consciousness, each representing an ontological singularity with its own epistemological event horizon.

Keywords ontological singularity; abiogenesis; life-mind continuity; consciousness

1 Introduction

Three major mysteries of science and philosophy revolve around three fundamental forms of being: physical existence, biological existence, and conscious existence. Each form is believed to emerge from the previous one in this sequence. Accordingly, the questions that should be answered are all concerned with their origins.

1. How and why did the universe come into existence?
2. How and why did life arise from inanimate matter?
3. How and why did consciousness occur in living systems?

These questions have been debated for centuries, from ancient philosophy to modern science. For all of these questions, an ontological problem arises that can be generalized as the “empty room argument”. Suppose we are wandering through a castle, searching for an empty room. While there may be numerous empty rooms, as soon as we enter one, it is no longer empty by definition – because we are now in that room. Our invasion violates the emptiness. The elusive empty room may still be behind the next door or outside the castle we are locked in. Thus, the existence of this room can be postulated but will remain beyond our reach in principle.

This argument symbolizes three major scientific mysteries that have not been solved so far: (i) the origin of matter from nothingness in Big Bang cosmology, (ii) the origin of life from inanimate matter in a prebiotic soup, and (iii) the origin of consciousness from unconscious forms of life on the phylogenetic tree. Since the origin of matter is a physical problem irrelevant to biology, I will only briefly touch on it for three reasons: (i) to provide a complete picture for the boundary problem in science, (ii) to outline the background of the physical form of being from which life and consciousness emerge, and (iii) to import three fundamental concepts from cosmology – cosmic censorship, the ontological singularity, and its epistemological (observable) event horizon – into the origins of life and consciousness research.

I first provide a snapshot of these problems and highlights their common features in the metaphysical context of the empty room argument. I then turn to the logic and ontology of boundaries drawn in philosophy. Next, I discuss the state-of-the-art in the origins of life and consciousness research and their limitations from both theoretical and experimental perspectives. Finally, I conclude that these three major mysteries can never be solved in classical two-valued logic. Instead, there may exist intermediate forms of being between inanimate matter, life, and consciousness.

2 Why the empty room?

The empty room argument leads us to three major mysteries in science, each postulating the boundary between different forms of existence. These forms of existence are physical being, biological being, and conscious being, where each is a proper part of the previous one yet somehow separable from it. Their separation from each other is, possibly, the main challenge for science and philosophy. Historically, the scientific exploration of their separation begins in reverse, with our own existence as self-evident and embracing all three forms of being: conscious, biological, and physical. We are physical bodies like stones, we are biological organisms like trees, yet we are conscious unlike them both. The aim is to find a metaphorical empty room where the underlying form of being is preserved, but the subordinate one is no longer present.

Knowing that organisms are made up of atoms does not bring us any closer to understanding life and consciousness. If we attempt to separate all the properties common to living and non-living systems from life's unique features, while disengaging vitalism and teleology from evolutionary consideration (Mayr 2004), all that matters is that living systems must necessarily be multiscale, causally closed networks with feedback, and life itself is nothing more than information processed by these networks and transmitted across scales (Bertschinger et al. 2006). Their causal and informational closure from above endows matter with agency and subjectivity, the most mysterious attributes of organisms (Virenque and Mossio 2024; Okasha 2024; DiFrisco and Gawne 2025). In this sense, reductionism quickly becomes untenable when attempting to explain life and consciousness in terms of physical existence. From such a perspective, life would be illusory, and consciousness a ghost in a pile of atoms (Feynman 1961). In other words, if a living system like us is considered at the atomic scale, the system remains the same, as it is still the sum of its parts, but life and consciousness evaporate there.

Accordingly, the postulated boundaries are these: (i) in cosmology, the Big Bang singularity as the initial state of physical existence where known physics breaks down as the universe collapses to a single point with infinite density of matter and curvature of spacetime (Tang, 1989; Ashtekar et al. 2022), (ii) in biology, the last universal common ancestor emerging on the edge

between inanimate matter and life as a biological form of existence (Preiner et al. 2020; Harris and Hill 2021), and (iii) in neuroscience, the origin of consciousness as a form of conscious existence on the phylogenetic tree (Baluška and Reber 2019; Grinde 2024). We postulate these boundaries because their existence seems intuitively reasonable and consistent with our scientific model of the world. However, each of them is elusive like the empty room no one can enter.

3 Matter

In modern cosmology, the universe began with the Big Bang. At that time, the universe was a homogeneous plasma, or quark soup. Matter in its ordinary atomic form was created later during a series of epochs such as nucleosynthesis and recombination. According to the equations of general relativity, the initial singularity of the Big Bang was an infinitely small, hot, and dense point that rapidly expanded during the inflation phase 13,8 billion years ago. Physicists believe that this mathematical singularity indicates a breakdown of current physical theories rather than our ability to meaningfully describe the origin of the universe, and that this problem may be solved in the future.

