

HUMAN-ENGINEERED SELF-REPLICATING MACHINES

Granville Sewell*

Department of Mathematics, University of Texas El Paso, El Paso, Texas 79968, USA

Abstract

How close are we really to a human-engineered self-replicating machine? A couple of thought experiments are proposed which help explain why such machines are still far beyond current human technology. And I conclude that we are unlikely to be successful in explaining how the self-replicating machines we see everywhere in the living world could have arisen through entirely natural causes, when we still do not know how such machines could be designed.

Keywords

self-replication • origin of life

A self-replicating machine is defined by the *Wikipedia* article (1) on this topic as ‘a type of autonomous robot that is capable of reproducing itself autonomously using raw materials found in the environment, thus exhibiting self-replication in a way analogous to that found in nature’. This article acknowledges that ‘although suggested earlier than in the late 1940s by Von Neumann, no self-replicating machine has been seen until today’.

With all our advanced technology, we are not close to producing human-engineered self-replicating machines. This is significant because it is widely believed (2, p.15), for example, that the first self-replicators on Earth must have arisen through chance chemical processes – it being impossible to appeal to natural selection of replication errors before anything could self-replicate.

To better appreciate the enormous difficulties in designing such machines, and thus the difficulties in understanding how the first living things arose on Earth, let’s think about what would be required to build, say, a self-replicating ‘model T’ car.

We know how to build a simple model T. Now let’s build a factory inside this car, so that it can produce model T cars automatically, and call the new car, with the model T factory inside, a ‘model U’. A car with an entire automobile factory inside, which never requires any human intervention, is far beyond our current technology, but it doesn’t seem impossible that future generations might be able to build a model U.

Of course, the model U cars are not self-replicators, because they can only construct simple model T’s. So let’s add more technology to this car so that it can build model U’s, that is, model T’s with car-building factories inside. This new ‘model V’ car, with a fully automated factory inside capable of producing model U’s (which are themselves far beyond our current technology) would be unthinkable complex. But is this new model V now a self-replicator? No, because it only builds the much simpler model U. The model V species will become extinct after two generations, because their children will be model U’s, and their grandchildren will be infertile model T’s.

So back to work, and each time we add technology to this car, to move it closer to the goal of reproduction, we only move the goalposts, because now we have a more complicated car to reproduce. It seems that the new models would grow exponentially in complexity. And even if we were able to engineer self-replicating cars, it is hard to imagine that without any human maintenance these cars could keep reproducing themselves for more than a few generations before errors accumulate to the point that all replication halts.

And here we have ignored the very difficult question of where these cars get the raw materials they need to supply their factories.

Some will object here that the first living things may have been much simpler than self-replicating cars. It is widely believed

* Corresponding author e-mail: sewell@utep.edu

that you only need to explain how very simple self-replicators could have arisen through chance chemical processes, because then natural selection of the resulting duplication errors could take over and explain how self-replicators far more complex than cars could have arisen. But even if we could explain the appearance of simple self-replicators, imagining trying to design self-replicating cars may help us appreciate the enormity of the difficulties facing *any* scientific explanation (let alone one which relies on replication errors) for the unimaginably complex self-replicators that we see everywhere in the living world.

Nevertheless, let's imagine trying to design something much simpler, like a self-replicating cardboard box. Let's take an empty cardboard box, which we will call box A, and build a completely automated factory inside which can produce empty cardboard boxes. The factory would, I presume, at least need to have some metal parts to cut and fold the cardboard and a motor with a power source to power these parts. But since the new box B only builds empty boxes, it is not a self-replicator. So let's add technology to the factory, so that the new box C could automatically produce box B's with their metal parts and motor and power source. This new box would have to be enormously more complicated. But box C is still not a self-replicator because it only builds the much simpler box B. So now we need to add more technology to the factory, so that it can build box C's, and on and on. Thus, it seems that designing any self-replicating machine, at least any machine of non-trivial complexity, would still be an enormously difficult problem. Again, we have ignored the question of where the factories in these boxes get their raw materials.

Although we have chosen to put aside the very difficult question of where our hypothetical replicators get their raw materials, if we want to make a point about the origin of life these 'raw materials' must not include biological material or human technology, which were not 'found in the environment' of the first self-replicators on Earth.

There are numerous projects that claim to have designed something close to a self-replicating machine. But on closer examination, all such claims are over-hyped.

For example, the Cornell device pictured in this [video \(3\)](#) can produce copies of itself ... as long as humans keep feeding it certain high-tech blocks. According to the Cornell news story [\(4\)](#) *Researchers Build a Robot That Can Reproduce*:

One of the dreams of both science fiction writers and practical robot builders has been realized, at least on a simple level: Cornell University researchers have created a machine that can build copies of itself

Their robots are made up of a series of modular cubes – called 'molecubes' – each containing identical machinery and the complete computer program for replication. The cubes have electromagnets on their faces that allow them to selectively attach to and detach from one another, and a complete robot consists of several cubes linked together.

