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Can New Life Be Created Synthetically?

Aishwarya Venkatramani *

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Can New Life Be Created Synthetically?

Aishwarya Venkatramani

University of Cambridge; av600@cam.ac.uk

Abstract: This paper presents a concise exploration of the synthetic biology currently to artificially create life, juxtaposed against natural life's emergence over Earth's 4.5-billion-year history. It explores the complexities of life's origins, sustaining factors, and the consequences of synthetic life creation, addressing key scientific milestones such as the Urey-Miller experiment and Jacques Monod's proposals. The narrative navigates through the roles of energy, Maxwell's demons, bifurcations, and genetic information in the emergence and evolution of complex biological systems. Despite significant strides in genetic engineering, the challenge of creating life from scratch persists, necessitating a deep understanding of diverse scientific disciplines. While synthetic biology holds promise for medicine and biotechnology, the creation of truly autonomous synthetic life forms raises ethical concerns. The paper also stresses the imperative for careful ethical evaluation of the societal and environmental implications arising from these advancements.

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1. Introduction

The emergence of life has long been a topic of fascination and inquiry among scientists, philosophers, and curious minds alike. Delving into the possibility of instant creation of synthetic life, and examining it in the wider context of the emergence of natural life over billions of years, opens up a realm of intriguing questions. What insights can we glean from the existence of life on Earth? What nuances are concealed in our current dominant understandings of life and its sustenance? In this , we will embark on a thought-provoking journey to explore the intricacies of life, its origins, the factors necessary for its sustenance, and the potential consequences of synthetic life creation. Through a critical lens, I will examine the notion that life may have originated by chance as a self-perpetuating system away from equilibrium, and consider the prospects of recreating this phenomenon synthetically in a shorter time frame.

Over its 4.5 billion-year history, Earth has undergone significant geological and biological transformations from the evolution of single-celled organisms to complex multicellular life, to the formation and breakup of continents, ice ages, and the rise and extinction of countless species. While geological formations similar to those on Earth can be found on other planets, life as we know it is unique to our planet. This makes life's origin and understanding a complex and ongoing debate among philosophers, scientists, and theologians.

2. Introduction

As scientists, we define life as a self-sufficient chemical system that can process, transform, and accumulate information from its surroundings [1–4]. We identify living organisms based on specific characteristics such as reproduction, metabolism, growth, and adaptation to their environment [5,6].The mechanisms through which these characteristics emerged from non-living matter on early Earth were not understood until the groundbreaking Urey-Miller experiment conducted by Stanley Miller and Harold Urey [7]. This experiment recreated the early environment on Earth and showed that the building blocks of life, such as amino acids, can arise from inorganic matter, providing significant insight into the possible origin of life on Earth.

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The development of life, from building blocks such as amino acids to functional molecules like proteins and RNA, to the complex multicellular systems we see today, was a long and complex process driven by chance and necessity. In his 1971 book "Chance and Necessity," Jacques Monod posited that life is not only a chance occurrence but also has a purpose and necessity [8]. Monod believed that life is teleological, meaning that it has a purpose, and that living organisms must be both autonomously morphogenetic and reproductively invariant to be considered alive [9]. These processes took inorganic geological dynamics to become self-perpetuating life. Being autonomously morphogenetic allows life to self-organise and develop its own shape without external influence, and being reproductively invariant refers to the stable production of similar genetic offspring [10,11].

Autonomously morphogenetic living systems require a constant input of energy to maintain their ordered and complex organisation which involves processes such as metabolism, growth, and reproduction [11]. This demand for energy by living systems inherently means that living systems are inherently always “out of balance” also known as to be away from thermodynamic equilibrium, as they need to create and maintain ordered structures that are typically disordered in nature. The importance of energy input in living systems can be seen in various examples [12,13]. One such example is the process of body temperature regulation in humans [14]. This process requires an energy-intensive mechanism that generates and dissipates heat to maintain a stable internal temperature even when the external temperature fluctuates. Furthermore, studies suggest that the origin of life itself may be linked to the availability and utilisation of energy sources, such as geothermal vents or lightning, which allowed for the emergence of self-sustaining chemical reactions that eventually led to the formation of the first living cells [12].