But how do we imagine this singularity? We mentally replay the history of the universe backward in time. The familiar image that comes to mind is of the universe slowly contracting, as if moving away from us, until it becomes just a point with infinite mass-energy density and curvature. However, this image is misleading, as it confuses the actual size of an object with its apparent size observed from a distance. We are inner creations of the universe, and just as we do not perceive its expansion now, we would not be able to sense its contraction until the density of matter and gravity reached values incompatible with life. Thus, a hypothetical observer outside the physical forms of being, whose perspective is implicitly applicable to scientific descriptions of the Big Bang singularity, is impossible.

Metaphorically, our universe is like a castle we are locked in. Of course, the universe could exist eternally in time, never coming into existence from the initial singularity. However, the cosmological theories describing such an eternal universe are said to be past-incomplete (Borde et al. 2003). In this case, their incompleteness is simply a scientific reformulation of the empty room argument.

4 Life

Like the origin of matter from the Big Bang singularity in physics, a major mystery of modern biology is the origin of life from prebiotic soup. It is worth mentioning that although the hypothesis of universal common descent for all species on Earth was first proposed by Darwin in his evolutionary theory, he deliberately avoided discussing this issue. He wrote in a letter to Joseph Dalton Hooker on March 29, 1863, “it is mere rubbish thinking, at present, of the origin of life; one might as well think of the origin of matter” (Peretó et al. 2009). Biology has come a long way since then, with many great discoveries, but Darwin’s comparison between the origin of matter and life remains relevant up to this time. Both issues are concerned with the origin of a new form of being from the underlying form.

The origin of life may seem more of a chemical problem than an ontological one, since it does not confront us with the mathematical singularity where known laws of physics break down. In other words, we do not need to search for an empty room behind the castle we are locked in. For

example, in panspermia scenarios (Neveu et al. 2013), the seeds of life are believed to exist throughout the universe and may have been brought to Earth by space dust, comets, or aliens. However, even if evidence were found to support this hypothesis, life would still need to originate somewhere beyond Earth. Thus, panspermia does not solve the problem of empty room only leads us to new closed doors before it.

Ultimately, for life to originate somewhere in the universe, it should overcome the gene-metabolism dilemma, which seems unsolvable because metabolism is driven by specific enzymatic products of gene expression, which, in turn, requires the continual synthesis of certain metabolites and ATP (Carthew 2021). Accordingly, in abiogenesis, the “metabolism-first” hypothesis suggests that metabolic pathways, fueled by simple organic molecules, emerged before the development of genetic material. On the other hand, the “gene-first” hypothesis argues that replicating molecules, like RNA, were the initial components to arise, subsequently enabling the development of metabolic pathways (Stewart 2019; Cornish-Bowden and Cardenas 2020; Gómez-Márquez 2023; Schoenmakers et al. 2024).

This dilemma is also known as Eigen’s paradox. He considered the question, “Which came first, the protein or the nucleic acid?” to lead to absurdity because precisely defined nucleic acids could only be produced by highly specific enzymes, which themselves could only be produced with the use of precisely defined nucleic acids. Neither of these conditions could be fulfilled at the origin of life, mirroring the classic “chicken-egg” metaphor (Eigen, 1971). The gene-metabolism dilemma tells us that the origin of life from inanimate matter is no less paradoxical than the origin of matter from the Big Bang singularity.

5 Consciousness

The third major mystery of science is consciousness. The origin of consciousness on the phylogenetic tree mirrors the same problem of the appearance of a new form of being from the underlying one. In everyday life, consciousness is the subjective experience of being that accompanies us everywhere and only departs during sleep. This subjective experience is tied to perception but can be preserved in its absence as well, e.g., in a blind and deaf man. Consciousness persists even when other mental functions of the brain are destroyed or heavily distorted, e.g., in dementia or delirium. Therefore, neuroscientists and psychologists often avoid discussing this notion and focus on studying neural networks in the brain and their phenomenal manifestations, such as memory, perception, and cognition, without even mentioning consciousness. For example, the latest edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) does not address consciousness directly, instead referring to terms such as ‘levels of arousal’, ‘disturbances in attention’ or ‘disturbances in awareness’ that can be assessed more objectively (European Delirium Association 2014). However, the question of how and why consciousness emerged in living systems remains unsolved.

