Life as We Do Not Know It

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LIFE AS WE DO NOT KNOW IT

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ABSTRACT

Information plays a critical role in complex biological systems. This article proposes a role for information processing in questions around the origin of life and suggests how computational simulations may yield insights into questions related to the origin of life. Such a computational model of the origin of life would unify thermodynamics with information processing and we would gain an appreciation of why proteins and nucleotides evolved as the substrate of computation and information processing in living systems that we see on Earth. Answers to questions like these may give us insights into non-carbon based forms of life that we could search for outside Earth. I hypothesize that carbon-based life forms are only one amongst a continuum of life-like systems in the universe. Investigations into the role of computational substrates that allow information processing is important and could yield insights into: 1) novel non-carbon based computational substrates that may have "life-like" properties, and 2) how life may have actually originated from non-life on Earth. Life may exist as a continuum between non-life and life and we may have to revise our notion of life and how common it is in the universe. Looking at life or life-like phenomena through the lens of information theory may yield a broader view of life.

Keywords: Information theory, origin of life, artificial life, thermodynamics, evolution, energetics

1. INTRODUCTION

Information plays a critical role in complex biological systems. I suggest that information processing capabilities distinguish life from other so-called non-living matter [1]. Information processing is one amongst many key ingredients for life.

There are novel computational substrates that allow information processing. Investigating novel non-carbon based computational substrates may yield a broader understanding of "life-like" properties. Some of these systems are described below:

1) Stars have an energy source and compartments. Disturbances from stars that undergo supernova at the end of their lifetimes lead to star formation in neighbouring galactic clouds and nebulae. This is conceptually similar to replication.
2) Weather systems like hurricanes persist for long times [1]; even weather systems on other planets like the Great red spot on Jupiter has persisted for a very long time and display complex behavior.

We can develop a framework for an information theoretic definition of life that is independent of the subjective definitions of only carbon-based life.

What life-forms could conceivably arise in our known universe subject to the known laws of physics? I hypothesize that carbon-based life forms are only one amongst a continuum of life-like systems in the universe.

2. AN INFORMATION THEORY OF LIFE

I hypothesize that the key components of an information-theoretic view of life are:

1) Information processing (software)
2) Information storage (memory)
3) The physical substrate (hardware) and the role of physical space
4) Information transfer (across both physical space and time)
5) Persistence of information
6) Energy and thermodynamics (energetic limits on information processing and life)

We expand on the possible properties of the substrate that allows information processing, information storage and information propagation:

2.1 Information processing

Systems of oil droplets are capable of complex behavior like replication. Computational simulations of these systems may shed light on whether
these systems would be capable of information processing. The system can be evolved using a genetic algorithm. The artificial "genome" would be the size of the droplet, its speed, charge on its surface, ambient air pressure and temperature. One test for

information processing would be verifying if an oil droplet can divide based on whether there are two other droplets in contact with it (this would function like a primitive AND gate). Such a simple model of information processing may allow for the emergence of co-operative behavior that would enhance survival. Similar approaches have been used in reaction diffusion systems without compartments.

2.2 Information storage and memory

Information storage and memory are critical components of life and life-like systems. We suggest testing if systems of oil droplets would be capable of storing information persistently. These systems are capable of a limited form of heredity and some limited form of memory. We suggest incorporating other factors in order to ensure that these systems remember their shape and have persistence. These factors would be additional physical structures (resembling a cellular cytoskeleton that would provide a physical scaffold on which to store information) and compartments that would allow richer dynamics within droplets to be coupled to cues outside the surface (similar to biological cell compartments and cell membranes).

2.3 The physical substrate (hardware) and the role of physical space.

Physical space and structures play a role in facilitating information processing. We suggest testing if there are special shapes of oil droplets that may allow efficient information processing and propagation.

In the immune system, dendritic cells with a large surface area and protrusions specialize in information transfer (by maximizing the surface area over which interactions occur and the number of interactions with other cells). Computational simulations may yield oil droplets with specialized shapes that are optimal for information transfer.

The immune system also has physical structures called lymph nodes that are information processing centers: these facilitate the interaction and information transfer between immune system cells and pathogens. Additional constraints in the oil droplet simulation that allows for physical structures (“artificial lymph nodes”) would also facilitate information propagation between different types of oil droplets that are also spatially separated (discussed below).

