

Towards a taxonomy of life-like systems: An information theoretic view of life

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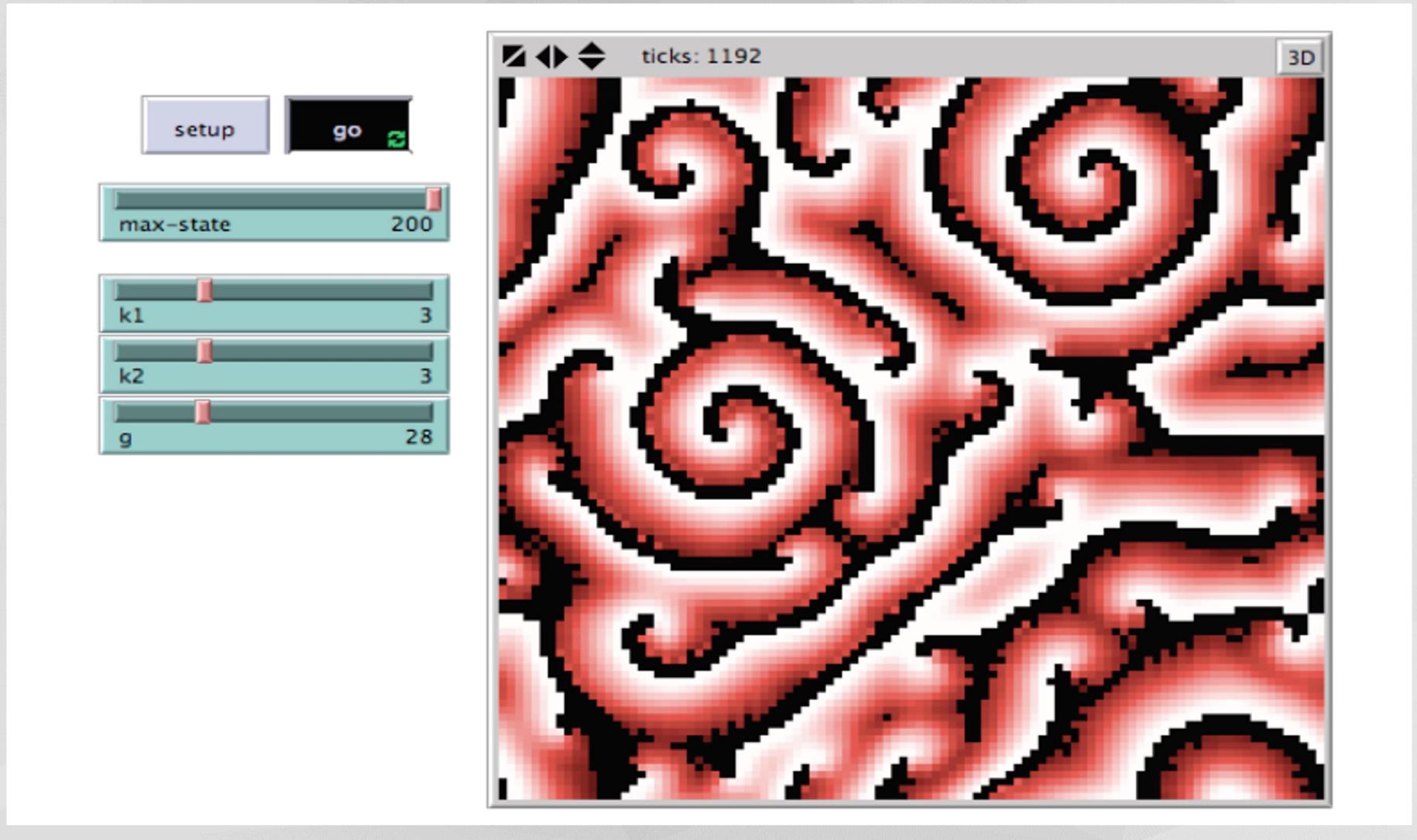
Reimagining life as we do not know it

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

Reimagining life

- Mathematical principles coupled with a mathematical definition of life, rather than only what we see on Earth, would better prepare us for life or life-like forms that may exist elsewhere in the Universe
- Not suggesting that we completely disregard what we see on Earth
- Keep an open mind, use an objective criterion for life

Reaction-diffusion systems like the Belousov-Zhabotinsky (B-Z) reaction are chemical oscillators and also display complex properties reminiscent of life.