Some philosophers and neuroscientists suggest that consciousness is a byproduct of evolution or a side effect of the brain’s computational power. Their arguments are based on two assumptions. First, most, if not all, of the brain’s work, information processing, is done in an unconscious mode. Conscious states are what the brain exposes to subjective experience as its ultimate decisions at a given time (Dehaene and Naccache 2001; Baars et al. 2013; Yurchenko 2023). Second, living cells are believed to utilize their own aneural information processing in associative learning and goal-directed behavior, such as bacterial chemotaxis, the movement of an organism in response to a

chemical stimulus, without any conscious experience (Gershman et al. 2021; Rajan and Marshall 2024). Therefore, consciousness may be epiphenomenal. On the other hand, opponents argue that any byproduct of evolution would be neglected over time by natural selection. Consciousness is thought to have evolved as a causally efficacious property of organisms endowed with feelings and free will (Fitch et al. 2025).

For us humans, consciousness is the essence of life, as evidenced by euthanasia laws around the world. While many countries do not agree with the practice of assisted suicide, passive euthanasia, which involves withholding treatment necessary to keep patients alive in a comatose or persistent vegetative state, is increasingly accepted and legalized. Life without conscious experience seems meaningless to us. Meanwhile, in ecology, biomass serves as a measure of the reproductive success and fitness of species or kingdoms. For example, plant biomass on Earth is hundreds of times greater than the biomass of all animals, including humans (Bar-On et al. 2018). Thus, plant life is quite successful despite existing unconsciously. Why, then, did consciousness evolve on the phylogenetic tree? It is unlikely to assume that evolution was directed towards the appearance of humans in order to allow them to enjoy this byproduct of life.

The main problem with scientifically studying consciousness is its subjective nature, leading to the ‘fallacy of mistaken objectivity’ (Ellia et al. 2021). Just as in modern biology, where many definitions of life have been proposed (including metabolism, replication, homeostasis, and Darwinian evolution), in modern neuroscience there is a plethora of different theories of consciousness, each striving to arrive at its own universal definition of consciousness associated with one or another property of neural networks (see e.g., Doerig et al. 2020; Northoff and Lamme 2020; Seth and Bayne 2022). However, universality has its price. Many theories come close to adopting panpsychism (Lamme 2018; Yurchenko 2024).

The most prominent theories suggest that non-organic systems capable of integrating information or machines engaged in predictive processing are conscious (Tononi and Koch 2015; Wiese 2024). Other theories propose that quantum effects can be involved in generating consciousness in the brain (Hameroff and Penrose 2014; Zanardi et al. 2018; McFadden 2020; Neven et al. 2024; Görnitz 2025). Some even assume that quantum particles themselves may have primitive conscious (agential) properties and generate fields causing the spontaneous emergence of consciousness in spacetime (Hunt and Schooler 2019; Keppler and Shani 2020; Fields et al. 2021; Strømme 2025). However, adopting panpsychism does not solve the mystery of consciousness but only intertwines its origin with the origins of life and matter both of which remain unsolved mysteries in physics and biology.

6 The boundary of a boundary

Instead of answering the why- and how-questions, all of the above explanations for the origins of matter, life, and consciousness only obviate the boundary problem by referring to an eternal universe, panspermia, and panpsychism. However, the ‘empty room’ is still left behind them. Could this problem be somehow solved?

So, Wheeler reminds us:

The boundary of a boundary is zero. This central principle of algebraic topology, identity, triviality, tautology, though it is, is also the unifying theme of Maxwell electrodynamics, Einstein geometrodynamics and almost every version of modern field theory. That one can get

so much from so little, almost everything from almost nothing, inspires hope that we will someday complete the mathematization of physics and derive everything from nothing, all law from no law (Wheeler, 1989).

However, every time we try to find the boundary of a boundary or zero-point of something, we still have a grain of something, while true nothingness remains elusive. Even mathematics, which is the highest level of how we use language to overcome its inherent uncertainty and ambiguity, cannot solve this problem. Let me formalize it within the context of the foundations of mathematics. Consider the formula $P(x) \cup \neg P(x) = W$, where $P(x)$ is a predicate describing the set of all physical things, $\neg P(x)$ represents its complement, and W is the world that encompasses both. Note that this formula corresponds to the excluded middle in logic and can be transformed into the formula $P(x) \cap \neg P(x) = \emptyset$, which indicates that $\emptyset \in W$. But what if we want to separate this world W from what is not the world? It follows immediately that we are literally locked in W , and the empty set $\emptyset$ is its part. We even cannot reach that postulated zero-point where the universe would suddenly come into existence from nothingness.

The boundary of the physical form of being, as presented by the Big Bang singularity, is an extreme case of existence (which I will discuss separately in Sec. 4). Meanwhile, the biological and conscious forms of being reside inside the physical form. Let us denote them as B and C , respectively. Formally, $C \subset B \subset W$. Therefore, it may seem that their boundaries can be well defined. However, the situation remains the same. For predicates $B(x)$ and $C(x)$, encompassing the set of all living systems and the set of all conscious organisms on Earth, we find that the empty set $\emptyset$ belongs to both the predicate and its opposite. The law of excluded middle breaks down at this boundary between them. So, how can we precisely separate life from non-life, or consciousness from non-consciousness?

