What is Life?
Autopoiesis and Cognition as the Essential Conditions for a System to be Considered Alive

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1 Introduction

Since the dawn of civilization, philosophers and scientists have grappled with ideas of life and cognition. Aristotle espoused a holistic world-view, that every thing possesses some wholeness or form which causes it to be the thing that it is. With the Scientific Revolution and Enlightenment, a more reductionist perspective became widely accepted as new theories of the universe and the laws which govern it replaced the old. The cycle between holism and reductionism continued with organismic biologists arguing that organizing relations exist as forms and that the organization of life cannot be solely understood through its parts. Systems theorists like Bertalanffy recognized that living systems maintain themselves in exchange with their environment; this process of exchange is life [20].

The form of organization of life is not material; rather, it is a pattern that movement of matter traces in space and time. Still, what are those patterns, and what are the essential characteristics of a living system? This essay will argue that autopoiesis is an essential aspect of the definition of life, that cognition is equally important, and that these two are not one and the same.

2 Autopoiesis as Life

Maturana and Varela define the essential characteristics of a living system at the cell-level: an enclosed organized system with a self-maintaining metabolism. The entire system must continually produce itself through chemical intake and auto-catalytic reactions, *ad mortem*, through circular causality. The autopoietic cell must have a boundary of its own making. It is predictable and non-random because it has a form and consumes energy from its surroundings to maintain that form [12].

Maturana and Varela hold that autopoiesis is necessary and sufficient to characterize the organization of living systems. Organization and its maintenance is identified with life itself. Fleischaker put this another way: whatever is living must be autopoietic, and whatever is autopoietic must be living [7].

This autopoietic perspective is taken one step further and labeled cognitive because the organism interacts with the environment in a cognitive way whereby the organism creates its own environment, and the environment permits the actualization of the organism [4]. Cognition, from this perspective, is akin to co-emergent adaptation.

Autopoiesis is the minimal level of sensitivity to the environment, the minimal level of cognition necessary for something to be considered alive. Autopoiesis, however, is necessary but not sufficient to categorize life because some artificial systems have been found that are autopoietic but not living.

2.1 Artificial Autopoietic Systems

One such chemical autopoietic system starts with a static aqueous vesicle made of surfactant *S*. A lipophilic precursor of *S*, *S*-*S*, binds with the vesicle boundary and is hydrolyzed there, which creates the surfactant *S*. The vesicle grows and divides into more stable vesicles; with more vesicles, more *S*-*S* binds to the boundary, and more vesicles are formed. This auto-catalytic process of hydrolysis

and growth within a boundary can be considered autopoietic and self-reproducing because the system builds its own boundaries through the reactions within the system, and those reactions are determined by the system itself [1].

Although this system is similar to a bacterium that absorbs sugar and a nutrient from the environment, the vesicular system should not be considered living while the bacterium should. This is because the vesicular system is only affected by the metabolites it is familiar with; it is unable to adapt in the face of new stimuli, even if they damage the unit [1]. No new metabolites can be integrated into the autopoietic vesicle's system. This suggests that something is missing from Maturana and Varela's definition of autopoiesis and life. Autopoiesis is not enough for an organism to be considered alive; it must also be cognitive, and the definition of cognition must be clarified to include the levels associated with adaptation and evolution.

3 Cognitive Systems

According to Maturana and Varela, cognition is the operation of any living system in the domain of interactions specified by its self-referential organizations. A living system is necessarily autopoietic; therefore, a living system is a cognitive system. The co-emergence of the autopoietic unit and its cognitive activity, biological selectivity through senses, is the process of life. Thompson expands upon Varela's notion that "living is sense-making" by arguing that life is autopoiesis, autopoiesis entails emergence of a self, emergence of a self entails emergence of a world *(Umwelt)*, the emergence of a self and world is sense-making, and sense-making is cognition [17].

Bitbol and Luisi question why, if there is an equivalence between autopoiesis and cognition, cognition is not included in the definition of autopoiesis. If cognition, a relational feature, is not included in the definition of autopoiesis, an organizational feature, then autopoiesis and cognition must be distinct processes [1]. Maturana and Varela's definition of life lacks an essential component: the organism's adaptive interaction with the environment [6]. Cognition entails two steps: assimilation, the integration of alternative environmental metabolites within the unit's preexisting system, and accommodation, biological adaptation which leads to evolution through an enduring modification to the system [1].

Cognition, or perception and action, can be defined in terms of the organism's internal structure. Both cognition and autopoiesis represent a general pattern applicable to all levels of life. The living structure of an organic unit interacts with the environment through cognitive sensors, which are products of the organism's development and evolution. Life is the synergy of three domains: cognition, autopoietic structure, and the environment, and therefore life has no meaning without cognition [4].

