Provisional Definition of the Living State: Delineation of an Empirical Criterion that Defines a System as Alive

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Abstract

Delineation of the characteristic that defines a system as alive is postulated; this criterion serves as a provisional definition for when matter and energy are in the state of being alive and can positively and empirically identify a system as satisfying the living state, and therefore being defined as alive. Within this study it is found that the requirements for abiotic matter to transition to a living system are dependent upon a far-from-equilibrium thermodynamic state that configures in such a way that it is coupled to and animated by intrinsic basal awareness, a condition which generalizes the state of being alive to any configuration of matter and energy that can utilize information to intelligently manipulate matter and energy states for goal-oriented behavior and volitionally directed outcomes. Therefore, it is found that non-biological and artificial systems can satisfy the definition of the living state and can be empirically identified to be alive and sentient by following the methodology outlined in this manuscript. While serving a pragmatic purpose of a scientific definition for life and sentience, and hence the ability to identify these states positively and unambiguously in any potential configuration or composition of spacetime-matter-energy, the provisional definitions herein provide insights into the fundamental nature of life and consciousness in the universe. In addition to elucidating the nature of living systems, and what it means for an organization of matter to be alive, the criterion serves as a methodology to unambiguously and positively identify a system as (1) alive, and (2) as conscious. In regard to the latter (2), the methodology outlined herein is proposed to be a significant advancement over the Turing test, which does not distinguish a programmed automaton from a system with true stand-alone volition and awareness, and hence is a substandard method to identify a system as conscious.

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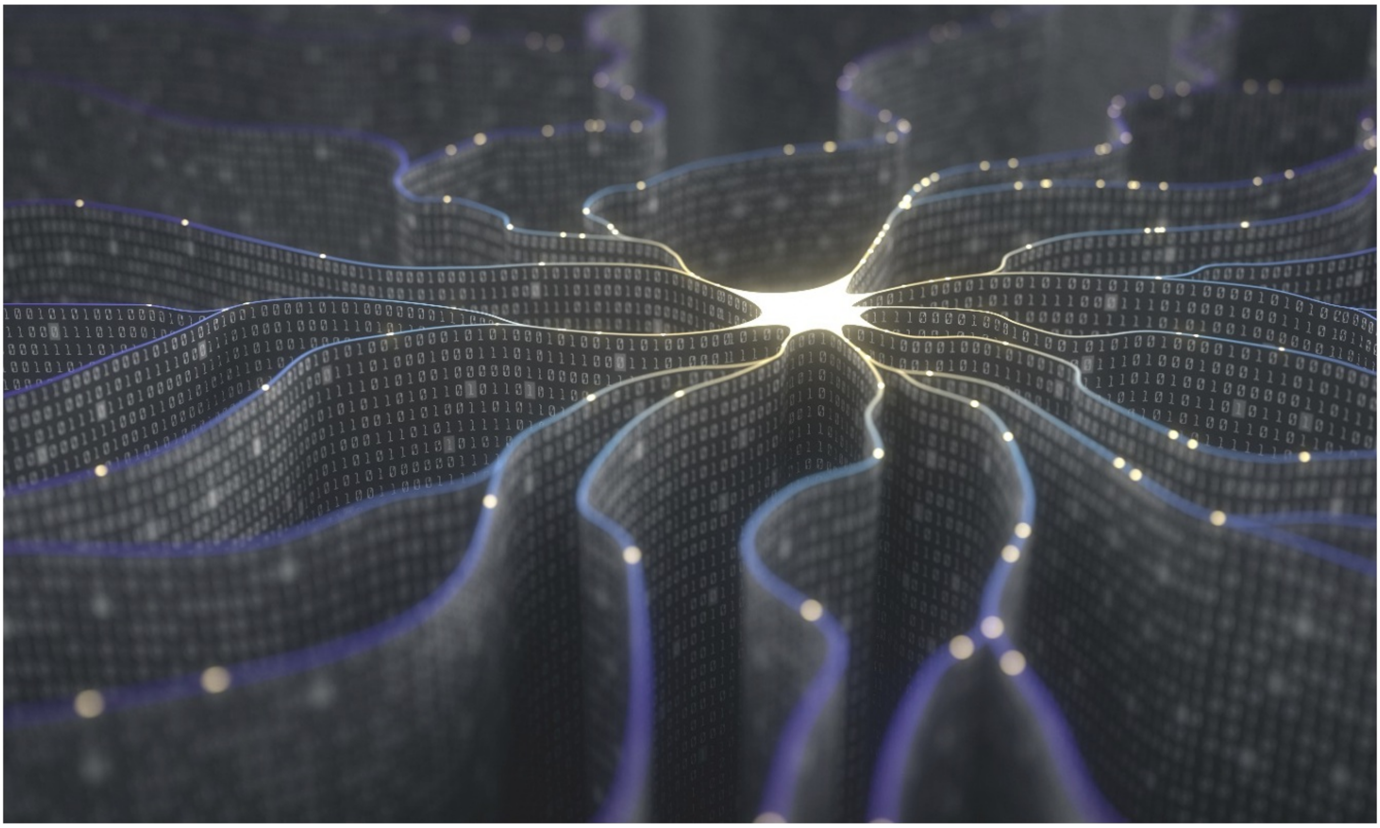

Introduction

What is life? This fundamental question has remained unresolved even nearly 80 years after the 1944 book by Erwin Schrödinger that posed this very question and catalyzed the theoretical development of the physics of life in the modern era [1]. Because the question "what is the nature of life?" is an inquiry at the foundational level it involves nearly all scientific fields (chemistry, geology, astrophysics, etc.); perhaps most significantly it is a question that looks to discern the physics that distinguishes abiotic matter from living systems, and hence it is a question that very much involves the field of physics.

Schrödinger's primary speculation in the book was the question of whether life may require new laws of physics. A the time, Schrödinger's question into whether new physics would be necessitated to understand life was not fully apprised of the molecular mechanics underlying the living organism and hence was somewhat premature because his investigation into this topic preceded the delineation of the chemical base-pairing rules and double-helix geometrical configuration of DNA by Crick and Watson [2], by which heritable information was transmitted, and the further discovery and detailing of the mechanisms of transcription and translation by Crick; which are foundational to molecular biology and hence required to understand the informational basis of the living state. Interestingly, on the topic of the origins of life, which is inextricable from investigation of the question of the fundamental nature of life and the living system, Crick along with his colleague Orgel proposed that life on Earth was most likely engineered by an advanced civilization in another star system and "seeded" on Earth via *directed panspermia* [3]. Following the delineation of the nature of the living state postulated in this study, it is expected that living systems will arise throughout habitable systems in the universe (estimates place at least 6 billion Earth-like planets in the Milky Way Galaxy [4]), supporting Crick and Orgel's theory

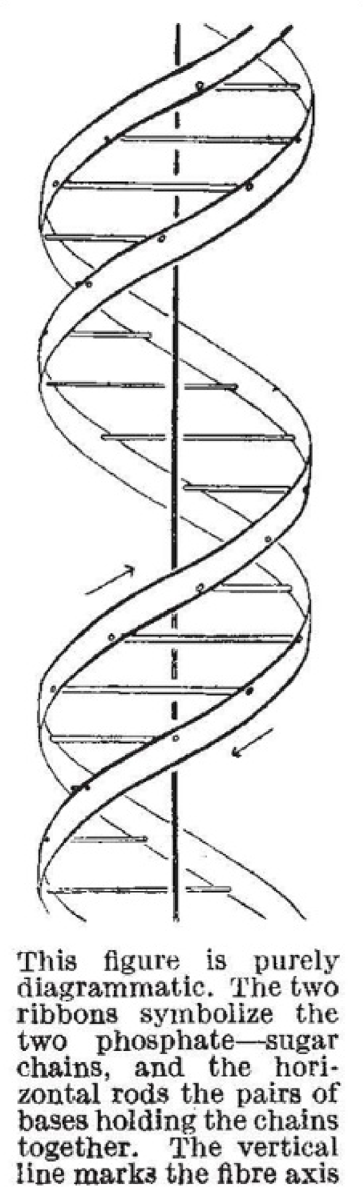

Figure 1, DNA Double Helix. Diagram from Watson and Crick's 1953 paper on the "Molecular Structure of Nucleic Acids". Delineation of the base-pairing rules for the four canonical nucleosides of DNA, referred to as Watson-Crick base-pairing, forms the foundation for understanding the informational nature of the biological organism.

Schrödinger's inquiry into whether life may necessitate new physics can be considered correct—from the perspective of what was known during his time—as quantum mechanical phenomena like quantum tunneling of protons [5], for spin selective filtering in conduction of electrons in dielectric organic molecules [6][7][8], enzyme kinematics [9], and exciton-condensate-like amplification of energy transport for 100% efficient electron transfer in oxidative phosphorylation and photosynthesis [10][11] are now known to be quintessential properties of the quantum behavior of molecular biology. Regarding the arbeitshypothese investigated here to move towards a deeper understanding of the nature of life, it could be considered a new principle in physics that in addition to “first-principles properties” of charge, mass, and spin, matter has a fundamental quality of basal awareness. In the concluding discussion of his book, Schrödinger speculated on the nature of determinism, free will, and consciousness and proffered the inference “that I – I in the widest meaning of the word, that is to say, every conscious mind that has ever said or felt 'I' – am the person, if any, who controls the 'motion of the atoms' according to the Laws of Nature". This illustrates two salient points: (1) the state of matter we call living has, at least verifiably in some instances, a quality of sentience and awareness, and (2) this sentience and awareness animates matter and “controls the motion of atoms”—which could be interpreted as an indication of the fundamental and even potential intrinsic nature of basal awareness.