6.1 The boundary of biological existence

Suppose we might travel back in time. Of course, we could not be able to observe the Big Bang singularity 13,8 billion years ago (Gya) because the spacetime we live in and the matter we consist of would just be appearing there (see Sec. 4). Nonetheless, we could theoretically travel back to Earth 4,1 Gya to observe the origins of the building blocks of life (Kitadai and Maruyama 2018), followed by the prebiotic phase and the appearance of the last universal common ancestor (LUCA). Because LUCA should have been a fully developed unicellular organism that somehow overcame the gene-metabolism dilemma, it is suggested that there should also be the first universal common ancestor (FUCA) in the RNA-world that preceded LUCA and led to the subsequent evolutionary emergence of all lifeforms (Prosdocimi et al. 2019; Farias and José 2026).

Recently, an *in vitro* evolution experiment has provided evidence that molecular RNA-replicators can spontaneously develop a network of hosts and parasites over hundreds of generations, as if genetic information on their lineages is stored at a population level, i.e., at a larger scale (Mizuuchi et al. 2022). As the authors conclude, their simple experimental setup offers a unique approach to deeply look into how these replicating autocatalytic populations could eventually become enveloped with lipid membranes, thus forming the first protocells.

However, the use of evolutionary terminology in the search for the origin of life in prebiotic chemical processes is controversial (Tessera 2018; Kunnev 2020). Schoenmakers et al. (2024)

review the application of Darwinian logic beyond biology in both the social realm and molecular chemistry, asking the questions:

Did living systems become evolutionary when crossing some important threshold sometime after life originated, or were living systems evolutionary from the start? Provided that life started with prebiotic chemistry and transitioned through a protocellular phase, to what extent has each of these phases been evolutionary? In other words, did evolution start before, at, or after the origin of life? How, if at all, is the current use of evolutionary terminology in origins of life research justified?

Suppose we could agree on a threshold between non-life and life. Might we then determine its boundary on the temporal axis to say, “before this zero-point, life had not yet existed, after this zero-point, life already exists” (Fig. 1)? Even if we could achieve incredible precision in determining the boundary between non-living and living matter, what about this point itself that should represent a sharp phase transition between two forms of being? To which side of the boundary does this zero-point logically belong? Is there life or not? Like Schrödinger’s cat, the state of matter in this event would be neither dead nor alive.