Reimagining life

- Novel non-carbon based computational substrates that may have “life-like” properties
- Systems of oil droplets exhibit life-like properties: they are able to replicate and consume energy
- Oil droplets also have been engineered to have compartments and derive propulsive power from an external energy source

Reimagining life

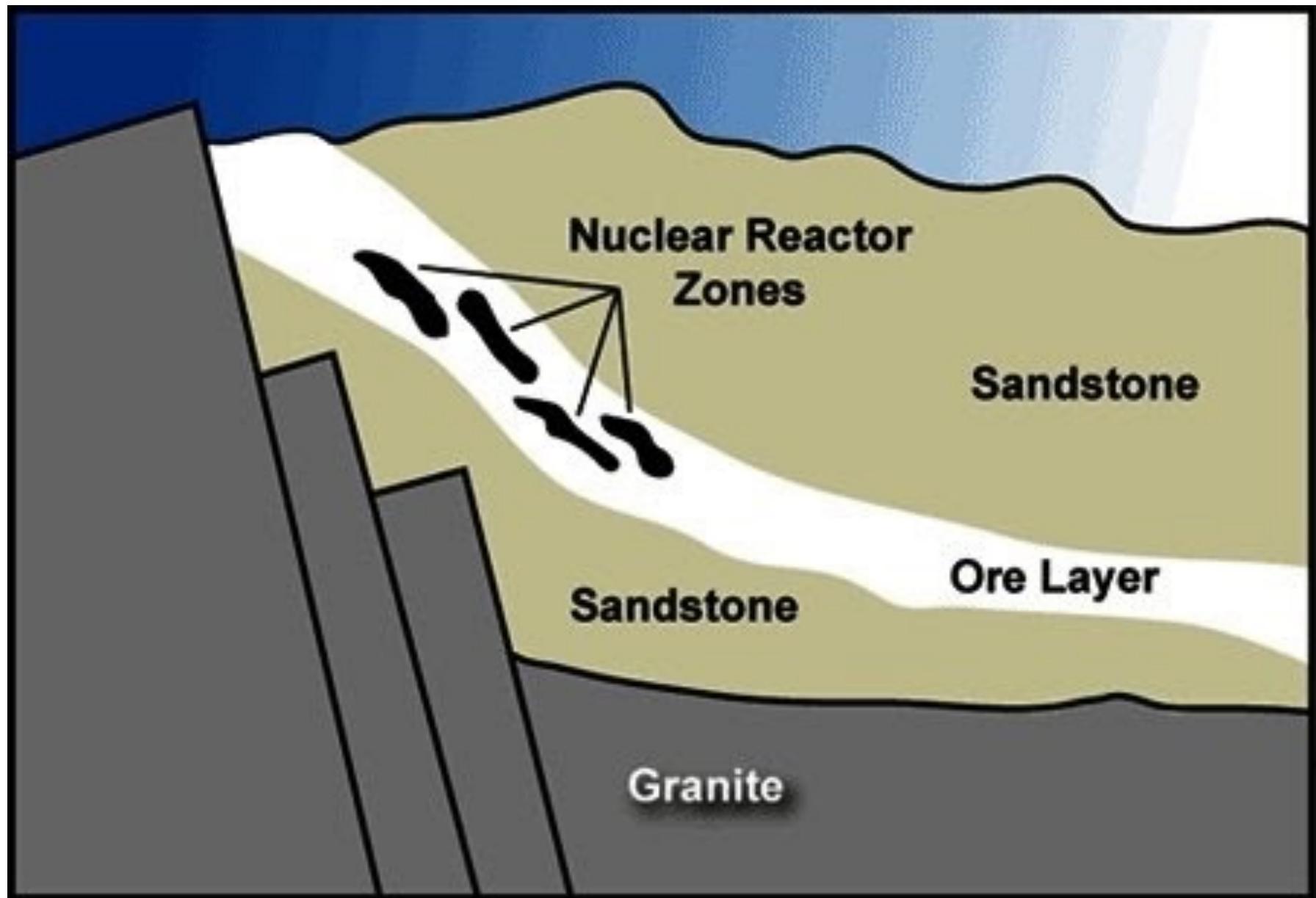
- Stars have an energy source and compartments. Disturbances from stars that undergo supernova at the end of their lifetimes lead to star formation in neighbouring galactic
- Interstellar clouds and nebulae (which is conceptually similar to replication)
- Spherical droplets, self-propelled colloids and motile crystals move about in remarkably life-like ways.
- Microscopic beads of artificially engineered materials exhibit swarming behaviour under the influence of an electric field.

Reimagining life as we do not know it

- Weather systems like hurricanes persist for long time;
 - weather systems on other planets like the Great red spot on Jupiter has persisted for a very long time and displays complex behavior.

Reimagining life as we do not know it

- Information processing (software)
- Information storage (memory)
- The physical substrate (hardware) and the role of physical space
- Information transfer (across both physical space and time)
- Persistence of information (selection and heredity, “lifetime”, robust to perturbations)
- Energy and thermodynamics (energetic limits on information processing and life)



