To Live Or Not To Live: Defining Life Outside Biological Systems

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Imagine a world restricted to a two-dimensional grid, on which black and white grid-boxes are the only distinct features. A world bereft of complexity and structure, of any physics, chemistry or biology. In fact, this entire world runs on two simple rules: a black square will turn white if it has anything other than exactly two or three black neighbors, and a white square with exactly three black neighbours will turn black.

The creator of this grid universe, one of the earliest examples of what theoretical computer scientists now call cellular automata, was John Conway, the legendary British mathematician who tragically passed away last year due to complications arising from COVID-19.[1] Although he made great contributions to several fields of mathematics, he is most well known for his grid world, which he dubbed the "game of life.[2]" That might seem surprising, since the description above seems nothing but a mathematical plaything. But, for philosophers, this quaint game raises questions about the very definition of what it means to be alive.

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HOW DO WE DEFINE LIFE?

Typically, an article questioning our ideas of what life is would start with what conventional wisdom tells us it is. However, "conventional wisdom" has not settled on a definition of life. One can find significantly different definitions of life from different sources. Merriam-Webster, for example, defines it as "an organismic state characterized by capacity for metabolism, growth, reaction to stimuli, and reproduction.[3]" While it is a handy definition, it is very easy to find examples of things universally agreed to be living which do not satisfy one, or several, of these requirements. A tree can not respond visually to almost all kinds of stimuli, a unicellular organism can hardly grow bigger than one cell, and inanimate objects like crystals can actually create copies of themselves under the right circumstances.[4]

A more profound problem with this definition is that it is based on humanity's experience with but a single paradigm of life. Limiting the scope of our definition in this way ignores the vast possibilities of life arising in unthinkably different ways throughout the universe. As Dr. Carol Cleland, philosophy professor at Colorado University at Boulder and member of NASA's Astrobiology Institute, puts it in an interview with *Astrobiology* magazine:

> ...in order to formulate a general theory of living systems, one needs more than a single example of life. As revealed by its remarkable biochemical and microbiological similarities, life on Earth has a common origin... The key to formulating a general theory of living systems is to explore alternative possibilities for life.[5]

A better approach, then, might be to approach the question of life from a more general perspective, taking into account the myriad

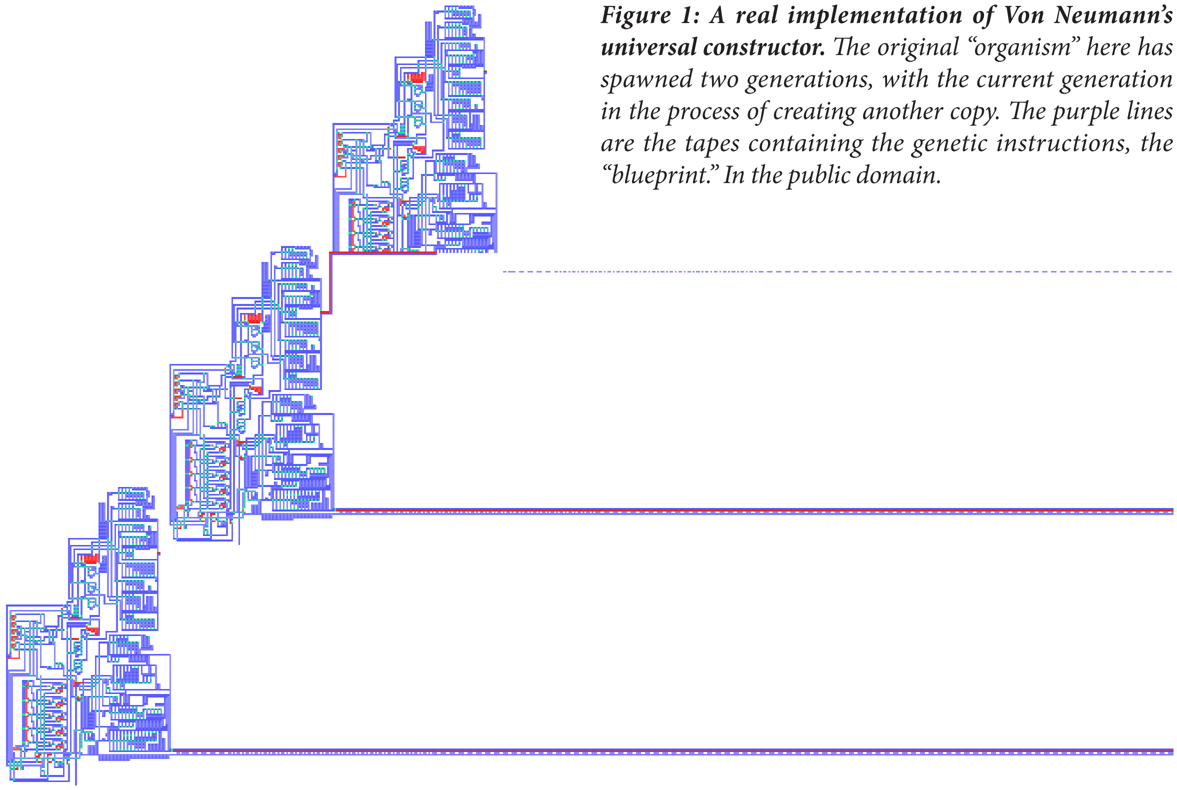


Figure 1: A real implementation of Von Neumann's universal constructor. *The original "organism" here has spawned two generations, with the current generation in the process of creating another copy. The purple lines are the tapes containing the genetic instructions, the "blueprint." In the public domain.*

possibilities of life throughout the universe. In fact, in 1994, a NASA committee was given exactly this task. Their proposed definition, sponsored by astronomer and host of the popular show *Cosmos*, Carl Sagan, was:

Life is a self-sustaining chemical system capable of Darwinian evolution.[6]

This definition is interesting in many ways. Most notably, it eschews all references to biological processes, focusing instead on the crucial intergenerational information flow central to Darwinian evolution.