3. Life as a self-sufficient system

Life requires self-organisation before it can become self-sustaining. This process of self-organisation is complex and has long been difficult to explain using the laws of physics. In 1977, Nobel laureate Ilya Prigogine demonstrated that complex matter can undergo spontaneous and irreversible processes that lead to self-organisation and increased order [13]. Prigogine’s work showed that in living systems, such self-reorganisation can happen to form complex and dynamic structures, which is known as emergence. Therefore, the spontaneous emergence of life is a consequence of the laws of physics pushing a living system away from equilibrium and the self-organising capacity of matter [14,15].

Living systems have evolved various mechanisms to maintain their organisation and function, despite the constant tendency towards disorder dictated by the second law of thermodynamics [16,17]. These mechanisms create conditions that push the system away from equilibrium, towards local order, and are often controlled by external agents known as Maxwell’s demons [18,19]. These demons are hypothetical beings which are machinery in life that can manipulate the energy levels of particles within a system, perceived to be violating the second law of thermodynamics in the process. In biological systems, the role of Maxwell’s demons is played by various molecular and cellular mechanisms that create order and promote self-organisation. Creation of the first cell-like structure which was thermodynamically unfavourable happened in an emergent way outside of equilibrium where individual phospholipids which are hydrophobic formed a circular miscel layer that created the first cell like structure. Such mechanisms are a part of regular life processes like the transfer of Adenosine triphosphate (ATP) energy molecules across cell membranes, the movement of neurotransmitters in neurons, and the self-assembly of proteins by chaperons and other biomolecules [20,21].

The concept of bifurcation provides a useful complement to the role of Maxwell’s demons in understanding how living systems maintain their organisation and function. Bifurcations highlight the fact that small changes in a system’s parameters can lead to significant changes in its behaviour and organisation. can drive the emergence and evolution of complex biological systems [22]. This spontaneous emergence was first demonstrated by Alan Turing in his work on Turing patterns [23]. He showed that the interaction between different chemical species gives rise to complex spatial

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patterns like the spots, strips and labyrinths on the skin of animals like leopards and cheetahs. Turing demonstrated how self-organising patterns can emerge from differences in concentration gradients of activators and inhibitors, and this idea has been applied to explain many biological phenomena such as the formation of limbs, fingers and processes during morphogenesis. Proteins which manage cellular processes are often bifurcated to form isoforms structures which have similar function but different structures and compositions). Which leads to the evolution of different forms that emerge from a single protein and with time they develop unique functions and the fittest survive, indicating that necessity is needed for a biological function to continue. We see the adaptation of biological systems to perform unique functions quite extensively in our ecosystem. This is seen in the adaptation of biological systems to perform unique functions such as bioluminescent lures in deep-sea creatures like anglerfish, the ability of tube works to survive in nutrient-poor environments, and the evolution of mammals from reptilian ancestors with features like fur and sweat glands to survive on land [24]. These systems that originated by chance have developed by necessity to survive by bifurcations in living processes [25].

On a larger scale, bifurcations are seen in the environment such as seasonal changes, temperature changes, rainfall that can lead to changes in a population's dynamics [26]. Life here becomes a collective system rather than individual - together working towards the survival of a collective species. Bifurcations can also lead to chaos in natural and biological systems, where small perturbations can lead to large and unpredictable changes. And chaos in the human body can occur for example when neurons in the brain and cardiomyocytes in the heart are disturbed in unknown ways, which can result in diseases like seizures or chronic heart failure. Life is full of such chance occurrences that makes it a dynamic, unpredictable, non-deterministic system. And these chance occurrences accumulate over time to develop new adaptations that self-perpetuate [27].