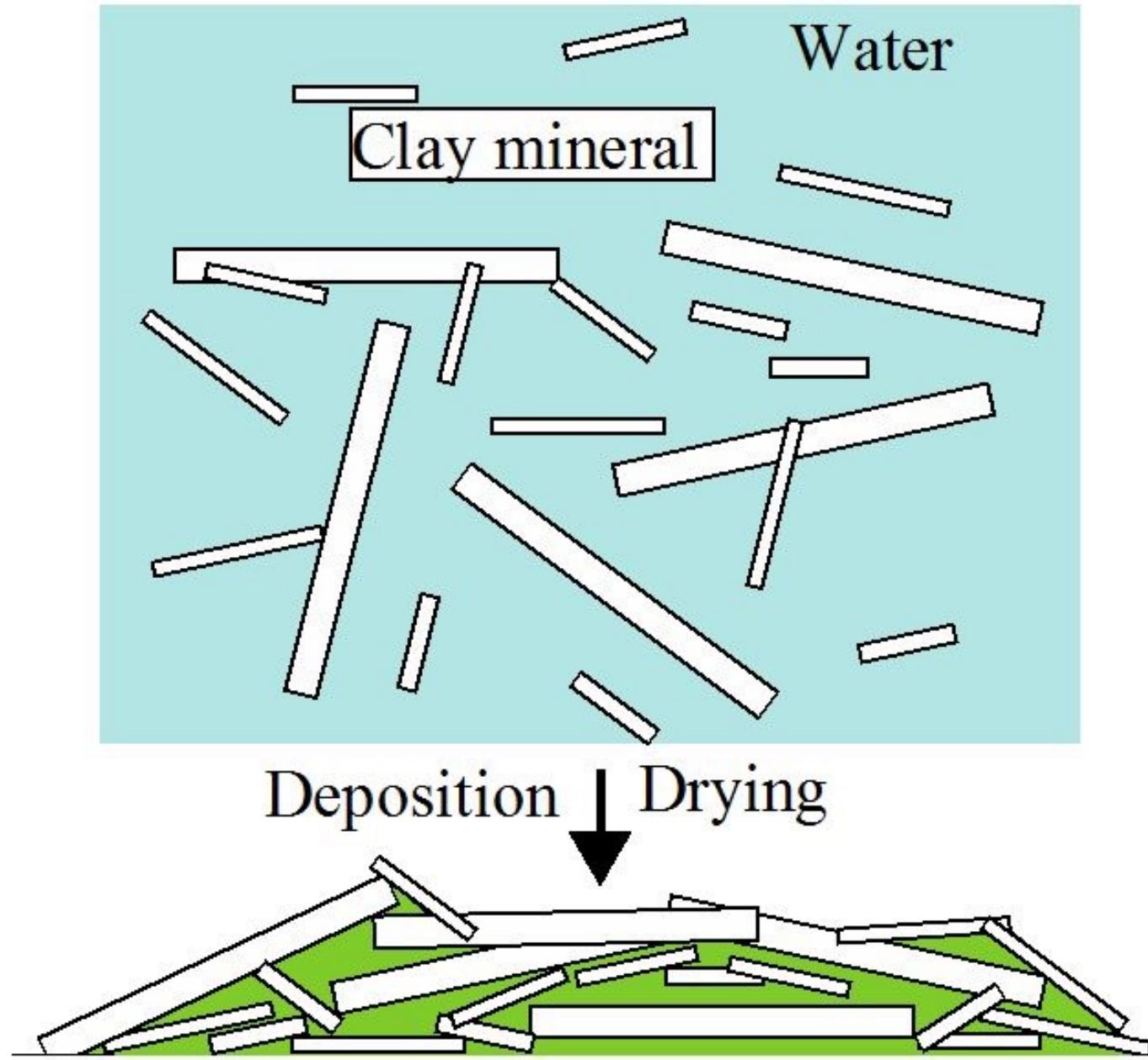


Figure 6 Schematic figure of the room (green) to function like the cell. Clay mineral layers were dispersed in water and then dry water but small room play the role like the cell. [4]

Selection and replication in clay

- Graham Cairns-Smith proposed that during the formation of a crystal of a mineral, particular types of lattice defects replicate as part of the crystallization process.
- It suggests that clay, as it crystallizes, sticks together, is capable of bringing in more clay (because clay will stick to it)
- Clay will dry and will get dispersed
- The imperfections in the clay crystal will be propagated.
- Hence these imperfections seem to replicate themselves, they are thus self-selecting. This process is similar to a rudimentary form of evolution.

Selection redefined

- We can define it as information transfer along time
- Some systems persist whereas others do not
 - Is there selection in stars? Or clay?
- Our work is complementary to work suggesting that “selection” can act on physical systems (such as stars and minerals) (Wong et al, *PNAS*, 2023)

Reimagining life as we do not know it

- Persistence, heritability and natural selection lie along a continuum.
- Hence the strict dichotomy and division between life and non-life may need to be revisited.