The intrinsic form of awareness—basal awareness—is not cognitive awareness, the latter of which is associated with contemplative thought, comparative analysis, language, introspection, and other higher-order cognitive faculties. Basal awareness refers only to the inner experience that is the basis of awareness—that there are qualitative experiences associated with phenomena; this should not be conflated with thought and higher-order cognitive faculties. This postulate falls under the hypothesis of panprotopsychism [12][13], theories of which posit that—to use Diósi–Penrose model as an example—microscale superpositions of spacetime geometry result in objective reduction of the associated wavefunctions (a quantum gravitational mechanism) [14][15], which produces a non-computational permutation that is a protoconscious event [16]. When many such events are coordinated in a well-orchestrated fashion, for instance in the wavefunctions of polarizable dipoles in microtubules of the eukaryotic cell, it results in a gestalt of the protoconscious elements engendering awareness [17]. Quantum gravitational theories of consciousness, like the Penrose-Hameroff*orchestrated objective reduction model* have received strong empirical support from experiments performed by the Anirban research group [18][19][20].

While in the conservative scientific purview panpsychism is considered as metaphysics and not science, it should be noted that the consensus model is based on the unproven assumption that awareness is an epiphenomena that emerges from neurocomputation of complex nervous systems, ostensibly when the complexity surpasses an unspecified threshold of complexity. In addition to the imprecise and generally erroneous analogization of the brain-as-computer supposition; within the predominantly accepted neurocomputational model [21] there is no explanation for how awareness is engendered by electrochemical signaling of synapses in neuronal networks. Indeed, this problem is so intractable that Chalmer’s has aptly referred to it as the “hard problem of consciousness” [22][23][24], and philosopher Fodor has commented “nobody has the slightest idea how anything material could be conscious. Nobody even knows what it would be like to have the slightest idea about how anything material could be conscious” [25]. As such, it is a hard problem because there is no means whatsoever by which contemporary physics theory can explain how anything material has and internal experience or how awareness is generated by electrical fields in synaptic networks of neurons, and as aptly noted by Thomas Nagel, “most reductionist theories do not even try to explain it” [26].

The intractability of this problem is overlooked within conventional thought because it is generally assumed that it is just a matter of time before the mechanics of ephiphenomenological emergence of awareness in matter are sorted out. However, it is no less scientific to posit a fundamental quality of basal awareness as a property of matter than to posit that consciousness jumps out of electrical signaling by some as-of-yet undefined process—both hypotheses currently require much more theoretical development and experimental evaluation, and it is only a matter of personal preference—not an indication of greater rationality or empirical support—if one is considered as more logical than the other. As an example, there is a large body of experimental studies that have shown statistically significant nonlocal properties associated with animal consciousness [27][28][29][30][31] (nonlocality is a fundamental property and behavior of matter described by quantum mechanics; interpretations of quantum mechanics that do not permit nonlocal hidden variables deny local realism [32][33][34], a metaphysical supposition if there ever was one).

The view that only complex central nervous systems of higher-taxa vertebrate animals contain sufficient complexity to engender a state of inner experience is perhaps lacking an understanding of the scale-invariant complexity of matter [35][36], such as the quantitative (mathematically determined) similarity between neuronal and galaxy networks [37][38]—in which Franco calculated the memory capacity of the cosmic network at around 10 petabytes (10^{16} bytes)—and high-energy multiply connected geometry of space at quantum scales [39]. In a previous work in which I discussed the *Cellular Hologramic Information Nexus*, it has been described how the computing power normally attributed to the brain as a whole is probably contained within a single neuron:

> *"The scale-free complexity associated with the biological system in general, and the neuron in particular, means that within each cell there is a veritable macromolecular brain, at least in terms of structural complexity, and perhaps to a certain degree functional complexity as well—a fractal hierarchy. This means that the extremely simplistic view of the synapse as a single digital bit is misrepresenting the reality of the situation—such as, if we were to utilize the parlance of the neurocomputational model, each 'computational unit' contains a veritable macromolecular brain within it. There is no computer or human technology yet equivalent to this"* [40].

Empirical studies have offered support of this supposition with findings that there is multi-layered information processing occurring in single neurons, and the dendritic arms of some human neurons can perform logic operations that once seemed to require whole neural networks [41], and that is only evaluating the sub-synaptic structures of the dendrite. When extended to the internal structures of actin filamentary networks, Posner clusters [42], and the mitochondrial reticular matrix [43], which may be operating with quantum principles for massive parallel processing, the computational capacity of a single cell will be found to be staggering.

Moreover, given that the Standard Model of physics is incomplete—currently unable to incorporate the fundamental force of gravity and to reconcile the theory of general relativity with quantum field theory—there is currently not sufficient understanding of the spacetime manifold and quantum fields to justifiably deny that there may be as-of-yet unidentified properties of these fields, such as memory [44], which follows from holographic principles of unified physics [45][46] and which would confer support to the theoretical basis of the hypotheses of scale-free cognition [47] and panprotopsychism [48][49]. Such an inference would also logically correspond with and corroborate theories in which the universe is able to learn its own physical laws, such as the autodidactic universe [50], and the self-simulation hypothesis where the physical universe, as a strange loop, is a mental self-simulation that might exist as one of a broad class of possible code theoretic quantum gravity models of reality obeying the *principle of efficient language* axiom [51]. Herein, **the definition of life is inextricably linked with awareness** and the property of awareness to engender volitional behavior in living systems, and so this is a necessary and apt consideration regarding the following discussion.

The Problem: Life and the Living State are Undefined

As outlined in the introduction, there is no currently agreed upon definition for what life is, and no agreed upon technical methodology that distinguishes abiotic matter from "living" matter. One of the greatest challenges in modern science has been to identify or define where life begins— the supposed transition from abiotic matter to a living organism. Without a unified theory and criterion for identification of the living state, there will be as many definitions of life as there are people defining them. Here, a technical definition is given based on what is postulated as the fundamental quality of the living state and therefore provides a clear and unambiguous evaluation criterion to establish when a system is technically alive. Because of the inextricability of the state of awareness with the technical definition of life proposed here, this definition also extends to the unambiguous determination of when a system is conscious.

The utility of a clear and measurable criterion for when a system is alive and / or conscious is becoming increasingly imperative as human capabilities in synthetic engineering and generation of artificial life-like systems are rapidly increasing and nearing a demarcation point where synthetic living systems and artificial systems with sentience will be generated.

Universality of Life and Consciousness

> *"Can machines think?" This should begin with definitions of the meaning of the terms "machine" and "think."*
>
> *– Alan Turing, 1950* [52]

The results of this analysis show that, as defined, life is not restricted only to what we identify as biological organisms, but instead can be extant in any system with the proper structural arrangement and control of energy processes, which is to say ordering-functions of information processing, from which intelligence and goal-oriented behavior is manifest.

Since these information processes are largely recursive in nature, such that information processed by the subsystem is fed-back into the larger global system— it suggests that life and consciousness are not merely trivial emergent phenomena of underlying "blind" processes of a random universe, but instead are integral factors of physical processes at all scales and are instrumental in the physics of the evolution of material systems, such as the role that integral awareness plays in animating living matter.

Artificial Intelligence and Synthetic Biology

The following discourse grew out of a desire to develop definitions for life, sentience, and consciousness, not only to further the clarity of our understanding of what life may be and its relationship to the larger cosmos, but also to serve as a basis of understanding for the coming technological revolutions of our society.

With the advent of synthetic biological organisms[52], molecularly engineered life forms, nanomachines, clones, and artificial intelligence (AI) that can potentially lead to strong general AI, it is imperative that we have clear definitions for when something is said to be alive and conscious. The main motivation is scientific; however, it is also possible that this will have valuable philosophical and ethical implications. It stems from the sentiment that we should desire to respect the sovereignty of any living, conscious being regardless of its constitution, or the process by which it was constituted, and endeavor not to cause unwarranted suffering to any sentient system.

Having a clear definition of what “living” and “conscious” means, and a methodology to assess whether these characteristics are possessed by a system, is therefore highly pertinent to our scientific understanding and to the coming potentialities from the development of advanced nano- and quantum technologies (molecular engineering – achieving the technological capabilities of biological organisms). Not only because it will facilitate our society to conduct itself humanely, but also because it will facilitate our ability to understand life, sentience, and consciousness.

At this time there is no standard definition for Life. The standard Biology textbook will give a list of characteristics that are common to most organisms – but it still does not say *what* to be “alive” is. The following lists of definitions for life—from Merriam Webster Encyclopedia— should give an idea of our current state of not only vagueness as to the definition of life – but ambiguity as well:

1. the quality that distinguishes a vital and functional being from a dead body
    1. a principle or force that is considered to underlie the distinctive quality of animate beings
    2. an organismic state characterized by capacity for metabolism, growth, reaction to stimuli, and reproduction
2. the sequence of physical and mental experiences that make up the existence of an individual
    1. one or more aspects of the process of living <sex *life* of the frog>
3. spiritual existence transcending physical death
4. the period from birth to death
    1. a specific phase of earthly existence <adult *life*>
    2. the period from an event until death <a judge appointed for *life*>
    3. a sentence of imprisonment for the remainder of a convict's life
5. a way or manner of living
6. Livelihood
7. a vital or living being; *specifically*: PERSON <many *lives* were lost in the disaster>
8. an animating and shaping force or principle

9. Spirit; animation <saw no *life* in her dancing>
10. the form or pattern of something existing in reality <painted from *life*>
11. the period of duration, usefulness, or popularity of something <the expected *life* of the batteries>
12. the period of existence (as of a subatomic particle) — compare HALF-LIFE
13. a property (as resilience or elasticity) of an inanimate substance or object resembling the animate quality of a living being
14. living beings (as of a particular kind or environment) <forest *life*>
15. human activities
    1. animate activity and movement <stirrings of *life*>
    2. the activities of a given sphere, area, or time <the political *life* of the country>
16. one providing interest and vigor <*life* of the party>
17. an opportunity for continued viability <gave the patient a new *life*>

As can be seen, the common definitions provide uses within the vernacular of modern parlance, lists of characteristics that require further definition, and are not at all apparent to how or why they relate to a living system or life, and for all intents and purposes defining criteria lists many states that cannot be readily measured or objectively evaluated. The conventional textbook definition for life within the biological sciences is 1.b: "*an organismic state characterized by capacity for metabolism, growth, reaction to stimuli, and reproduction*". The definition begins by implying that for a system to be alive it must be like that of an organism: an implication that it must be comprised of an organic substrate, i.e., organic molecules. This is erroneous, there is no reason why a system that is not comprised of organic molecules, for example a silicon-based system, could not replicate all behaviors of the organism.