An autopoietic system is a system of processes that auto-catalyzes the components that reproduce itself and regulates its boundary. The system is cognitive if sensory inputs trigger actions to allow adaptation to new stimuli [3]. So, autopoiesis and cognition are not the same, but both are necessary for a system to be considered living.

The difference in complexity of living things, therefore, is an emergent property that results from simple components that dynamically connect to each other in dense ways, such as within the human nervous system. The global cooperation of the various parts of the nervous system spontaneously emerge when the states of participating neurons reach a mutually satisfactory state [21]. This systems view holds that human-level complexity is a result only of our evolutionarily advanced sense organs and the language with which we augment our sensory perceptions.

3.1 Objections

Boden disagrees with the notion that cognition is perception or adaptation and argues that an organism may be alive but not cognitive. Boden contends that it is unnecessary to allow all living things to be cognitive because the interaction with different environments does not entail knowledge and cognition. Although organisms can exist in various environments, and an environment crucial to the survival of one species may be inaccessible to another, this does not directly translate to knowledge. Ascribing the same cognition to "buttercups as readily as bison" obscures the differences between animals and plants. The conflation of cognition with adaptation is a problem for Boden, who argues that adaptation and knowledge are separate, and that it is best to use the word "cognition" more strictly [2]. It seems like Boden is a proponent of some sort of internal knowledge representation that must act as a complexity measure.

It is not clear, though, that humans model or create explicit representations of the world to interact with it. The representational framework espoused by GOFAI ideas, from disciplines ranging from psychology to robotics, has recently been supplanted by ideas of embodiment and predictive mechanisms leading to intelligence [5] [21].

4 Conclusions

At first glance, these perspectives all seem to hinge on definitions. Maturana and Varela define cognition as adaptation within an autopoietic framework, Bitbol and Luisi with an evolutionary expansion, and Boden as knowledge, problem-solving, language, memory, and perception. The difference between these definitions may come down to complexity, and thus it is appropriate to attribute different levels of cognition to different creatures depending on their capabilities. However, it is a worthy goal to develop these ideas into a framework and baseline definition of cognition - and life - based on shared characteristics, despite the desire to attribute a "special-ness" to human-level intelligence. After all, many creatures can do the same things as humans: plants can learn by association, and even single-celled slime molds use memory to navigate in a complex environment [8] [14]. Perhaps, then, we should be more ready to ascribe complexity and cognition to these organisms because they can learn, adapt, and evolve.

There is a clear separation between autopoiesis as a structural framework for life and cognition as a relational and adaptive framework for life, as Bitbol and Luisi claim. Although autopoiesis is a good start in creating a definition, adaptation and evolution are necessary as well. A living system must be capable of self-maintenance through processes that regenerate the system and the boundary enclosing it. The system must also regenerate itself through cognitive (adaptive) interactions with its environment. Cognition, therefore, is adaptive interaction with the environment, and autopoiesis is the regenerative network of processes which allows self-maintenance. These combine to define life.

When evaluating artificial systems, as in the vesicular example above, it is not hard to define it as non-living. However, does that simply result from its simplicity? Consider, as a thought experiment, an artificially intelligent being that somehow incorporates all of the autopoietic and cognitive criteria espoused by Maturana and Varela, and even Bitbol and Luisi. Would that organism be considered alive, though it does not contain the biological criteria to which we are accustomed, such as genetic material? Or does alive-ness stop at the biological cell? We would assume, because the criteria above are satisfied, that it is indeed alive.

Maturana and Varela emphasize that we must be aware that the phenomenon of knowing cannot imply that we grasp facts and store them in our head; the act of knowing brings forth a world. How, then, do we know what we know? The answer they provide is, "When we have set forth a conceptual system that can generate the cognitive phenomenon as a result of the action of a living being, and when we have shown that this process can produce living beings like ourselves, able to generate descriptions and reflect on them as a result of their fulfillment as living beings operating effectively in their fields of existence" [11]. Jonas offers a similar answer: we know that the world exists and that living beings exist within it because of our direct experience of being alive [9].

Even by asking the question, "What is Life?" we presuppose some idea about what it means to be alive, that there is some organization or quality shared among living things [11]. Some of those qualities - autopoiesis and cognition - have been discussed here. Through these definitions of cognition, autopoiesis, and life, a variety of organisms that we consider to be alive satisfy the criteria and can exist effectively in their own realms. Although it may be impossible to determine with certainty what life and cognition mean, what is certain is that these are issues we must continue to discuss and keep in the forefront of our scientific, and human, dialogue as the future, and all the innovation it brings, comes ever nearer.

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