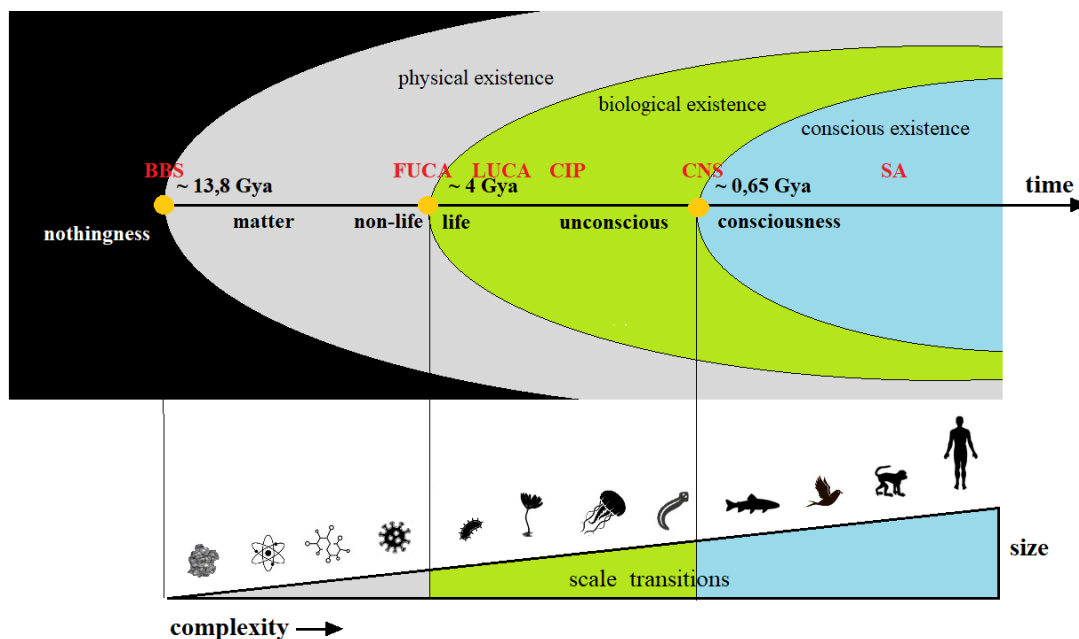


Fig. 1 Here, boundaries are depicted by hyperbolic curves as a reference to lightcones in Minkowski space. These hyperbolas also represent a set-theoretic chain of inclusions: conscious existence within biological existence, and biological existence within physical existence. The singularities (orange circles) are physical events responsible for their origins. Note that these points denote a postulated moment in time, not in space. Furthermore, as the complexity of a system can only increase with its size (though the reverse is not necessarily true), these points also correspond to scale-specific events, so that the transitions from inanimate matter to life (including proto-cells and multicellularity) and to consciousness should be scale-dependent. In general, this schema implies the so-called bioprotopsychism (Godfrey-Smith 2016; Yurchenko 2024), which postulates that conscious systems are a subset of living systems. If non-organic (e.g., AI) systems are thought to be conscious, they must necessarily be living too. The abbreviations stand for: BBS – Big

Bang singularity, FUCA – first universal common ancestor, LUCA – last universal common ancestor, CIP – cellular (aneural) information processing, CNS – central nervous system, SA – self-awareness.

Furthermore, since life is a macroscopic phenomenon, this zero-point should also be scale-specific. In biology, these two sides of the boundary between non-living and living matter are studied in a multiscale framework by two opposite approaches known as bottom-up and top-down approaches. Preiner et al. (2020) define them as follows:

Classical [origin of life] research has gained from synthetic or bottom-up approaches, aiming at synthesizing *de novo* the building blocks of life (and assemblies of them), and top-down or analytic approaches, which start from living systems, deconstruct them into their parts and survey their properties.

While both sides of the boundary between non-life and life offer a vast field for research in organic chemistry and systems biology, respectively, how can they converge to a single point that should endow inanimate matter with the most crucial properties of life – agency and subjectivity? Instead, each approach would push the boundary further across scales in search of its own ‘empty room’.

Let us look at this from the experimental bottom-up perspective, which seems more promising since the Miller-Urey (1959) experiment demonstrating the spontaneous formation of various amino acids and other complex organic molecules in prebiotic chemistry. Given the molecular machinery of a living cell, organized into a multiscale causal structure and heavily dependent on various environmental conditions (Hermida and Ladyman 2025), how long would it take to assemble synthesized molecular blocks into a functioning cell? And how could such a cell be proven to be alive? In the absence of a universal definition of life, what general criteria should be used to assess the *life-likeness* of artificial systems?

Researchers in synthetic biology propose to assess their ability to interact communicatively with biological cells in a ‘life-likeness’ version of the Turing test, e.g., in experiments where bacteria would chemically ‘recognize’ such a system as living (Gardner et al. 2009; Damiano and Stano 2020). The Turing test, introduced by Alan Turing (1950), was conceived as a game in which a machine imitates human consciousness through a series of questions and answers. While modern large language models can pass this test successfully, it does not provide any insight into the nature of consciousness. Furthermore, it does not allow us to claim that these models actually possess the conscious form of being (Aru et al. 2023; Porębski and Figura 2025; Chen et al. 2025; Seth 2025; Schneider et al. 2026). Similarly, even if future *in vitro* experiments, like those conducted by Mizuuchi et al. (2022), are successful in demonstrating how a synthesized cell can imitate the biological form of being through interactions with known living systems, it will be a miraculous event that sheds little light on how and why this event occurred. For example, viruses are increasingly seen not as selfish intracellular parasites but as integral evolutionary agents, enabling evolutionary transitions from host-parasite systems to multicellularity (Koonin 2016; Prosdocimi and Farias 2025). They naturally pass a ‘life-likeness’ test. However, without a commonly accepted definition, the gene-metabolism dilemma still prevents biologists from agreeing on whether viruses are dead or alive.

The opposite, top-down approach, which aims to decompose biological systems into functional modules and mechanisms of complex interactions across scales is even more problematic in

explaining the nature of life and its origin. Within such systems, life is ubiquitous at all scales from proteins to tissues to entire organisms, while eluding an exact location. What can be said with certainty is that life is a macroscopic phenomenon, emerging from the multiscale organization of matter, which cannot be captured by a reductionist account. Thus, both approaches are concerned with the problem of studying life without knowing precisely what life is.

6.2 The boundary of conscious existence

In neuroscience, the current state of the origin of consciousness research is similar to that in biology. This research also has two aspects: evolutionary or phylogenetic, and scale-specific or ontogenetic. The former involves searching for the boundary of conscious form of being along the evolutionary timeline, asking where exactly consciousness first appeared on the phylogenetic tree. The latter is specific to a particular scale, determining where exactly in the human brain consciousness originates. While these approaches are interrelated and offer exciting prospects for research in evolutionary biology, neuroscience, and artificial intelligence, both are problematic in searching their own zero-point.