What does a definition of life focused on evolutionary characteristics say about how we think about life? If the defining feature of life is something as simple, as *mathematical*, as the flow of genetic information, how complex does a living thing need to be to be considered alive? Indeed, this question is so rich with possibilities that it has spawned an entire field of study, that of artificial life, whose foundations were laid by the seminal work of John von Neumann.

ARTIFICIAL LIFE

Once we identify Darwinian evolution as a fundamental requirement for life, the question becomes one of identifying the simplest, most fundamental requirements of life. What would the simplest life look like? The famous mathematician, John von Neumann, took the first steps in the 1940s towards answering this question through his now-famous universal constructor.

Von Neumann's professed goal was to develop a model "whose complexity could grow automatically akin to biological organisms under natural selection.[7]" His focus on the growth of complexity associated with evolution reflected the recognition of information flow as a central characteristic of life. His model consisted of three parts: first, a *universal constructor* (UC) mechanism which, given appropriate instructions, could construct anything it was instructed to; second, a *blueprint*, which would serve as an instruction set to construct the UC itself; and last, a *universal copy machine*, which, given a blueprint, could construct (almost!) exact copies of that same blueprint. Once a "new machine," or a single organism, was constructed using the universal constructor mechanism and a given blueprint, that blueprint could be handed off to the copy mechanism. The copy mechanism would then copy that blueprint and give it back to the organism, which could use its UC mechanism to develop a new "offspring." Tiny errors in the copying mechanism would produce slight variations in the blueprints, which would build up to result in what we see as evolution, giving this model the necessary features of life.[8]

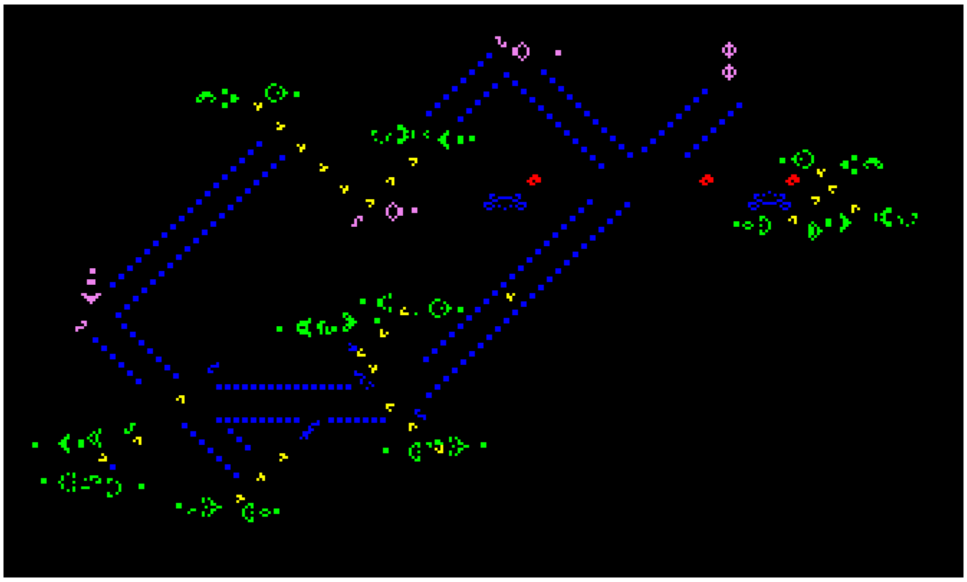
To anyone with any basic biology experience, all of these processes will seem very familiar. Indeed, one could probably raise the same argument again: does this mechanism not seem to just borrow from how we know actual life works? But that's precisely why von Neumann's machine is so fascinating: he developed this model *before* the discovery of the role of DNA in reproduction.[9]

IS AI ALIVE?

The computational/mathematical definition of life opens up very new ideas about what we consider to be life, far removed from the carbon-based, organic structures that we are used to associating with life. It is here that we return to John Conway's monochrome

"Life is a self-sustaining chemical system capable of Darwinian evolution."

__Figure 2: A racetrack created in Conway's game of life.__ Don't let the colors fool you: they have just been added to differentiate between different kinds of objects. All unlit cells are still "dead" and all lit cells of any color are "alive" in the exact same state. This system contains many kinds of objects: spaceships and gliders, which travel across the grid; guns, which shoot smaller objects across the grid; and reflectors, which send a travelling object back along its original path. If such amazing complexity, and such a diversity of objects, can be created from just three basic rules, how complex would a system need to be to give birth to life? In the public domain.



game. It provides a simple environment with just two rules, but from these two basic rules, wonderful complexity arises. We can build patterns of dark cells which instantly die off or attain stable equilibrium states, patterns which undergo thousands of cycles of evolution before entering a stable state, or patterns which oscillate between several different states. In 2013, one pattern was discovered which actually creates a copy of itself before being destroyed in the process — the first example of a reproducing system in the Game of Life.[10] In the present, full-scale logic gates and even Neumann-esque universal constructors have been built in the Game of Life. With sufficient complexity, a replicator in the Game of Life may even be able to reproduce with variations: almost resembling Darwinian evolution.

In a world where all of physics is just two rules of state, could a game of life UC or replicator be considered "living?" A biologist would unequivocally say no, but if we extend this analogy to non-carbon-based life, it becomes a trickier question. If complex self-replication and the ability to store and transmit information down generations are taken as the essential characteristics of life, at what point will robots, or even artificial intelligence software, take the next step into being considered alive?

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IMAGE REFERENCES

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