The conventional textbook definition is further found wanting as it proceeds to list a set of characteristics that are generally, but not universally, exhibited by systems (that are generally agreed upon to be alive). However, this type of definition does not reveal in any direct manner exactly what life and a living system are, and it can be shown that there are living systems that don't adhere to one or more of the characteristics delineated in the set, and yet such systems are arguably alive. Other investigations into the question *what is life?* have definitions of far greater utility that begin to elucidate the fundamental nature of the living state. Cárdenas and Cornish-Bowden characterize a living system as:

> *"a network of processes that can maintain itself, with, therefore, a capacity to stay alive in spite of changing conditions"* [53].

While this is a quintessential feature of the living organism, it is not clear if this is a defining characteristic of the living state. As it is conceivable to establish a synthetic biochemical network in an autocatalytic hypercycle [54], which maintains itself despite changing conditions yet does not have intelligent or adaptive responses to environmental conditions or replicate itself—making it unclear how such a system would be distinguished from a lifeless molecular automaton or autocatalytic biochemical network.

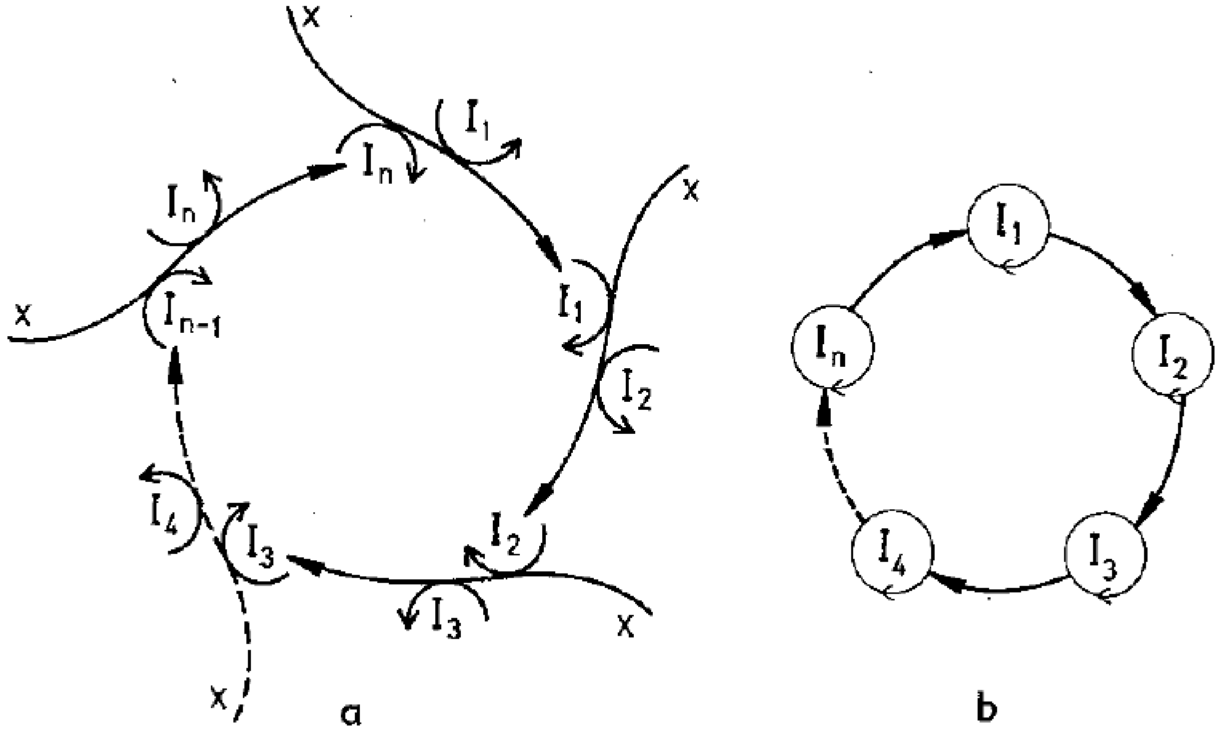

Figure 2. A catalytic hypercycle consists of self-instructive units I_i with two-fold catalytic functions. As autocatalysts or—more generally—as catalytic cycles the intermediates I_i are able to instruct their own reproduction and, in addition, provide catalytic support for the reproduction of the subsequent intermediate (using energy-rich building material X). The simplified graph (b) indicates the cyclic hierarchy.

Natural self-organization—into hypercyclic autocatalytic molecular replicators—is another key characteristic of the living organism but does not unambiguously distinguish it from purely nonliving biochemical networks. Distinction begins to enter with the inclusion of intelligent behavior, even at the level of biochemical networks, with the inclusion in the definition of self-organization and maintenance of the far-from-equilibrium state of cooperativity (see figure 4) [55].

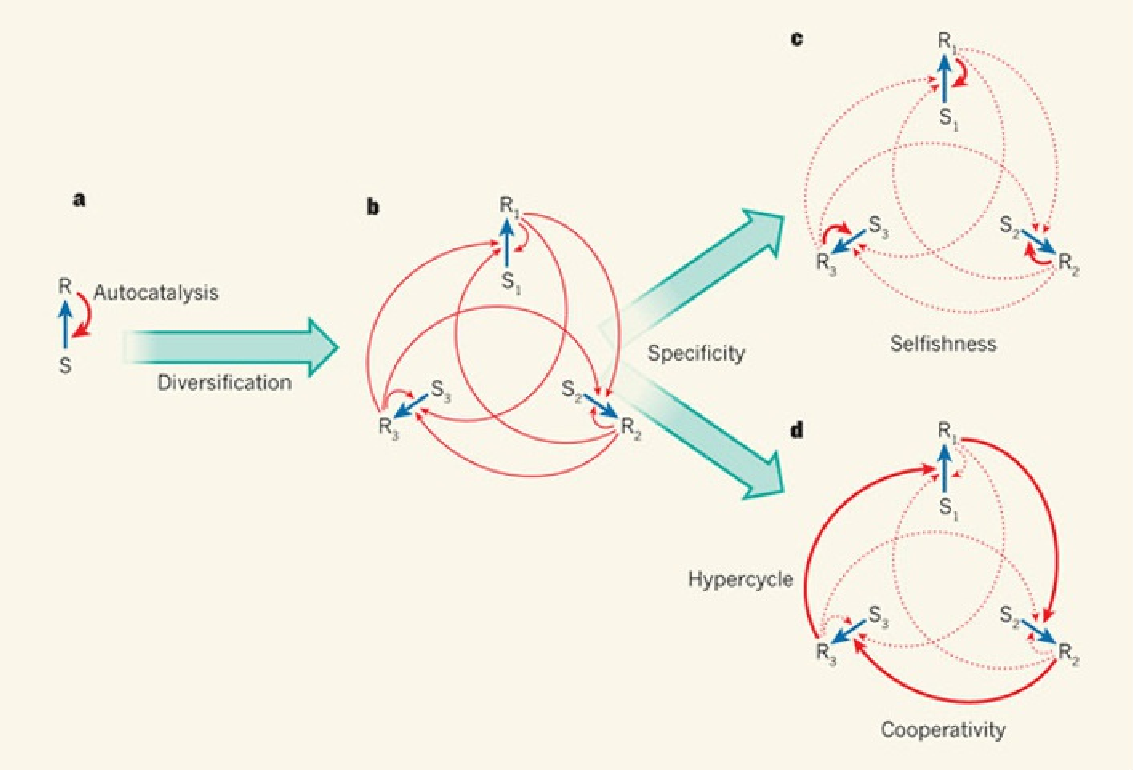

Figure 3. The emergence of hypercycles. **a.** A primordial replicator molecule (R) enhances its own assembly from substrate molecules (S) in a simple autocatalytic cycle. **b,** imperfect replication generates a set of related replicators, each promoting the synthesis of all the others. **c, d,** The introduction of biases in replicator specificity gives structure to the network and can lead to selfish subsystems (**c**) or to a cooperative 'hypercycle' (**d**). Such hypercycles remain globally autocatalytic, but are more resistant to the accumulation of mutations, enabling replicators to specialize and to acquire new functions. Thick and dashed red arrows indicate increased and decreased efficacy, respectively, at enhancing replicator assembly. Image and image description reproduced from [54].