Towards a taxonomy of life-like systems

- Oil droplets
- Raleigh convection cells
- Clouds
- Stars
- Clay
- carbon-based life (life as we know it)
- innovations, ideas and memes
- viruses
- Gaia (planetary scale)
- Alife (Lenia, GoL, Avida, computer viruses)
- Natural nuclear reactor (Oklo)

Towards a taxonomy of life-like systems

System	Selection	Persistence	Heredity	Genes	Replication
B–Z reaction systems	Limited	Yes	Limited	No	No
Natural nuclear reactor (Oklo)	None	Yes	None	No	No
Clay	Limited	Yes	Limited	No	Limited
Stars	Limited	Yes	None	No	Conceptual
Gaia	None	Yes	None	No	No
Artificial Life (e.g. Avida)	Yes	Yes	Yes	Yes	Yes
Innovations, ideas	memes	Yes	Yes	Yes	No
Yes					
Oil droplets	Limited	Transient	None	No	No
Rayleigh–Bénard convection cells	None	Yes	None	No	No
Clouds	None	Transient	None	No	No

Table 1. A tentative taxonomy of life-like systems, showing whether each system exhibits Selection, Persistence, Heredity, Genes, and Replication.

Takeaways

- think of life as computation
- on any kind of substrate
- Life and life-like systems as a continuum
- *Taxonomy of life-like systems*

Takeaways

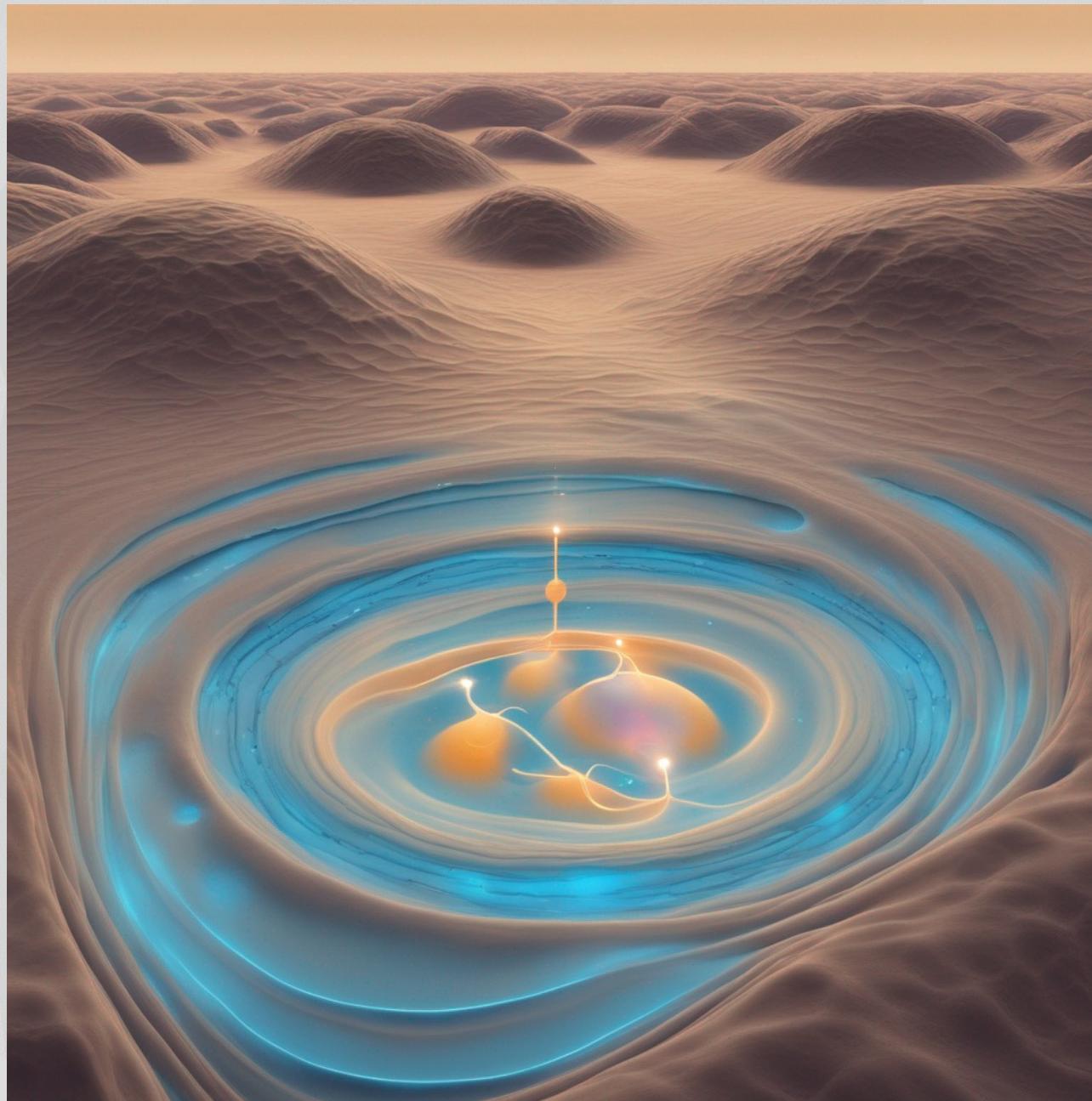
- Our current view of life may be anthropocentric and carbon-centric (“carbon chauvinism”)

Intelligence in animals, humans and machines: a heliocentric view of intelligence? *AI & Society*, 2024

- Gradations of life-like systems like stars, clouds, life-like systems, Gaia, etc.