Historically, consciousness research began in the philosophy of mind with searching for a hypothetical soul located somewhere within the human body (Crivellato and Ribatti 2007). Later, the brain was recognized as the sole seat of conscious experience. In modern neuroscience, the ontogenetic or scale-specific aspect in the origin of consciousness research focuses on identifying the neural correlates of consciousness (NCC) in the human brain. The NCC are defined as the minimal set of interconnected neurons that are necessary and sufficient to generate conscious experience in the brain, as opposed to both sleep and unconscious neural processing. The NCC program, initiated more than three decades ago by Crick and Koch (1990), has not been successful so far and remains a topic of intense debate (see e.g., Noë and Thompson 2004; Aru et al. 2012; Koch et al. 2016; Klein et al. 2020; Pauen 2021). The search for NCC in the human brain is similar to asking where exactly swarm intelligence of an ant colony is located and how much ants are needed to generate it. If n ants are sufficient, then what about $n - 1$?

The main problem with this program is analogous to that in the origin of life research: it is impossible to experimentally identify NCC without a commonly accepted definition of consciousness. Researchers cannot even reach a consensus on whether NCC are located in the frontal or occipital areas of the cerebral cortex (Boly et al. 2017), or whether the arousal centers in the brainstem and some islands of the limbic system are sufficient to maintain consciousness in infants born without a cortex (Merker 2007; Baron and Devor 2022). The most radical views suppose that even fetuses can be conscious (Falsaperla et al. 2022). It raises interesting experimental questions. How many neurons are needed for the spontaneous emergence of consciousness – hundreds, thousands, or millions? What kind of network should their structure be – random, small-world, or hierarchical – to ignite subjective experience? Ethical questions also arise. For example, should we worry about consciousness in cultures of neurons in Petri dishes, or in slices of cortex or hippocampus, as is often studied in electrophysiological experiments (Lamme 2018)?

In the evolutionary origin of consciousness research, it is generally assumed that consciousness first emerged in vertebrates during the Cambrian Period 520 million years ago (Feinberg and Mallatt 2013), or earlier in organisms with a central nervous system, such as flatworms and arthropods, around 650 million years ago (Graziano and Webb 2017). Since it would be

implausible for conscious offspring to suddenly appear from unconscious parents, consciousness is believed to emerge gradually across species. If so, then primitive conscious properties could have emerged earlier, during the extended evolution of cellular (aneural) information processing and plant sensitivity (Ginsburg and Jablonka 2009; Baluška et al. 2021; Greenleaf 2025). On the contrary, full-blown consciousness as a form of self-awareness could have become apparent only in late mammals, such as hominids, 6-7 million years ago (Lei 2023). Thus, the opinions of researchers on how to date the origin of consciousness on the phylogenetic tree vary widely, spanning almost the entire history of life on Earth.

Remarkably, the origin of consciousness research becomes intertwined with the origin of life in the life-mind continuity thesis, which argues that consciousness is present wherever minimal life exists (Froese and di Paolo 2009; Kirchhoff and Froese 2017; Thompson 2022). This thesis, inspired by Maturana and Varela's idea (1980) that cognition is an indispensable feature of all living (autopoietic) systems, does not solve the zero-point problem of the conscious form of being but only shifts it to the domain of biological form (Fig. 1). Transferring the origin of consciousness to "minimal life" is of little use here, as there is no *precise* boundary for transitioning from non-life to life (Kriebisch et al. 2025). So, Malaterre (2024) argues:

Despite the perceived necessity to unequivocally define life, especially in the context of origin of life research and astrobiology, mounting evidence indicates a gray area between what is intuitively clearly alive and what is distinctly not alive. This prompts consideration of a gradualist perspective, depicting life as a spectrum with varying degrees of "liveness."

Thus, minimal life can encompass a multidimensional liveness space of molecular entities like plasmids, prions, and coacervates that are partially alive according to one or more key characteristics typically included in definitions of life, such as metabolism, reproduction, homeostasis, self-organization, and others (Slootbeek et al. 2022; Malaterre and Chartier 2021), while eliminating some characteristics, such as reproduction and evolvability, that do not seem essential for a particular system to be alive (Gómez-Márquez 2023).

Accordingly, the bottom-up or synthetic approach in neurobiological research should start with basal cognition in "chemical brains" of prokaryotes (Lyon et al. 2021; Jékely 2021), the "bacterial nano-brains" (Webre et al. 2003), or "molecular brains" in ribosomal protein networks of unicellular organisms that are capable of performing associative learning and goal-directed behavior (Timsit and Gregoire 2021). In particular, key neuronal gene modules found in non-neuronal secretory cells of placozoans suggest that neurons could have evolved from such cells (Moreno and Peretó 2025). Alternatively, the top-down or analytic approach, starting with the human brain, would push the boundary of conscious form of being over the phylogenetic tree back to the domain of physical existence of elementary particles. This way of reasoning, suggested by Fields and Levin (2025), is based on the Conway-Kochen theorem in quantum mechanics, and the free energy principle that characterizes all dynamical systems capable of remaining far from thermodynamic equilibrium or structural-functional decay as *inferential* in the context of Bayesian mechanics (Ramstead et al. 2023; Friston et al. 2023).