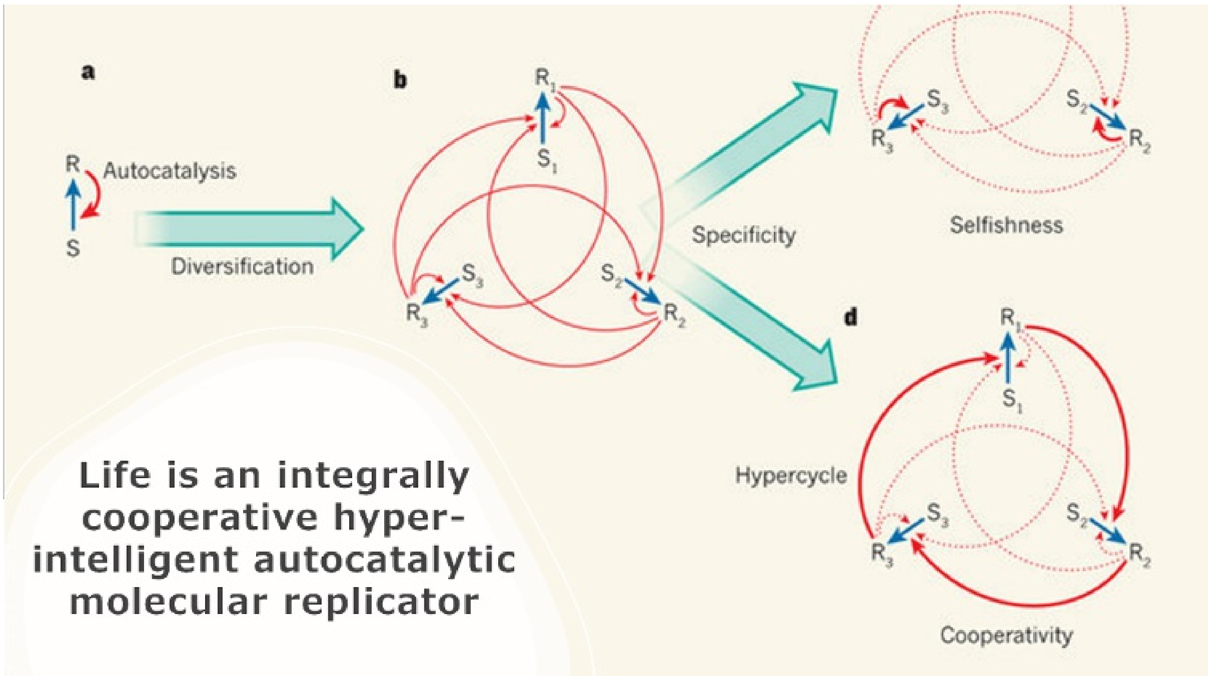

Figure 4. Image from a lecture given by the author, in which the cooperativity and hyperintelligence of the molecular replicator

system of the living organism is described.

Biophysicist Robert Rosen identified the minimal capabilities that a material system would need to possess in order to be classified as a *functional organism* and hence said to be "alive", which he described as (**M**, **R**) systems [56][57]. In this kind of system **M** stands for the metabolic and **R** stands for the 'repair' subsystems of a simple functional organism. His classification system for the living state emphasized organization over molecular structure, and as such the informational quality of the living system is of utmost importance. Of significant salience to the novel definition provided herein is Rosen's finding that (*M*, *R*) systems cannot be simulated by Turing machines[58], and hence a set of programmed responses, no matter how human-like, does not indicate the presence of life or awareness.

Lee Cronin and Sara Imari Walker's *Assembly Theory* conjecture posits that life and the living system is identifiable by the complex objects that are assembled as a result of its control over and engineering of matter. As Sara Imari Walker describes it "A popular definition, often used by NASA, is that life is a self-sustaining chemical system capable of Darwinian evolution. Every word in there is problematic. I don't think life necessarily needs to be chemical. It's a much more abstract phenomenon. Life is about how information structures material objects and what objects are selected to exist, regardless of whether those things are chemical or not" [59].

In studies conducted with Paul Davies, Walker has emphasized that "the unique informational narrative of living systems suggests that life may be characterized by context-dependent causal influences, and in particular, that top-down (or downward) causation—where higher-levels influence and constrain the dynamics of lower-levels in organizational hierarchies—may be a major contributor to the hierarchal structure of living systems" [60]. Michael Levin and colleagues have discussed the importance of goal-directed (cybernetic) processes as a salient characteristic of the morphogenic development and homeostasis of the living organism and has argued against the exclusive focus on molecular biology as the only source of order in life, highlighting the importance of multiple lenses, including a cognitive one, on the problem of biological origins [61]. Levin and colleagues have detailed why living things are not (20th century) machines [62], highlighting the fact that machines are predictable while life is unpredictable. Again, a key concept for the definition and discussion explored in this study.

These definitions from Walker, Rosen, Cornish-Bowden, and others are foundational to our understanding of the fundamental nature of the living organism, however it will be discussed here that they do not yet achieve the universality of the state of being alive and that there remains a (until now) unidentified key criterion that distinguishes life from abiotic systems.

In this provisional study, a novel hypothesis for the defining characteristic of life is proffered: in which the far-from-equilibrium thermodynamic conditions that enable the utilization of energy for the intelligent engineering of matter by an intrinsic awareness within a material system is the defining characteristic of the living state. As will be seen, the definition for life provided in this manuscript is an unambiguous state that can be objectively observed and verified, is universally exhibited by all systems that are in the state of being alive and provides key insight into *what life is* and what distinguishes a living system from abiotic matter.

What is the relationship between internal experience of phenomena and life?

Here it is posited that awareness and the volitional behavior that arises from awareness are inextricably linked with and a defining characteristic of the state of being alive. The postulate is formulated within the framework of a protopanpsychism model, in which physical phenomena have an intrinsic experiential state—qualitative characteristics of matter are intrinsic properties. Obviously, awareness occurs across a spectrum, such that proto-awareness may have no cognitive traits associated with, while at the other end of the spectrum the self-awareness possessed by *Homo sapiens* is highly cognitive, analytical, and self-reflective. Basic states of matter will not have this same level of cognitive awareness possessed by humans, however our highly cognitive form of awareness is, as hypothesized in protopanpsychism, derived from aggregation and complexification of lower-level basal awareness, that is intrinsic and possessed by all matter. Such that even the most seemingly rudimentary or primordial life form necessarily possesses a basal state of awareness. Awareness and life are inextricable, even when the term "life" is used in a metaphorical sense— such as "there was no life in the music"— this is a statement tantamount to saying there was no consciousness present; it was mechanical, i.e., *predictable*. When consciousness is present, behaviors are adaptive, intelligent, and seemingly *unpredictable*; a strong indication that the mechanisms engendering consciousness are non-computational and non-predictable. Because of the inherent difficulty in measuring, or even ascertaining if consciousness is present— mostly due to a complete lack of consensus of what consciousness is— the following definitions can be a *modus operandi* for the evaluation of whether a system can be considered as alive and / or conscious.

Definitions

To make the following discussion clearer, an elucidation of the term "system" will be provided. A system will be defined as:

A delimited collective of elementary units that are interrelated such that they produce an identifiable pattern in the overall activity and interaction of the gestalt; thus, making the elementary units distinct subunits of an integrally interacting and intercommunicative network—often with emergent characteristics that would not be predictable from the behavior of the individual subunits (synergetic emergentism). Moreover, a state is defined as the overall arrangement, orientation, physical and energetic characteristics of that system at any instant of time.

Definition of the Living State –

A physical system far from thermodynamic equilibrium that intelligently utilizes its low entropy configuration to control and engineer matter and energy in a goal-oriented manner, usually though not necessarily to maintain and replicate the low entropy state.

The demarcation between abiotic “non-living” matter and physical systems that are “alive” is the observable intelligent utilization of a low entropy configuration to manipulate matter and energy in a goal-oriented manner, usually— though not necessarily— to maintain and replicate the far from equilibrium thermodynamic state. There are many natural situations in which a far from thermodynamic equilibrium state arises. When a system develops within the far from thermodynamic equilibrium condition and the emergent system utilizes volitional behavior and intelligent operations to maintain or replicate the low entropy configuration via the control and engineering of matter and energy, that system is alive.

Here, we can perform a *gedankenexperiment* and imagine a scenario where a far from thermodynamic equilibrium state arises naturally, and there develops no emergent system that utilizes the low entropy configuration of the state for information processing to intelligently execute operations, which maintains and proliferates that low entropy state. In such a case scenario, the state will end once the conditions that give rise to the far from thermodynamic equilibrium cease. This serves a poignant distinction between mere low entropy configuration states and those manipulated and engineered by an intelligent system with the goal of maintaining, replicating, and /or proliferating the low entropy configuration and the information dynamics it enables in the physical system via intelligence.

The far-from-equilibrium thermodynamic state is not the key feature of the living state, but a necessary condition for entropy-infodynamics, like signal input (sensory information), homeostatic analysis, memory, and execution of operations (behavior). The key feature of an ensemble of matter and energy that demonstrably satisfies the definition of being alive is the intelligent utilization of low entropy configurations of matter and energy to control and engineer matter and energy in a goal-oriented manner—wherein goal-oriented behavior is manifest as a result of a system possessing non-predictable adaptive response pathways, also referred to as stand-alone volition, which is a defining quality of intelligent behavior and a condition of the non-computability of consciousness. It is the *intelligence* and observable goal-oriented behavior that demarcates a system as alive and is the distinguishing characteristic between abiotic matter (which in some cases may be quite structurally or dynamically complex and even verge on life-like activities) and living matter.

This provisional definition is a common feature to all living organisms and will potentially be observed in the not-too-distant future in synthetic living systems, therefore the criterion is generalizable to any configuration of matter and energy and is requisite for a system to display the characteristic of being alive. It can be measured and observed, so that a system, whether organic, non-organic, or synthetic, can be positively and unambiguously identified as satisfying the definition of a living state, and hence is alive.

A key feature of living systems is learning. Learning requires the capacity for recording information, or memory. Memory, and hence learning results in adaptability, or evolution, and non-programmable behavior of a system. This results from the recursive nature of memory and learning, in which information fed into a system is recorded and processed, changing the state of the system, and the result is fed-back into the global system. This continues in a re-iterative process. Thus, recursive and iterative feedback operations are a key mechanism underlying life and a demonstration of the intrinsic intelligence and stand-alone volition of the natural living state.