- Carl Sagan in his novel *Contact* wrote:
- “... we are trapped by our time and our culture and our biology. How limited we are, by definition, in imagining fundamentally different creatures or civilizations. And separately evolved on very different worlds, they [alien intelligence] would have to be very different from us.”
- We hope these perspectives will challenge us to come up with alternatives to our current anthropocentric viewpoints of life.
- This may motivate novel ways to search for intelligence elsewhere in the Universe.

- Use art, AI and science fiction to reimagine life as we do *not* know it
- Let us imagine a future far ahead in time
- The year is 3000



Created using DreamUp AI tool

Further Reading

- *Towards a taxonomy of life-like systems: An information theoretic view of life* Soumya Banerjee
- <https://www.researchgate.net/publication/394377865> Towards a taxonomy of life-like systems An information theoretic view of life
- *Re-envisioning Life as We Do Not Know It using Generative AI and Science Fiction* Soumya Banerjee
- <https://www.researchgate.net/publication/394444212> Re-envisioning Life as We Do Not Know It using Generative AI and Science Fiction



Conceptual image of Clarke's Star-Child. Created using DALL-E.

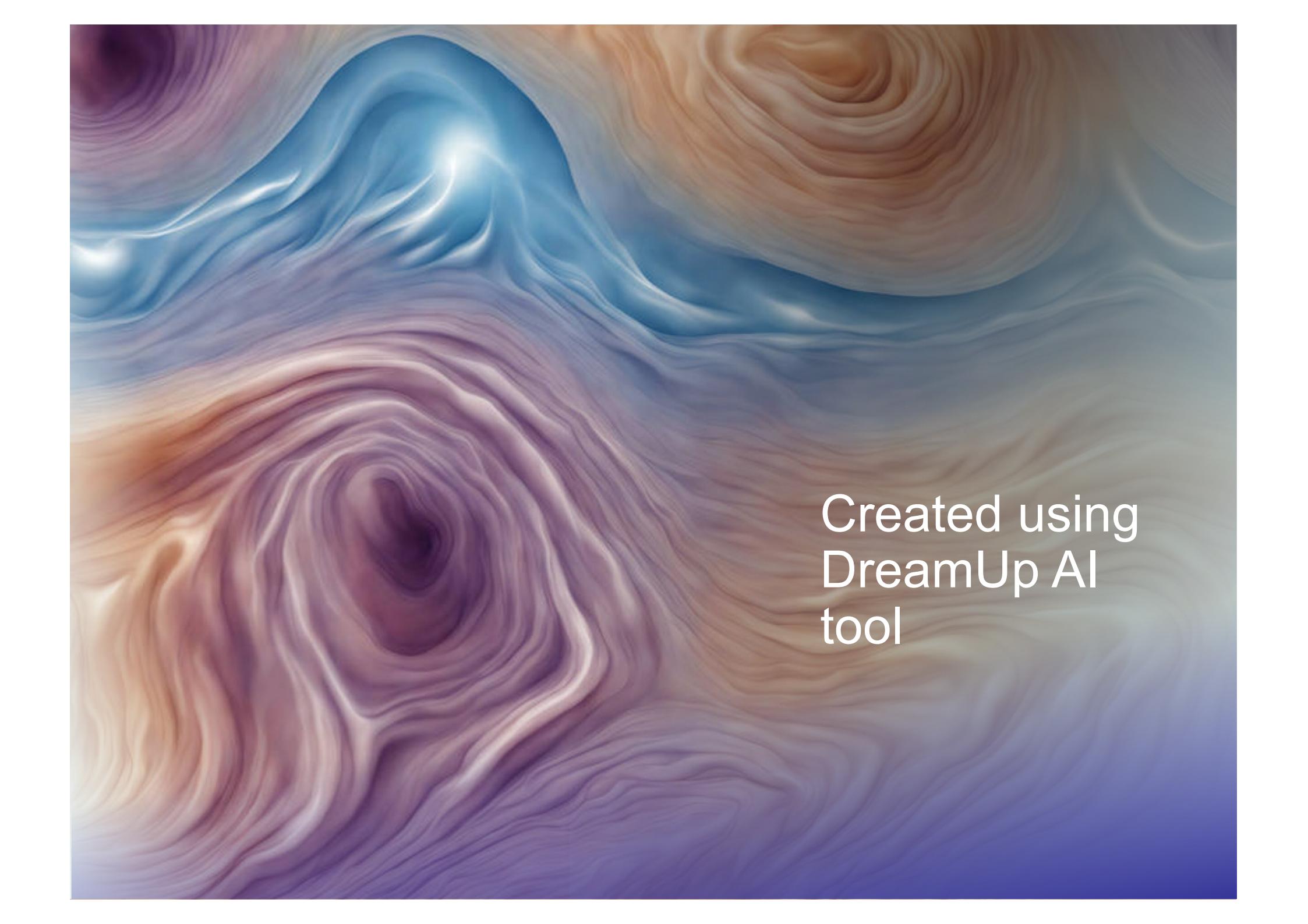


Visualization of speculative plasma-based intelligence. Created using DALL-E.