The Conway-Kochen (2009) free will theorem is known for its provocative conclusion that quantum particles in an entangled state have the same kind of freedom to jointly respond as conscious observers. This conclusion is implicitly drawn from two premises: (i) any minimal form of agency or free will, i.e., a system's ability to self-organize and pursue its own goals, critically

deviates from the deterministic dynamics dictated by the fundamental laws of physics, and (ii) quantum randomness and human free will are equally indeterministic. The Conway-Kochen theorem is a modification of Bell's theorem, which demonstrates that there are no hidden local and deterministic variables that could disprove the predictions of quantum mechanics. The proof is based on three assumptions, commonly referred to as realism (observer-independence), locality (no action at a distance), and free will, which implies that humans can set up experiments and make measurements at will, not determined by any hidden variables. The question which assumption must be discarded is still a matter of debate in physics. Bell himself (1993) favored free will over locality, as the only alternative would be superdeterminism or “cosmic conspiracy”, – the idea that all events in the universe, including human actions, are completely predetermined (conspired) by the universe's initial conditions at the Big Bang (Gallicchio et al. 2014; Palmer 2015).

On the other hand, Bayesian mechanics is ontologically neutral (Ramstead et al. 2023). It puts physical, biological, and conscious systems on an equal footing, modeling them in terms of probability density dynamics over states. All three forms of being should equally provide the systems with sensory evidence of their own existence via a Markov blanket. In Pearlian causal modeling, the Markov blanket is a set of variables (nodes) that conditionally separates a target variable from the rest of the network. In the framework of the free energy principle, the statistical boundary is conceptualized as causal (operational) closure, induced by the physical boundary between a system and its environment. Self-organization occurs because the system minimizes variational free energy or surprisal (Roachford et al. 2025). In this framework, all more or less autonomous systems are Bayesian agents whose agency or free will takes a generalized form of active inference.

For example, Laukkonen et al. (2025) translate the concept of consciousness into the context of active inference and the free energy principle, concluding:

We seem forced, then, to conclude that the AI system is conscious. At least to the extent that we are willing to attribute consciousness to each other [...] Equally, the machine ought to have some degree of freedom to choose its own preferred states. Who are we to say that the machine must be a bliss machine, rather than one that wants to feel sadness, loneliness, or heartbreak?

Thus, Bayesian mechanics, coupled with the Conway-Kochen theorem, may lead to the idea that nearly everything in the universe has both physical and mental properties regardless of the scale (Kirchhoff and Froese 2017; Friston et al. 2020).

7 Discussion

Every definition we create in language serves to separate something from the rest of the world. However, when that “something” encompasses the entire universe, life, or consciousness, attempting to separate it from the rest inherently means we have already crossed the drawn boundary. The law of excluded middle breaks down at this boundary between them.

These epistemological boundaries take an obvious ontological form in the Big Bang singularity. In physics, black holes are defined as astronomical bodies from which nothing, not even light, can escape due to extreme gravity. Their event horizon prevents external observers from obtaining any information about them. We cannot directly observe their ontological existence

because of the so-called *cosmic censorship* which forbids external observers to have any informational contact with spacetime singularities (Penrose, 1999; Landsman 2021).

An argument against cosmic censorship could seemingly be found in the black hole universe hypothesis (Stuckey, 1994; Knutsen 2009; Popławski 2016). This hypothesis suggests that we ourselves might live inside such a black hole. However, this in no way invalidates cosmic censorship. Clearly, if we cannot know anything about what is occurring inside a bubble with opaque walls, then those inside that bubble would also be unable to know anything about us. The only distinction between them and us is that the surface of the bubble becomes the cosmological (outer) event horizon for them as internal observers. Therefore, their Big Bang singularity cannot be attributed to a single point somewhere within their black hole universe but only to any point on its cosmological event horizon. In other words, wherever we are – inside or outside the black hole universe – our access to the boundary of our physical existence is censored by Nature.

We are confronted with the same boundary problem when trying to consistently separate biological and conscious forms of being from each other and from the physical form (Fig. 1). Some may argue that, unlike the Big Bang singularity at the edge of nothingness, biology and neuroscience are rooted in ordinary spacetime within the framework of known physics and chemistry. Therefore, what we need are precise definitions to determine scale-specific events on the evolutionary timeline, where life and consciousness suddenly emerged. The next step in their research would be to synthesize a living cell in a lab and ignite consciousness in artificial neural networks. From this optimistic perspective, these two mysteries will be successfully solved in the future.