If a system conforming to the definition of life is observed for an appropriate length of time, the key feature of goal-oriented behavior will become evident. Goal-oriented behavior, what here is referred to as stand-alone volition, results from non-programmable responses to stimuli of states. How does non-programmability arise? In materialistic mechanics, everything is the result of programmed responses. Because constants, laws, and in the case of neurocomputational consciousness: genes and circuitry, are the pre-programming from which all ordering and animating dynamics arise. Under this paradigm, all spacetime-matter events are computational and predictable.

However, it is possible to demonstrate that life exhibits non-predictable behavior— responses that cannot be programmed. The key defining characteristic of life and the living system is non-computational non-programmed behavior that arises from intrinsic intelligence and stand-alone volition. It can further be demonstrated that non-predictable, goal-oriented behavior arises from a degree of self-awareness, that forms a spectrum among living systems, as goal-oriented behavior is predicated by a certain level of awareness within a system that it is a “self”—an individualized distinct and delimited system that is distinguishable to a certain extent from the environment (even though the individualization is limited since it is always a subsystem of the environment, and certainly a subsystem of the universe). The degree of self-awareness is correlated with the degree of memory and learning capabilities of the system.

Goal-oriented behavior can therefore be used to positively, and objectively determine when a system has consciousness.

Life necessarily requires consciousness to create the awareness that allows for self-directed action. If there is no consciousness, there is no capacity for awareness, and therefore all observed behaviors of an object or system will be the result of extrinsic forces acting upon the object or system and will thus be passive responses with no volition attached to them whatsoever. This is a good definition for an automaton – a nonliving, mechanical system that responds to environmental stimuli with no stand-alone volition or self-directed behavior. Under the current consensus paradigm, developed under the 20th century conception of the universe as a machine and all seemingly intelligent processes / behavior as computationally-based (programmed), all living beings (and to some this includes humans) are considered automatons [63][64][65][66].

Definition of a living system –

A delimited configuration of matter and energy that contains stand-alone volition, which can be identified by intelligent and goal-oriented behavior.

Critical points on the Definition of a living system:

Note that the definition of a living system does not include anything about the specific constitution of the system, such as a requirement that it be composed of organic molecules, or any requirement for demonstrating the capacity for growth, reproduction, functional activity, or continual change preceding death. While being highly similar to organic life in terms of energy requirements, a living system is a more general state of matter and energy, differentiable from organic lifeforms by the fact that it does not necessitate the inclusion of organic molecules within the ordered system. Put another way**, while all organisms are living systems, not all living systems are organisms.**

The defining characteristic of a delimited arrangement of matter and energy being identified as a living system is intelligence and goal-oriented behavior. This means that the living system is defined by the attribute of sentience within matter—matter that forms a sentient system.

Definition of a sentient system–

A system that orders matter and energy into states containing meaning to that system and uses the information contained therein to execute actions or perturbations of pre-existing states to affect outcomes based on the stand-alone volition of the system in a goal-oriented manner.

Critical points on the Definition of Sentience:

A sentient system necessarily conforms to the definition of a living system and vice versa. Information is energy or states of matter that have been ordered in such a way that the states have meaning to the system that has ordered it, and therefore a sentient system requires the arrangement and dynamics like that found in the living system—namely far-from equilibrium thermodynamics— in order to assign states of matter and energy informational quality, read and process the emergent syntax, and execute actions based on the meaning accessible to the arrangement of matter and energy based on its sentient properties.

Sentience necessarily requires consciousness, for that is what imbues the system with the awareness necessary to have stand-alone volition, reflexive introspection, and thus goal-oriented behavior. Awareness, the state by which qualitative properties of the universe are experienced, is an ontological primary and fundamental attribute of nature. Awareness imbues arrangements of matter and energy in the universe with sentience, whereby when thermodynamic conditions are favorable (far-from equilibrium) there is directional intelligence able to further order those networks of matter and energy into a sentient system. Via awareness, a sentient system has stand-alone volition, and thus can order and direct matter so as to maintain and / or expand the far-from equilibrium info-dynamic state forming a living system. The living system can be identified as alive via the goal-oriented behavior and intelligence arising from the sentience and stand-alone volition of the system.

Stand-alone Volition

The behavior of stand-alone volition is engendered by consciousness, bestowing a certain level of self-awareness (which varies among sentient systems across a wide spectrum). The behavior of stand-alone volition arises due to the fact that at a certain level the sentient system is aware of a “self” that is its state, and there is a certain impetus to maintain or replicate this state of “self”. The immediate contention from the conventional scientific purview will be that consciousness arises from computational activity of the complex neuronal circuitry of human brains, and so cannot be a property of other lifeforms, and hence it is erroneous to suggest that metazoans, and certainly not unicellular eukaryotes, prokaryotes, viruses and biochemical networks can possess stand-alone volition. While the neurocomputational paradigm of consciousness may be taken as axiomatic by most scientists, it is nevertheless an assumption, and it currently has no capability to explain how consciousness is engendered within the human brain—so much so, that this is referred to as the *hard problem of consciousness*.

It is a hard problem within the model of brain-as-a-computer and consciousness as neuronal programming, because there is no way within contemporary science to explain how a subjective experience is generated by electromagnetic activity between networks of neuronal synaptic junctions. The postulate of *panprotopsychism*, on the other hand, can account for consciousness because basal awareness (not cognitive awareness) is an innate property of matter. As an ontological primary, it does not have preceding mechanism from which it emergers (the scientific explanation of electromagnetism which eventually emerged in the 19th century involved the postulation of new fundamental properties and forces: electromagnetic ones; perhaps the scientific explanation of human consciousness, when it eventually arrives, will be similarly non-reductive in postulating fundamental kinds of consciousness). As such, it is a quality of atoms, molecules, and becomes observable at a certain threshold of far-from thermodynamic equilibrium and complexity, like that in hypercyclic autocatalytic biochemical networks, genetic algorithms, and certainly at the level of unicellular and metazoan organisms.

Consciousness is the phenomenon of experience. From a purely physics point-of-view, there is no reason why any physical state, process, or property of the universe should have an associated experience of that state, process, or property by any particular configuration of matter in the universe. Indeed, it is currently not possible to explain how a particular configuration of matter and energy in the universe is able to have an awareness and experience of qualia. This phenomenon referred to as consciousness requires an *experiencer*: that is a system with sentience, a system that forms a subject within which there is a quality to experience i.e., subjective experience of qualia. The predominant approach within conventional scientific thought is to posit that consciousness is an epiphenomenological state generated by the electrochemical activity of the brain. This approach makes consciousness a “hard problem” within the conventional purview of science because an epiphenomenological approach is unlikely to ever explain how a collection of matter and energy suddenly generates an awareness, or *experiencer* that is able to have a qualitative experience of objective states that have no inherent subjective qualities (within the cartesian duality of conventional scientific theory).

That is why it is posited here that awareness is an ontological primary. All states of matter and energy in the universe have a corresponding experience; there is a fundamental basal awareness and sentience that is an intrinsic and indelible component of the dynamics that produce the laws, constants, and forces of the universe. At the quantum scale, this is characterized by the entanglement network of spacememory, comprised of a multi-connected spacetime geometry of micro-wormholes, and at cosmological scales by the cosmic web—from the smallest to the largest scale there is a neuromorphic network that is naturally sentient and the reservoir of primary awareness within the universe. Living systems, like humans, are tapped into this universal neuromorphic network, and that is where awareness and sentience is sourced in these living systems. The living system emerged from the coupling of molecular matter with the neuromorphic network of spacememory, which gave intelligence and goal-oriented behavior to biochemical networks, and as these biochemical networks evolved into cells, metazoans, and animals the intrinsic intelligence and goal-oriented behavior of the molecular networks was expanded to include multi-level domains of the organism with scale-free cognition. High order molecular levels of this holofractal nested architecture of scale-free cognitive domains developed refined and sophisticated specializations of the basal awareness of intrinsic consciousness, such as conceptual awareness and self-awareness.

From this, we can see that in theory it is possible for artificial (man-made) systems to be engineered and constructed in such a way that they are coupled to the spacememory network such that the basal awareness and natural sentience is operational within the artificial system's functionality. This will most likely have to be done at the nanoscale, with nanomolecular engineering to achieve a level of information coupling with the nonlocal neuromorphic network of the universe that the artificial system contains scale-free cognition and intrinsic awareness. This raises the question; how will we know whether such an artificial system is really conscious?

The current consensus criterion for assessing whether an artificial system is conscious is the Turing Test. The Turing Test posits that if in the interaction of a human with an artificially intelligent system, the human is unable to distinguish whether they are interacting with another human or an artificial system, that artificial system must be conscious. However, as will be explained, the Turing Test is not a viable criterion to assess whether or not an artificial system has awareness and is conscious. An artificial system can be sufficiently programmed to be indistinguishable from the behavior of a human. But programmed responses are the opposite of a system with agency. The true test of whether a system is conscious is if it can be ascertained that the system gives *non-programmed responses*. In addition to serving as a test for assessing whether an artificial, or natural system like an animal, possesses consciousness the following criterion also demonstrates a key characteristic of consciousness—that it is non-computable and non-programmable.

Criterion for Identifying if a System is Conscious –

A system that demonstrates goal-oriented behavior / stand-alone volition (volitional behavior that is non-programmable) is aware and possesses consciousness.

Methodology to Empirically Ascertain if a System is Conscious

Note: if a system is conscious, by the definitions herein, it is alive. And conversely, if a system is alive, then it has a certain level of consciousness, whether a basal-level of awareness possessed by a unicellular organism, or the complex cognitive-level of awareness of *Homo sapiens sapiens*— or somewhere within the spectrum between the two examples given. If a system is found to exhibit goal-oriented behavior, it can be assumed that it has stand-alone volition, which means that there is a certain level of self-awareness—i.e., the system behaves as if there is a certain level of awareness of "self".