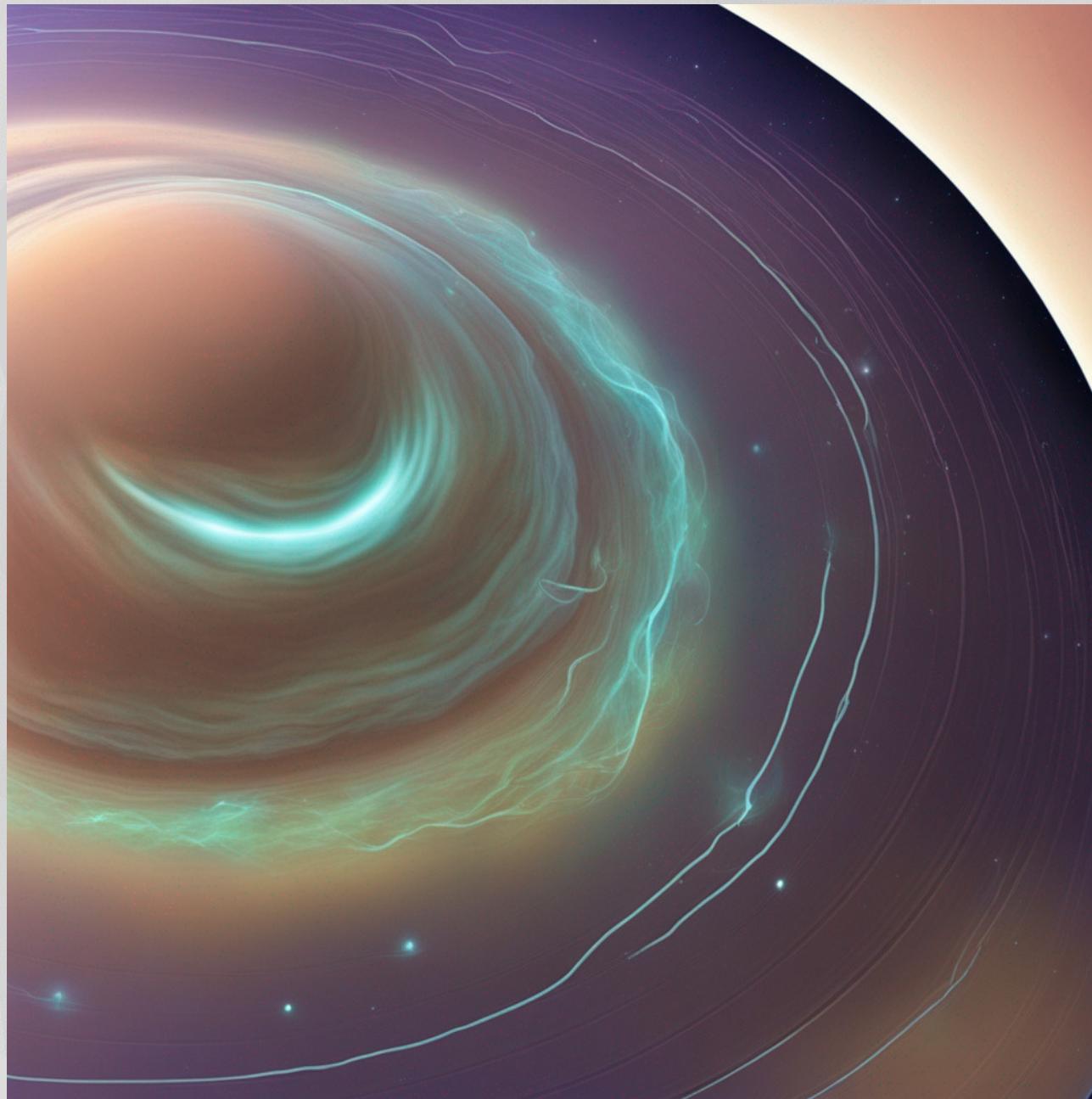
Further Reading

- Teaching resources (activities for children and college students)
- [**Beauty of Life in Dynamical Systems: Philosophical Musings and Resources for Students, Journal of Humanistic Mathematics**](#)
- <https://scholarship.claremont.edu/jhm/vol13/iss2/23/>
- [**A Roadmap for a Computational Theory of the Value of Information in Origin of Life Questions,**](#) Soumya Banerjee, *Interdisciplinary Description of Complex Systems* 14(3), 314-321, 2016

- Current SETI limitations : Most searches focus on carbon–water-based biosignatures and human-like technosignatures.
- Alternative life possibilities : Intelligence could arise from superconducting helium oceans, self-organizing plasma fields, or purely informational substrates.
- Novel detection channels : Look for coherent magnetic oscillations, unusual stellar spectra, anomalous waste heat, or irregular astrophysical modulations.
- Generative AI + science fiction : Mine speculative narratives to identify recurring archetypes of non-carbon life.
- Expanded search strategies : Target cold exoplanets for superconductive life, magnetically active stars for plasma intelligence, and other unconventional habitats.