4. Life being self-perpetuating

For self-perpetuation, biological systems require inherent information that can govern their fate and be autonomously morphogenetic and reproductively invariant [28]. Genetic information in living systems largely dictate these criteria, but information in living systems also exhibits "learning" in that living systems can adapt to new information by creating memory. While thermodynamics can help us understand the sustenance of life, it is also crucial to recognize that processes such as memory formation and functionality are also governed by the laws of thermodynamics. In 1972, John Hopfield demonstrated in his paper on "kinetic proofreading" the importance of being away from thermodynamic equilibrium for biological systems, specifically neurons and networks of neurons [29, 30]. These systems can explore different states by being in different thermodynamic conditions, and small fluctuations in a biological system can enable the exploration of different configurations that may facilitate memory formation. This lays the groundwork for understanding memory in artificial systems like computers, which can also benefit from studying chaotic systems that enable neurons to store memories [31,32].

When it comes to memory systems and genetic information, DNA is often the first thing that comes to mind for biologists. DNA carries encoded genetic instructions that govern the growth and function of living organisms, including the brain, which processes information and forms memories through neuronal activity. The transfer of genetic information between organisms or within the same organism, as occurs through homologous recombination and CRISPR, provides evidence of the sophisticated computing abilities of biological systems shaped by evolution [33]. Homologous recombination entails the exchange of genetic material between DNA molecules that are similar but not identical [34]. CRISPR, a bacterial defence mechanism, captures and stores foreign DNA in the genome for defence against viral infections. This information transfer mechanism not only ensures genetic stability within species but also facilitates the sharing of advantageous traits across different species and making life genetically invariant.

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5. Life as genetically invariant

Genetic invariance is maintained during the process of genetically engineering or manipulating the DNA of living organisms. Through genetic engineering, information encoded in an organism's DNA can be manipulated to alter the way it behaves and performs certain functions, resulting in the creation of new, enhanced species. Since the beginning of life on Earth, DNA has been written in a four-letter amino acid code: A, T, G, and C [35]. However, scientists have recently discovered new amino acids, expanding the genetic code. Despite this, organisms have been genetically engineered to new forms while maintaining the same morphogenetic starting structure that has evolved over millions of years.

Synthetic biology is an emerging field in biology that aims to create new biological systems [36]. In recent years, significant progress has been made in creating synthetic cells, which are designed and built from scratch using non-biological components. These cells are created by combining genetic material and other biological components with synthetic materials and chemicals. In 2010, researchers at the J. Craig Venter Institute announced the creation of the first synthetic bacterial cell by assembling the genome of the bacterium Mycoplasma mycoides from scratch [37]. Artificial systems have also been developed to have decision-making abilities. However, the creation of synthetic cells and organisms has raised concerns and debates about what constitutes life and whether these artificial systems can be considered alive. While these synthetic cells can carry out basic functions and replicate, they lack the complexity and autonomy of natural living systems. The development of life as we know it today took billions of years to evolve through natural selection, genetic mutations, and environmental interactions. The intricate and dynamic nature of life's building blocks, such as DNA, proteins, and cells, poses immense complexity that is difficult to replicate in a laboratory setting.

Despite advancements in genetic engineering and biotechnology, creating new life forms from scratch or extensively modifying existing ones is a formidable task. The multifaceted and interconnected nature of life's molecular and cellular processes requires a deep understanding of various disciplines, including biology, biochemistry, genetics, physics and systems biology. Additionally, ethical and societal considerations, including the potential risks and consequences of creating synthetic life, must be carefully evaluated and addressed.

6. Conclusions

The development of synthetic biology has the potential to revolutionise fields such as medicine, biotechnology, and environmental science. Remarkable achievements have been made in designing biological systems with specific functionalities, such as producing biofuels, drugs, and enzymes. However, creating new life forms with complex and autonomous behaviours remains a challenge. If realised, synthetic life forms may represent a new era or type of life, distinct from the forms of life we know today. They may have different properties, behaviours, and ecological interactions, which could have profound implications for our understanding of life and its implications for society and the environment.

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