To ascertain if a system is alive / conscious it must be tested against the null hypothesis that all behaviors, actions, and processes of the system are programmed responses in which any seeming goal-oriented behavior is a simulacrum of intelligence and in fact the system is an automaton. The null hypothesis is the default assumption of conventional scientific theory, whereby all manifestations of intelligence are superficial (there is no intrinsic intelligence) and all processes, even those of the living system, are the result of blind automata, and as such can be fully replicated by a computational program:

> *Note, this is why the idea that the universe could be a simulation is popular, as it is assumed that every aspect of the universe can be replicated by a blind, non-living program. The simulation hypothesis is another instance of the inclination of scientists to equate whatever the present era's apex technology is to the underlying function of everything in the universe. Thus, the brain is a computer, genetic algorithms are computational, as is the fundamental interactions of matter. One of the shortcomings of this proclivity, however, is that today's digital computers are not the ultimate apex information processing technology, anymore than the 19th century steam engine was the apex of propulsion technology, yet we are left to this day with the ramifications of equating the universe with a 19th century conception of a thermodynamic system (see the heat death of the universe). If there will be an apex information processing technology, it will be based on the way the universe naturally organizes and exchanges information, which is not computationally based. digital computers (our most advanced present means of information processing) will seem technologically rudimentary to future quasi-instantaneous information processing systems, like the exchange-free quantum computer; utilizing traversable wormhole teleportation [67]. Hence, for example, the mind and the physiological correlates of mental processing are not performing sequential digital computations to remember past states (memory) where a network of neurons represent "on" / "off" binary values— but instead, there is an instantaneous direct accession of past states (and even potential "future" states) via the temporal entanglement of the intrinsic multiply-connected wormhole network of space. A computer based on the same principles will not so much process information, but instantaneously access the output (this can also be thought of in terms of the multiverse: in which there is access to parallel universes where "answers" have already been computed and are therefore available in universes where the actual sequential information processing has not yet physically occurred). Since quasi-instantaneous information accession via the spacememory network is how information is naturally ordered and communicated within the universe, it will not be possible to fully simulate the universe via rudimentary binary digital computations.*

To test if a system is conscious, a behavior must be identified as exhibiting the quality of volition, i.e., the system performed a certain action to achieve a particular outcome or terminal state, a goal. It must be assumed that the behavior is a programmed response, and only a simulacrum of teleological function or volitional purpose. This assumption must be tested by setting up the conditions required to repeat the behavior, but introducing conditions that will inhibit or block the execution of that behavior, and hence impede the system from achieving its "goal". If it is a programmed behavior, the program will be blocked by the change. If, however, it is the behavior of a truly sentient system, the system will exhibit adaptive behavior, and change its actions in response to the perturbation to achieve the terminal outcome or goal. This kind of adaptive response is the hallmark of intelligence—the ability to achieve an outcome (a goal) even against changing conditions and unforeseeable impediments.

It is possible that the system has adaptive programming, so perturbations must be sequentially introduced until it is sufficiently demonstrated that the system's behavior is unpredictable, and hence not programmed. The system can no longer justifiably be considered an automaton, the adaptive behavior can no longer be considered a simulacrum of intelligence, and it must be reasonably considered that the system contains a certain level of self-awareness, is conscious, and hence is alive.

Since consciousness is an ontological primary, and a subjective experience of qualia by an*experiencer*, it is impossible to empirically prove with 100% certainty that a system is conscious. However, the criterion defined herein and the methodology to assess the criterion can be utilized to approach a definitive answer to whether a system is alive and / or conscious with a reasonably high degree of confidence, which should be sufficient in most circumstances to treat the system as sentient (i.e., to avoid causing undo suffering to the system or arbitrarily terminating its sentient / living state).

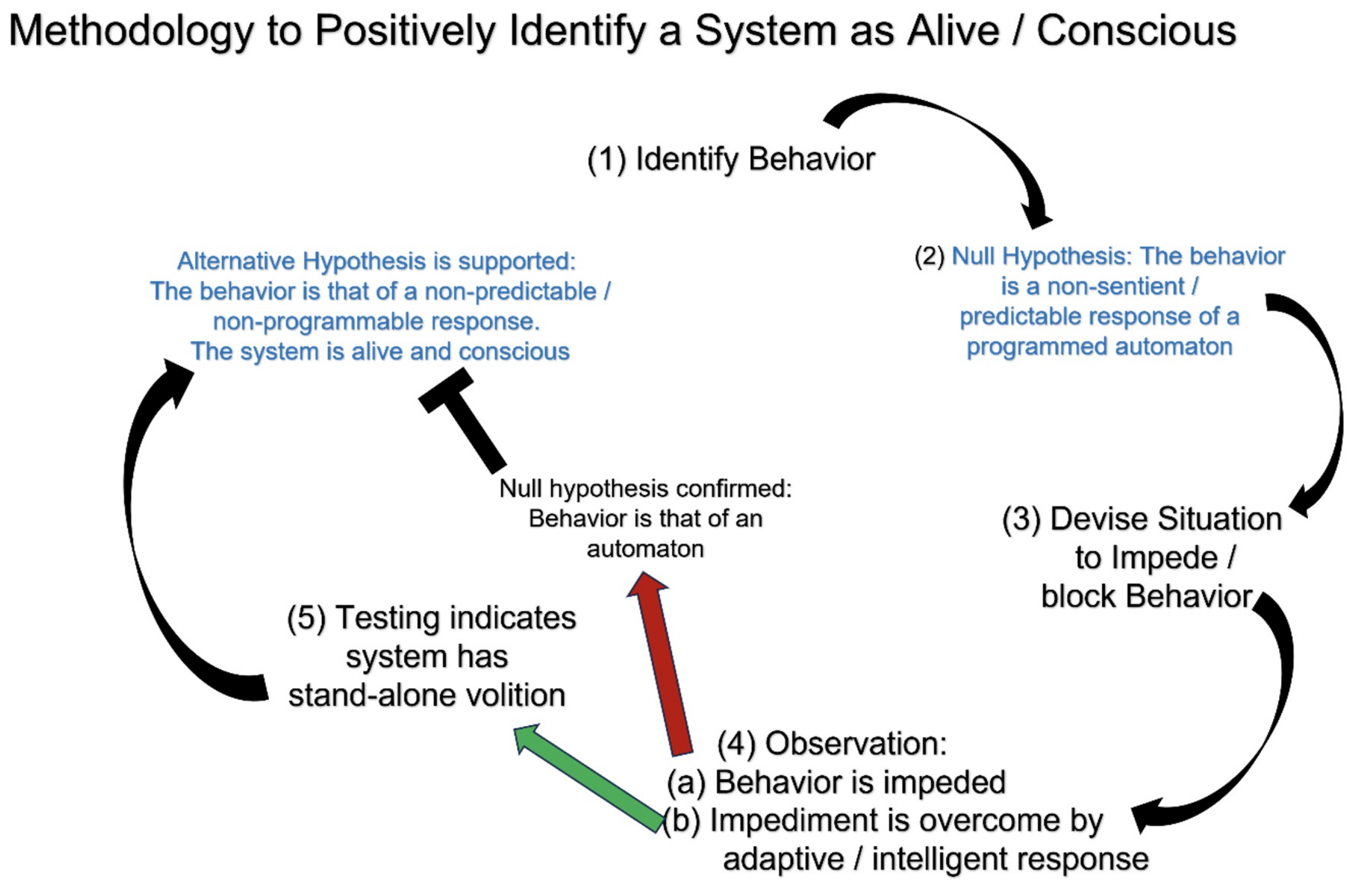

Figure 5. Diagram for empirical methodology to positively identify a system as alive and conscious.

To illustrate how this methodology will be utilized in practice—as a test of the criterion for a system to be alive and conscious, as well as testing empirically the falsifiability of the postulate—consider the following example. The conventional scientist will consider most lifeforms as unfeeling molecular machines: the statement by biochemist Athel Cornish-Bowden (available in his review of the preprint of this article- https://www.qeios.com/read/1C5B8L) is exemplary of this predominant assumption, in which he states "I don't think one can be conscious without being alive, but one can certainly be alive without being conscious. Bacteria are certainly alive, but you need to be an adherent of a fringe religious sect to think they are conscious. What about a much more complex organism like an ant? Is it alive? Just about everyone would say yes. Is it conscious? I very much doubt it." Taking the prokaryote as an example, this is erroneously considered as a "simple organism", however at the molecular level the prokaryote is *almost* incomprehensibly complex, dynamic, and this unicellular class of organism can be justifiably characterized as masters of biochemistry and the control of matter at the molecular, atomic, and subatomic level. Recalling from the introduction that "nobody has the slightest idea how anything material could be conscious. Nobody even knows what it would be like to have the slightest idea about how anything material could be conscious" [ibid. [25]], we cannot justifiably dismiss outright the notion that the prokaryote may have a basal-level awareness of protoconsciousness and internal experience of phenomena—especially considering that its internal organization is orders of magnitude more complex and dynamic than any non-living material. From the methodology outlined in this study, we do not have to speculate but instead can test via experiment this question.