The background of the image features a vibrant, abstract pattern of swirling colors. It consists of several distinct, luminous swirls that radiate from a central point. The colors transition through various hues, including deep blues, bright yellows, fiery reds, and earthy browns. These swirls are set against a darker, more muted background that provides a strong contrast, making the central colors stand out. The overall effect is reminiscent of a celestial body like Jupiter or a microscopic view of a complex fluid system.

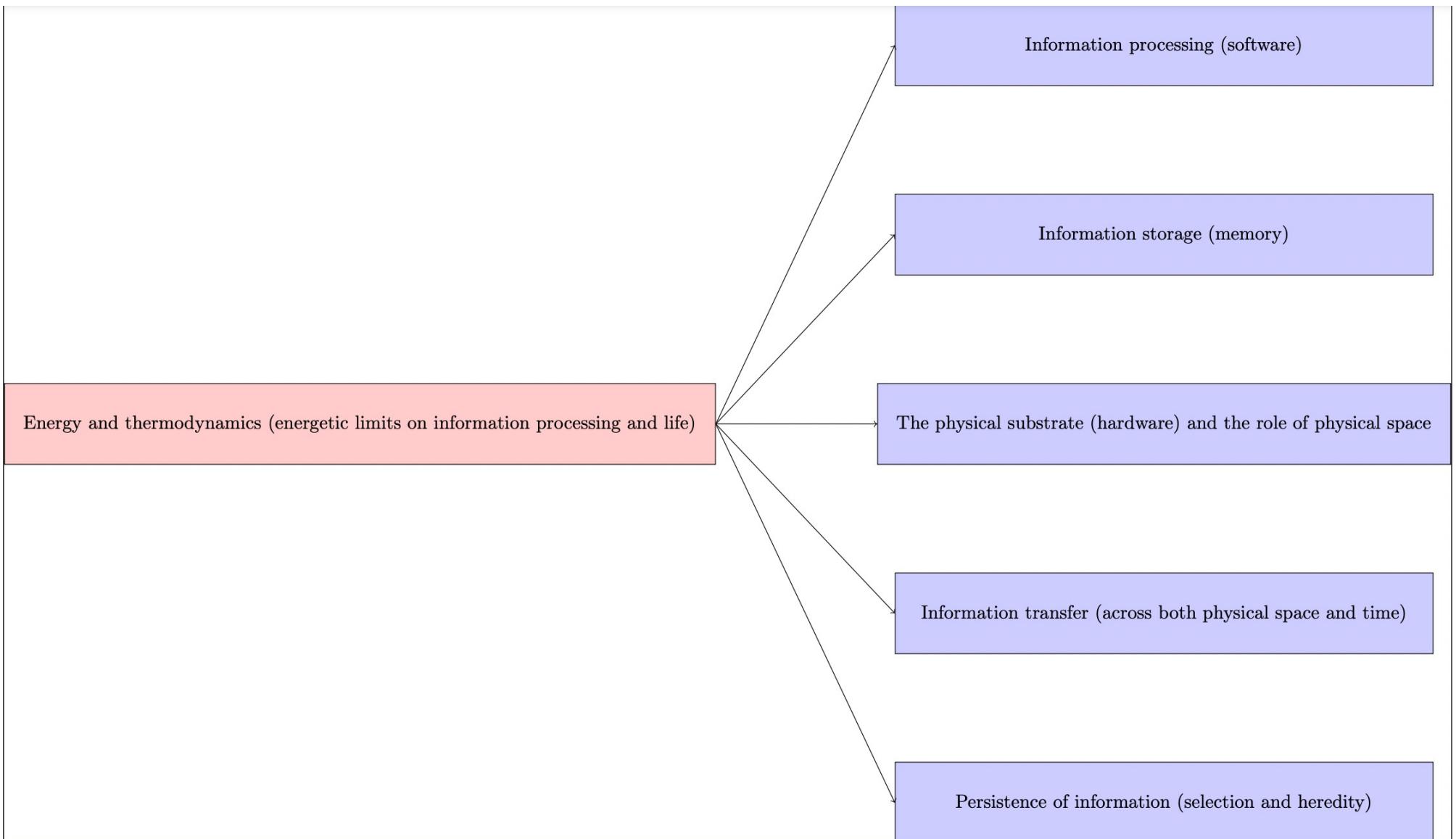
Created using
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tool



- link to story (*Crusade*, Arthur C. Clarke)
 - <https://www.youtube.com/watch?v=Li0TnrRTmM8>

- Another idea to consider is that what we human beings define as life is very anthropocentric and also relates to concepts that are relevant only for a human. For example, an alien being might have a concept of a lightning. It may define lightning as electricity flowing from a cloud to the ground. However, this may not fully align with what the word lightning really means for a human being. The word lightning has many other connotations and many other concepts for a human being. For example, the word lightning for some human beings might conjure up images or being out for a walk in the wilderness and then being stuck outside while it is raining and there is lightning: a very dangerous but thrilling experience. If