2.4 Information transfer and propagation in space and time.

Simulate propagation of information and the evolution of co-operative behavior. We recommend computationally simulating other “species”: smaller droplets that can propagate and relay information faster (like small molecules called chemokines in the immune system that are specialized for carrying information). It would also be fruitful to investigate the effect of introducing these “species”:

a) Specifically testing if this would allow for the emergence of co-operative behavior and co-operative information processing amongst different droplets,

b) Testing if faster propagation of information is good for the whole system since beneficial mutations can spread fast but so can deleterious mutations.

c) Testing the role of both short-range and long-range interactions in spreading innovative mutations (where mutations would be changes to the virtual “genome” mentioned earlier)

2.5 Persistence of information

A strong requirement for life and life-like systems is that information should persist. This would result in selection of attributes that may also be heritable. We note that conceptually, selection and heredity, and memory and persistence of information, are similar and point to the survivability and robustness of these systems.

2.6 Energy: energetic limits on information processing

We suggest computationally simulating the energetic demands of systems like oil droplets. The simulations would have an explicit energy term, which would be varied over a realistic range. The effects of changing energy on the resulting dynamics and information processing capabilities of the system can then be readily observed.

Such a computational model should allow us to test:

a) if features of information processing should emerge faster, and

b) the rate of information processing itself is faster based on the energy or temperature of the system.

There may be an optimal range of energy and temperatures for information processing to be viable: too cold and molecular motion would cease; too hot and critical physical structures capable of sustaining information processing would dissociate faster than they would arise.

Thermodynamics is thought to play an important role in the evolution of life and life-like systems [1]. Simulations like these may help eventually unify thermodynamics and information processing under a common theory.

3. RELEVANT WORK

Looking at life and life-like systems through the lens of information processing can yield a broader definition of life [1]. Similar viewpoints have also been proposed before in thinking about the Universe as a computer [3].

Measures of complexity have been used in socio-economic systems and how economies become more complex [4].

This can also lead to resources for teaching students the basics of what an information theoretic viewpoint of life may look like [5].

The information theoretic viewpoint can also lead to novel reconceptualization of consciousness [6].

4. DISCUSSION

Information processing is fundamental to life. A computational model of the origin of life would unify thermodynamics with information processing. Such a model would enhance our understanding of how the interaction of information processing with energy and thermodynamics may lead to life-like properties. This would also lead to an understanding of the energetic limits on information processing in life-like systems.

I hypothesize that the key components of an information theory of life should include:

1) Information processing (software)
2) Information storage (memory)
3) The physical substrate (hardware) and the role of physical space
4) Information transfer (across both physical space and time).
5) Persistence of information (selection and heredity)
6) Energy and thermodynamics (energetic limits on information processing and life)

Such a theory would give us an appreciation of why proteins and nucleotides evolved as the substrate of computation and information processing in living systems that we see on Earth. Are other computational substrates viable and energetically feasible? What forms of substrates capable of information processing could conceivably exist? Answers to questions like these may give us insights into non-carbon based forms of life that we could search for outside Earth.

Arthur C. Clarke wrote imaginatively about complex intelligent life arising from electrical currents in superconductors on a cold seemingly lifeless planet [2]. He imagined the electrical currents as being only slowly attenuated (due to superconductivity) and ultimately leading to neuron-like networks capable of intelligence. He proposed a completely different computational substrate: electrical currents in superconductors. The story challenges our imagination and although unlikely to be feasible, challenges the very notions of life.

Our ultimate aim is to develop a framework for an information theoretic definition of life that is independent of the subjective definitions of only carbon-based life. What life forms could conceivably arise in our known universe subject to the known laws of physics? We hypothesize that carbon-based life forms are only one amongst a continuum of life-like systems in the universe.

Life may exist as a continuum between non-life and life and we may have to revise our notion of life and how common it is in the universe. Looking at life or near-life through the lens of information theory and thermodynamics may yield a broader view of the origin of life that the general public may find of interest.

5. ACKNOWLEDGEMENTS

This work was inspired by the short-story “Crusade” written by Arthur C. Clarke.

REFERENCES

[1] Banerjee, Soumya. A Roadmap for a Computational Theory of the Value of Information in Origin of Life Questions, *Interdisciplinary Description of Complex Systems*, 14(3), 314-321, 2016

[2] Clarke, Arthur. Crusade, The wind from the Sun. Vista 1996.

[3] Seth Lloyd - Is Information the Foundation of Reality? https://www.youtube.com/watch?v=a35bKt1nuBo

[4] Hidalgo, Cesar. Why Information Grows: The Evolution of Order, from Atoms to Economies, 2017

[5] Banerjee, Soumya. Beauty of Life in Dynamical Systems: An Aesthetic Viewpoint of Life. OSF Preprints, 2018

[6] Banerjee, Soumya. Emergent rules of computation in the Universe lead to life and consciousness: a computational framework for consciousness, *Interdisciplinary Description of Complex Systems*, 19(1):31-41, 2021