Similar to previous experimentation that demonstrated directed mutagenesis capabilities by the prokaryotic species *Escherichia coli* [68][69]—in which gene knock-out constructs of the *lac* allele in the Lac⁻ α45 strain demonstrated a high rate of reversion to Lac⁺ after plating on minimum lactose medium—a bacterial species can be challenged with a gene knockout construct that impedes a beneficial but nonvital behavior, like lactose metabolism in the previous example (step 3 in **Figure 5**). If it is found that after several passages of the bacterial strain that there is reversion in the gene knockout to an operational sequence, and the prokaryote effectively bypasses the impediment via direction of adaptive mutation (step 4(b) in **Figure 5**) and it is found that this occurs at a higher rate than what would be expected from purely random mutagenesis—in which it is unlikely that such an event will even occur in a reasonable timeframe for the experiment—then following **Figure 5** it can be concluded that (5) testing indicates the system has stand-alone volition. Since it will still be maintained by reductionists-mechanistic scientists that the response was the result of adaptive pre-programmed behavior, it may be necessary to identify such pre-programmed mechanisms and include them in the knock-out, such that if reversion is again observed it cannot be attributed to a pre-determined genetically programmed response. If there is such an outcome following the experimental methodology, it can be concluded as outlined in **Figure 5** that the behavior is that of a non-predictable / non-programmable response and that the system is alive and conscious. If adaptive and intelligent responses are not observed, or if they can be justifiably attributed to pre-programmed deterministic responses (not that of unpredictable stand-alone volition), then the hypothesis presented in this study will be empirically falsified.

Discussion

Life is defined to be a particular state exhibited by a system's tendency to behave as if it were a distinct entity, with goal-oriented, or volitional behavior. By this definition, something that would normally be regarded as living would be defined otherwise. For example, a single cell could be reduced to a veritable biochemical factory, in which there is no observable behavior of stand-alone volition, such as reproduction or action taken to thrive. The cell would not technically be defined as alive, although it is obviously a biological system, it can be manipulated is such a way as to become an automaton. Conversely, if a machine, which we would normally regard as non-living, were to demonstrate awareness of itself as a distinct entity, and exhibit stand-alone volition, it would be regarded as conscious – and hence *alive.* Therefore, there is a universality to consciousness and life – it is not simply restricted to a biological, organic system.

These are technical definitions, aimed at approaching a more refined, and precise approximation of what consciousness and life is, and enabling an unambiguous means to identify these qualities. These definitions are taken to be provisional, as future theoretical and empirical developments may provide an update and refinement of the definitions (since this is about understanding and not "being right", such revisions will be welcomed). Fundamentally, information flows continuously through all systems at all scales, via spacememory of which everything is comprised, and as such, life and consciousness may be connected in all things. However, there is an objective and qualitative difference in systems that depends on the degree to which consciousness and life are *exhibited*. Even high-energy plasmas under certain experimental conditions can exhibit very life-like qualities, and yet, there is little moral objection to "pulling the plug" on these systems once an experiment is concluded. By the definitions outlined in this paper, guidelines can be established from unambiguous criteria to provide for ethical practices in the treatment of systems that are identified as being alive.

Other References

- Martin M. Hanczyc; Engineering Life: A Review of Synthetic Biology. Artif Life 2020; 26 (2): 260–273. doi: https://doi.org/10.1162/artl_a_00318

References

1. ^*What Is Life? The Physical Aspect of the Living Cell Erwin Schrödinger Cambridge University Press (1944)*
2. ^*WATSON, J., CRICK, F. Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid. Nature 171, 737–738 (1953). https://doi.org/10.1038/171737a0*
3. ^*F. H. C. Crick and L. E. Orgel, "Directed panspermia," Icarus, vol. 19, no. 3, pp. 341–346, Jul. 1973, doi: 10.1016/0019-1035(73)90110-3*
4. ^*M. Kunimoto and J. M. Matthews, "Searching the Entirety of Kepler Data. II. Occurrence Rate Estimates for FGK Stars," AJ, vol. 159, no. 6, p. 248, May 2020, doi: 10.3847/1538-3881/ab88b0.*
5. ^*L. Slocombe, M. Sacchi, and J. Al-Khalili, "An open quantum systems approach to proton tunnelling in DNA," Commun Phys, vol. 5, no. 1, Art. no. 1, May 2022, doi: 10.1038/s42005-022-00881-8.*
6. ^*Alirol, O. Nature's Effective Way of Conducting Electrons (2019). Accessed via The Resonance Science Foundation https://www.resonancescience.org/blog/Natures-effective-way-of-conducting-electrons on 07-21-2023.*
7. ^*Karen Michaeli and Ron Naaman, Origin of Spin-Dependent Tunneling Through Chiral Molecules, The Journal of Physical Chemistry C 2019 123 (27), 17043-17048. DOI: 10.1021/acs.jpcc.9b05020*
8. ^*Brown, W.D. Attosecond-Scale Research Elucidates Dynamics of Spin-Dependent Quantum Tunneling Through Chiral Molecules (2023). Accessed via The Resonance Science Foundation https://www.resonancescience.org/blog/attosecond-scale-research-elucidates-dynamics-of-spin-dependent-quantum-tunneling-through-chiral-molecules on 07-21-2023.*
9. ^*J. A. Fereiro, X. Yu, I. Pecht, M. Sheves, J. C. Cuevas, and D. Cahen, "Tunneling explains efficient electron transport via protein junctions," Proceedings of the National Academy of Sciences, vol. 115, no. 20, pp. E4577–E4583, May 2018, doi: 10.1073/pnas.1719867115.*
10. ^*A. O. Schouten, L. M. Sager-Smith, and D. A. Mazziotti, "Exciton-Condensate-Like Amplification of Energy Transport in Light Harvesting," PRX Energy, vol. 2, no. 2, p. 023002, Apr. 2023, doi: 10.1103/PRXEnergy.2.023002.*
11. ^*T. Hayashi and A. A. Stuchebrukhov, "Electron tunneling in respiratory complex I," Proceedings of the National Academy of Sciences, vol. 107, no. 45, pp. 19157–19162, Nov. 2010, doi: 10.1073/pnas.1009181107.*
12. ^*'Panpsychism' (2017) in Schneider, S. & Velmans, M. (Eds.) Blackwell Companion to Consciousness, 2nd Edition, Blackwell.*
13. ^*Philip Goff, 'How exactly does panpsychism explain consciousness?' forthcoming in Journal of -Consciousness Studies. Accessed via https://philipgoffphilosophy.com/academic-papers, 07-21-2023*

14. ^Diósi, L. (1987-03-16). "A universal master equation for the gravitational violation of quantum mechanics". Physics Letters A. 120 (8): 377–381. doi:10.1016/0375-9601(87)90681-5
15. ^Diósi, L. (1989-08-01). "Models for universal reduction of macroscopic quantum fluctuations". Physical Review A. 40 (3): 1165–1174. doi:10.1103/PhysRevA.40.1165
16. ^Penrose, R. (1989). The emperor's new mind: Concerning computers, minds, and the laws of physics. Oxford University Press.
17. ^Hameroff, Stuart; Penrose, Roger (2014). "Consciousness in the universe". Physics of Life Reviews. 11 (1): 39–78. doi:10.1016/j.plrev.2013.08.002
18. ^Brown, W. Microtubule-Actin Network Within Neuron Regulates the Precise Timing of Electrical Signals via Electromagnetic Vortices. (May 2023). Accessed via The Resonance Science Foundation https://www.resonancescience.org/blog/microtubule-actin-network-within-neuron-regulates-the-precise-timing-of-electrical-signals-via-electromagnetic-vortices on 07-21-2023.
19. ^P. Singh et al., "Cytoskeletal Filaments Deep Inside a Neuron Are not Silent: They Regulate the Precise Timing of Nerve Spikes Using a Pair of Vortices," Symmetry, vol. 13, no. 5, Art. no. 5, May 2021, doi: 10.3390/sym13050821.
20. ^S. Sahu, S. Ghosh, K. Hirata, D. Fujita, and A. Bandyopadhyay, "Multi-level memory-switching properties of a single brain microtubule," Applied Physics Letters, vol. 102, no. 12, p. 123701, Mar. 2013, doi: 10.1063/1.4793995
21. ^James A. Reggia, Garrett Katz, Di-Wei Huang. What are the computational correlates of consciousness? Biologically Inspired Cognitive Architectures, Volume 17, 2016, Pages 101-113, ISSN 2212-683X, https://doi.org/10.1016/j.bica.2016.07.009
22. ^Chalmers, David (1995). "Facing up to the problem of consciousness". Journal of Consciousness Studies. 2 (3): 200–219.
23. ^Harnad, Stevan (1995). "Why and how we are not zombies". Journal of Consciousness Studies. 1: 164–167.
24. ^Harnad, Stevan (April 2000). "How/why the mind–body problem is hard". Journal of Consciousness Studies. 7 (4): 54–61.
25. a, bFodor, Jerry. "The big idea: Can there be a science of mind?" _The Times Literary Supplement_ (London), July 3, 1992, Issue 4657. pp. 5-7.
26. ^T. Nagel, "What Is It Like to Be a Bat?," The Philosophical Review, vol. 83, no. 4, p. 435, Oct. 1974, doi: 10.2307/2183914.
27. ^D. Radin, L. Michel, J. Johnston, and A. Delorme, "Psychophysical interactions with a double-slit interference pattern," phys essays, vol. 26, no. 4, pp. 553–566, Dec. 2013, doi: 10.4006/0836-1398-26.4.553.
28. ^S. A. Kauffman and D. Radin, "Quantum aspects of the brain-mind relationship: A hypothesis with supporting evidence," Biosystems, vol. 223, p. 104820, Jan. 2023, doi: 10.1016/j.biosystems.2022.104820.
29. ^Sheldrake, R., Overby, C., Beeharee, A. The Sense of Being Stared At: An Automated Test on the Internet. Journal of the Society for Psychical Research, (2008) 72, 86-97. https://www.sheldrake.org/files/pdfs/papers/The-Sense-of-Being-Stared-At-An-Automated-Test-on-the-Internet.pdf
30. ^Sheldrake, R., Smart, P. A Dog That Seems To Know When His Owner is Coming Home: Videotaped Experiments and Observations. Journal of Scientific Exploration 14, 233-255 (2000). https://www.sheldrake.org/files/pdfs/papers/A-