- Selection and replication in clay
- Graham Cairns-Smith proposed Say, for example, you have two different crystal patterns, one of which results in a stickier clay that has more or better ways to get stuck on other substances. If a landslide or other geologic activity dumps a sample of each into a river, the non-sticky crystals wash out to the ocean and are lost. The sticky ones catch on the riverbank, and start accumulating and growing, thus building up into a clay deposit. Then a dry season hits, and the river lies empty for a while. The clay dries out, cracks, and is blown by the wind. Most of these airborne flakes still have the same microscopic crystalline structure as the



- Anthropocentrism
- Carbon ‘chauvinism’
- <https://link.springer.com/article/10.1007/s00146-021-01182-4>
- <https://link.springer.com/article/10.1007/s11023-024-09686-w?fromPaywallRec=false>

- Takeaways
 - AI can we recognize it?
 - limits on information processing and life

- Takeaways
 - Complex systems viewpoint
 - Multicellular organisms

- alife virtual creatures Avida
- continuum of life-like creatures and continuum of selection
- information transfer and information maintenance

- collective agency. distributed agency in protocell communities. we need to move away from notions of agency in individuals. we only think of agency in individuals because we are individuals
- selection can happen in different ways say stars or clay
- selection in B-Z and oil droplets?
- memes
- viruses

- Mechanical computers

- Future work
 - Use AI techniques to detect such life-like systems
 - NCA

- Future work
 - clay
 - NCA

The black cloud

for the concept that the existence of “life” may not be constrained by the conditions that are ordinarily considered to be essential based on the singular example of life on earth.

https://en.wikipedia.org/wiki/Hypothetical_types_of_biochemistry

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Dusty plasma-based
biology

Nonplanetary life

Non-chemical life

In 2007, [Vadim N. Tsytovich](#) and colleagues proposed that life-like behaviors could be exhibited by dust particles suspended in a [plasma](#), under conditions that might exist in space.^[6]

Waves replicate and persist. Not on their own. But they and clouds persist because of shore and beach. The environment helps it persist. Similar conditions over time on a beach mean that waves will persist and keep on appearing on the beach. Hence this is like replication even though the genome is not in the cloud or wave but exists jointly on the wave and beach, i.e. it is a product of the cloud or wave and the environment. The organism and the environment are strongly coupled.

Organisms adapt their environment to suit their needs and they also specify the contents of the world they live in

AI has the potential to accelerate the search for intelligence elsewhere in the Universe. Some have surmised that AI also has the potential to cause human extinction and hence act as a Great Filter for intelligence in the universe \cite{Garrett2024}. It seems likely that a prudent use about of AI along with international regulations may benefit humanity and its quest for intelligence in the Universe. Hence, searching for signs of computation and information processing can complement current efforts in search for extra-terrestrial intelligence (SETI).

% XXXX next paper see origins of life paper
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http://www.projectrho.com/public_html/rocket/alienbody.php#cryslife %
http://www.projectrho.com/public_html/rocket/alienbody.php#energylife %
<https://beltoforion.de/en/drake-equ>

- Energy life
- https://www.projectrho.com/public_html/rocket/aliensbody.php#energylife
- **For what is life but organised energy? Does it matter what form that energy takes—whether it is chemical, as we know it on Earth, or purely electrical, as it seemed to be here? Only the pattern is important; the substance itself is of no significance.**

- Future work
- patterns on stones XX artificial systems such as Conway's game of life. convection cells.
- concrete application cite the paper that cited me
XX

- Going back to the story
 - can we recognize it as life if we see it
- are other computational substrates viable and energetically feasible?
- what forms of substrates capable of information processing could conceivably exist?

- What do you think that ALife and Artificial life forms can tell us about non-carbon based intelligence? Can it give us insights into what an alien intelligence might look like? It may open up our minds to different kinds of intelligence. We spent a lot of time thinking we were the only intelligent species. Then we started knowing about dolphins and octopus. XX
- ALife programs and computer programs like the Game of life can help us understand different kinds of intelligence. It can open our minds to different kinds of intelligence

- Different kinds of selection
- Selection on clay
- Geological forces?

- I propose a continuum of life-like systems and a continuum of selection like mechanisms.
- I suggest looking at these complex systems through the lens of information. This is not just in the sense of Shannon-like information theory.
Jitka paper Ref XX

It is clear that the framework of information “a la Shannon” alone does not explain the key aspects of biology; this is mainly because biological information is essentially related both to meaning and to biological function, and these are missing concepts in Shannon’s framework. Shannon’s information relates to the “quantity” of different states that a given system can assume and is more directly related

- Scifi can inspire
- Rich source of ideas

Reimagining life as we do not know it

- The field is ripe for integration
- “*This comparison may seem facile, but it is out of such deliberate oversimplification that the beginnings of a general theory are made. The formulation of a theory of sociobiology constitutes, in my opinion, one of the great manageable problems of biology for the next twenty or thirty years*”- E.O. Wilson, *Sociobiology*



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