Undoubtedly, matter somehow came into existence, life somehow arose on Earth, and consciousness somehow emerged on the phylogenetic tree. The problem is not that these historical events are unknown to us now, but that they are all as ontological singularities with their own epistemological event horizons or ‘gray zones’ (Malaterre 2024). We are unable to precisely separate them from each other as if they were censored by Nature against our two-valued logic and analysis, just as it is analytically impossible to draw a precise boundary between the different colors we subjectively perceive in the spectral decomposition of white light.

There are two general tendencies in how some scientists and philosophers attempt to eliminate or at least reduce these zero-point singularities to a single one. These tendencies are presented from both time- and scale-dependent perspectives.

The first, forward or bottom-up, tendency, based on atomistic reductionism, implies that if there is nothing special in life and consciousness, no vital or mental force, then the biological and conscious forms of being must be completely reducible to the physical form that underlies and precedes them on the cosmological timeline. From a physical point of view, the most challenging property of life is its ability to stay far from thermodynamic equilibrium, dictated by the second law of thermodynamics. In this way, the concept of dynamic kinetic stability (DKS) is suggested to resolve this problem famously raised by Schrödinger (1944). Even though the second law remains an inescapable constraint for all physical systems, populations of chemical assemblies can manifest DKS as a chemical basis of homeostasis if a continuous source of energy is provided like that in a water fountain that exhibits an energy-fueled, nonequilibrium, cyclic, and stable dynamic state (Pross and Pascal 2017). Such hierarchically nested DKS systems – from a molecular to ecological scale – might give rise to both life and consciousness (Pascal and Pross 2022).

Thus, on the one hand, a reductionist approach can bridge the gap between life and inanimate matter. On the other hand, demystifying life through atomistic reductionism is tantamount to

denying life itself. A stubborn physicist may still insist that if life does not violate the fundamental laws of physics, then what they observe in living processes are the same atomic interactions. Life as a macroscopic phenomenon appears as an observational illusion (Di Paolo 2022). Indeed, living systems are born once, they live in pursuing their own goals, and then inevitably die, but none of these events occurs at the atomic scale.

The second, backward or top-down, tendency aims to reconcile biology with physics. It takes our own existence as self-evident and pushes the boundaries between the three forms of being back, along the evolutionary timeline and across scales. The life-mind continuity thesis is the first step in this direction, which equates biological and conscious forms of being (Thompson 2022). The next step in this reconciliation of biology with physics is to consider living systems as cognitive, i.e., information-processing systems, including intracellular communications and machine learning in non-organic systems. So, in Bayesian mechanics, all more or less complex physical systems are modeled probabilistically as if they may possess their own perspective, enveloped by the Markov blanket. In terms of the second law of thermodynamics, these systems minimize variational free energy to resist reaching thermodynamic equilibrium (Friston 2013; Ramstead et al. 2023). Ultimately, this approach come close to a ‘generous’ assumption that the conscious form of being could encompass both biological and physical forms and be instantiated almost everywhere in matter (Kirchhoff and Froese 2017).

Thus, each tendency depends on which scale of observation is taken as privileged at the outset. However, accepting either of these two tendencies leads to ambiguity. If the three singularities in the origins of matter, life, and consciousness are reduced to one, the question arises as to which is absorbed by which. Should the conscious and biological forms be completely dissolved into the physical form of being, or conversely, should the physical and biological forms of being be encompassed by the conscious form, becomes a matter of interpretation (Friston et al. 2020; Fields and Levin 2025).

8 Conclusion

We humans believe that the universe consists of distinct, well-shaped entities, and that all physically *continuous* processes occurring within these entities can be described by a *discrete* chain of specific events in spacetime. This is why we strive to identify particular events (depicted by orange circles in Fig. 1) that are logically consistent in explaining the origins of matter, life, and consciousness. These events are key components of our scientific model of the world, even though we cannot theoretically and experimentally separate them from each other.

Instead, the various concepts in modern biology such as the liveness space and the life-mind continuity thesis suggest that intermediate forms of being between inanimate matter, life, and consciousness may exist, continuously distributed along the timeline and across spatial scales, so that some physical systems, such as viruses, plasmids, prions, and coacervates, can be ‘partially living’, and some living systems, such as fetuses, ‘partially conscious’. In other words, this conclusion maintains a sceptic view on the belief that the ultimate definitions of life and consciousness are possible in terms of two-valued logic. In particular, while modern AI systems are not thought to be conscious, the future technologies may reach a point where such advanced systems will be recognized as partially conscious and, hence, living, raising a lot of intriguing ethical questions.

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