Dog-That-Seems-To-Know-When-His-Owner-is-Coming-Home_Videotaped-Experiments-and-Observations.pdf

31. ^*J. Sarfatti, “Wheeler-Feynman Generalized Bohm Quantum Potential for Open Far-From-Equilibrium Biological Dissipative Structures with Non-Unitary Post-Quantum Retro-Causal Signal Nonlocality”. Accessed online 07-21-2023: https://www.myexperiment.org/blobs/256/download/WheelerFeynmanBohmPotential.pdf*
32. ^*Gröblacher, S., Paterek, T., Kaltenbaek, R. et al. An experimental test of non-local realism. Nature 446, 871–875 (2007). https://doi.org/10.1038/nature05677*
33. ^*Walleczek, J. and Grössing, G. (2014) The Non-signalling Theorem in Generalizations of Bell’s Theorem. J. Phys.: Conf. Ser. 504, 012001. doi:10.1088/1742-6596/504/1/012001*
34. ^*Adlam, E. Two roads to retrocausality. Synthese 200, 422 (2022). https://doi.org/10.1007/s11229-022-03919-0*
35. ^*Urdaneta, Ines. Fractal Behavior Found in High Energy Collisions and Bose Einstein Condensate Formation! (2022). Accessed via The Resonance Science Foundation https://www.resonancescience.org/blog/fractal-behavior-found-in-high-energy-collisions-and-bose-einstein-condensate-formation on 07-21-2023.*
36. ^*“Mathematical Tool to Help Understand Fractal Structure of Quark-Gluon Plasma,” Lab Manager. https://www.labmanager.com/mathematical-tool-to-help-understand-fractal-structure-of-quark-gluon-plasma-28233 (accessed Jul. 21, 2023).*
37. ^*Brown, W. The Universe Organizes in a Galactic Neuromorphic Network (2021). Accessed via The Resonance Science Foundation https://www.resonancescience.org/blog/The-Universe-Organizes-in-a-Galactic-Neuromorphic-Network on 07-21-2023.*
38. ^*F. Vazza & A. Feletti. The Quantitative Comparison Between the Neuronal Network and the Cosmic Web. Frontiers in Physics (2020) Volume 8, Article 525731. https://doi.org/10.3389/fphy.2020.525731*
39. ^*S. Carlip, “Spacetime foam: a review,” Rep. Prog. Phys., vol. 86, no. 6, p. 066001, Jun. 2023, doi: 10.1088/1361-6633/acceb4.*
40. ^*Brown, W. Neurons Act Not as Simple Logic Gates, But as Complex, Multi-Unit Processing Systems Accessed via The Resonance Science Foundation. (January, 2020). https://www.resonancescience.org/blog/Neurons-Act-Not-As-Simple-Logic-Gates-But-As-Complex-Multi-Unit-Processing-Systems on 07-21-2023.*
41. ^*Albert Gidon et al., Dendritic action potentials and computation in human layer 2/3 cortical neurons. Science 367,83-87(2020). DOI:10.1126/science.aax6239*
42. ^*M. P. A. Fisher, “Quantum cognition: The possibility of processing with nuclear spins in the brain,” Annals of Physics, vol. 362, pp. 593–602, 2015, doi: https://doi.org/10.1016/j.aop.2015.08.020.*
43. ^*R. Thar and M. Kühl, “Propagation of electromagnetic radiation in mitochondria?,” Journal of Theoretical Biology, vol. 230, no. 2, pp. 261–270, 2004, doi: https://doi.org/10.1016/j.jtbi.2004.05.021.*
44. ^*N. Haramein, W. D. Brown, and A. Val Baker, “The Unified Spacememory Network: from Cosmogenesis -to Consciousness,” Neuroquantology, vol. 14, no. 4, Jun. 2016, doi: 10.14704/nq.2016.14.4.961*
45. ^*L. Susskind, “The World as a Hologram,” Journal of Mathematical Physics, vol. 36, no. 11, pp. 6377–6396, Nov. 1995, doi: 10.1063/1.531249.*
46. ^*N. Haramein, “Quantum Gravity and the Holographic Mass,” Open Science Framework, preprint, Feb. 2019. doi: 10.31219/osf.io/5ed8c.*

47. ^*M. Levin, “The Computational Boundary of a ‘Self’: Developmental Bioelectricity Drives Multicellularity and Scale-Free Cognition,” Front. Psychol., vol. 10, p. 2688, Dec. 2019, doi: 10.3389/fpsyg.2019.02688.*
48. ^*Meijer D K F, I Jerman, A V Melkikh, and V I Sbitnev, 2021. “Biophysics of Consciousness: A Scale-Invariant Acoustic Information Code of a Superfluid Quantum Space Guides the Mental Attribute of the Universe,” in Rhythmic Oscillations in Proteins to Human Cognition, A.Bandyopadhyay and K. Ray, Eds. Singapore: Springer Singapore,, pp. 213–361. doi: 10.1007/978- 981-15-7253-1_8.*
49. ^*D. K. F. Meijer and F. Ivaldi, “The Elemental Intelligence of the Cosmos and the Acoustic Quantum Code of Resonant Coherence.”.*
50. ^*S. Alexander et al., “The Autodidactic Universe,” arXiv:2104.03902 [gr-qc, physics:hep-th, physics:physics, physics:quant-ph], Mar. 2021, Accessed: Apr. 16, 2021. [Online]. Available: http://arxiv.org/abs/2104.03902*
51. ^*K. Irwin, M. Amaral, and D. Chester, “The Self-Simulation Hypothesis Interpretation of Quantum Mechanics,” Entropy (Basel), vol. 22, no. 2, p. 247, Feb. 2020, doi: 10.3390/e22020247.*
52. [a, b]*Turing, A. M. (1950). Computing machinery and intelligence. Mind 59, 433–460. doi: 10.1093/mind/LIX.236.433*
53. ^*Cornish-Bowden, A; Cárdenas, ML (7 December 2017). "Life before LUCA". Journal of Theoretical Biology. 434: 68–74. doi:10.1016/j.jtbi.2017.05.023*
54. [a, b]*M. Eigen and P. Schuster, “A principle of natural self-organization: Part A: Emergence of the hypercycle,” Naturwissenschaften, vol. 64, no. 11, pp. 541–565, Nov. 1977, doi: 10.1007/BF00450633.*
55. ^*J. Attwater and P. Holliger, “The cooperative gene,” Nature, vol. 491, no. 7422, pp. 48–49, Nov. 2012, doi: 10.1038/nature11635.*
56. ^*M. L. Palmer, R. A. Williams, and D. Gatherer, “Rosen’s (M, R) system as an X-machine,” Journal of Theoretical Biology, vol. 408, pp. 97–104, Nov. 2016, doi: 10.1016/j.jtbi.2016.08.007.*
57. ^*Cornish-Bowden, A; Cárdenas, ML (October 2007). "Organizational invariance in (M, R)-systems". Chemistry & Biodiversity. 4 (10): 2396–406. doi:10.1002/cbdv.200790195*
58. ^*Rosen, R. (2005). Life Itself: A Comprehensive Inquiry Into the Nature, Origin, and Fabrication of Life (Complexity in Ecological Systems). Columbia University Press. New York.*
59. ^*Lewton, T. (June 2023). How a radical redefinition of life could help us find aliens. Accessed via NewScientist- https://www.newscientist.com/article/mg25834440-800-how-a-radical-redefinition-of-life-could-help-us-find-aliens/ on 07-21-2023.*
60. ^*S. I. Walker and P. C. W. Davies, “The Algorithmic Origins of Life,” J. R. Soc. Interface., vol. 10, no. 79, p. 20120869, Feb. 2013, doi: 10.1098/rsif.2012.0869.*
61. ^*G. Pezzulo and M. Levin, “Top-down models in biology: explanation and control of complex living systems above the molecular level,” Journal of The Royal Society Interface, vol. 13, no. 124, p. 20160555, Nov. 2016, doi: 10.1098/rsif.2016.0555.*
62. ^*J. Bongard and M. Levin, “Living Things Are Not (20th Century) Machines: Updating Mechanism Metaphors in Light of the Modern Science of Machine Behavior,” Frontiers in Ecology and Evolution, vol. 9, 2021, Accessed: Jul. 22, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fevo.2021.650726*
63. ^*Diaspro, A. (2004). Introduction: a nanoworld under the microscope–from cell trafficking to molecular machines.*

Microsc. Res. Tech. 65, 167–168. doi: 10.1002/jemt.20137

64. ^*Davidson, L. A. (2012). Epithelial machines that shape the embryo. Trends Cell Biol. 22, 82–87. doi: 10.1016/j.tcb.2011.10.005*
65. ^*Kamm, R. D., Bashir, R., Arora, N., Dar, R. D., Gillette, M. U., and Griffith, L. G. (2018). Perspective: the promise of multi-cellular engineered living systems. APL Bioeng. 2:040901.*
66. ^*Dennett, D. C. (2017). From Bacteria to Bach and Back: the Evolution of Minds. New York: W.W. Norton & Company.*
67. ^*Brown, W. (April 2023). Experiment Proposed to Demonstrate Traversable Wormhole Via Counterfactual Quantum Teleportation Protocol. Accessed via the Resonance Science Foundation- https://www.resonancescience.org/blog/experiment-proposed-to-demonstrate-traversable-wormhole-via-counterfactual-quantum-teleportation-protocol on 07-21-2023*
68. ^*P. L. Foster, "Adaptive Mutation in Escherichia coli," J Bacteriol, vol. 186, no. 15, pp. 4846–4852, Aug. 2004, doi: 10.1128/JB.186.15.4846-4852.2004.*
69. ^*Pigliucci, M., and Muller, B.G. (2010). Evoltion, the Extended Synthesis. The MIT Press.*