This device does absolutely nothing but rearrange into stacks the 'molecubes' that humans keep building and feeding them, so in addition to requiring raw materials built by humans, it could probably not be considered a 'non-trivial' self-replicator. To make this into a true self-replicator, we would need to add a factory which automatically produces the molecubes, and then we would need to add a factory which could produce the molecube-producing factory. And so on.

The RepRap printers [\(5\)](#) have been advertised as the 3D printers that can print themselves, but many key components such as 'sensors, stepper motors and microcontrollers' have to be produced independently. The printer designers [\(6\)](#) write 'RepRap has been designed to be able to print out a significant fraction of its own parts automatically'. But as seen in the car and box examples, partial self-replication is easy, it is full self-replication that is hard, because the goal of full self-replication does not hold still as you approach it. And, of course, humans have to supply the raw materials and assemble even the printed components.

Eric Anderson, in a chapter of Lo et al. [\(7\)](#) entitled 'A Factory That Builds Factories That Build Factories That ...' mentions another device claimed to be 'the world's first self-replicating 3D printer' and says that 3D printers are 'not even close' to being self-replicating. He suggests that the design of truly self-replicating 3D printers suffers from the same problem we encountered in the car and box thought experiments: 'Worse, every time we include a new part or an additional mechanism to assist with this challenging self-replication process, that new part or mechanism also must be replicated'.

A team from Harvard, Tufts and the University of Vermont reports the recent creation of the 'first living robots that can reproduce' [\(8\)](#) but on closer examination [\(9\)](#) the raw materials used to build the 'robots' are embryonic frog cells, which do all the hard work in this experiment. A mobile aggregate of frog cells gathers dissociated frog cells together, which somehow self-organize into similar mobile aggregates and, with help from humans (and frogs, who keep supplying new cells), the process can continue for several generations before it stops.

It is possible to design a computer program which, when executed, produces a copy of itself. But such a program is

not a machine, just a series of 1's and 0's, and it cannot really make a copy of itself. It is aptly called a 'virus', because it needs a computer (with operating system installed) to be able to reproduce, and the computer is not replicated.

The car and box thought experiments above may make us wonder if we could ever design any self-replicating machine. The new car models, for example, *seem* to grow exponentially in complexity. But maybe with clever planning they could be made to converge to a self-replicating 'model Z', though it is hard to imagine how. For example, we don't have to start with a model T, and the model U car does not necessarily have to build a model T. Nevertheless, the final model Z must still be able to build a model T – with a factory inside which can build model T's with factories inside which So, I don't claim to have proved that human engineers could never build a self-replicating machine, I am only showing why it is so extraordinarily difficult.

Perhaps we could imagine a 3D printer which could be programmed to print *any* 3D object, including machines with sophisticated electronic circuitry and complex moving parts. Such a machine might be able to replicate itself. (Remember that this doesn't just mean it could print out all of its own parts – if humans or other machines are required to assemble the parts, the machine is not a self-replicator.) But even if it were possible to build such a machine, there is still the raw materials supply problem, and it is obviously not useful in understanding how the first 'simple' self-replicators appeared on Earth.

The *Robotica* article (6) by the designers of the *RepRap* 3D printer series includes a short summary [following the outline in the Freitas and Merkle book (10)] of efforts to design self-replicating machines. They cite Von Neumann (11) as the first to propose such a machine. But his theoretical machine had to reside in a stockroom with an unlimited supply of spare parts and is thus, like the real Cornell device, also not helpful in understanding how life began. The authors call their printers 'assisted' self-replicating machines and acknowledge that 'an artificial autotrophic self-reproducer remains an unachieved Utopia for the subject. Whilst theoretical work has been undertaken in the area, all the concepts presented so far are extremely vague on the engineering involved in artificial reproduction'.

A 2020 *Biomimetics* paper by Ellery (12) illustrates the current state of theoretical work on artificial reproduction. From the abstract: 'We present work in 3D printing electric motors from basic materials as the key to building a self-replicating machine to colonize the Moon Life must have emerged from the available raw material on Earth

and, similarly, a self-replicating machine must exploit and leverage the available resources on the Moon. We ... explore the construction of a self-replicating machine using a universal constructor'. He later defines a universal constructor as 'a machine that can construct any other machine given the appropriate program of instructions and other resources such as materials and energy'. The paper is naturally 'vague on the engineering involved' but does recognize some of the difficulties in creating artificial life: 'Of course, the environment does not constitute a sea of ready-made parts, so any real-world self-replicator must self-construct its own parts from available raw materials in its environment'.

Will human engineers ever be able to design machines which mimic the first living things and reproduce themselves, generation after generation, using raw materials not manufactured by humans or other living organisms? The thought experiments and discussion above may cause us to wonder if this will ever happen.

And wouldn't something this far beyond the reach of current human technology also be far beyond the reach of unintelligent, chance, chemical processes?

Of course, there are significant differences between the way humans have tried to do self-replication and the way living things do it, and some may argue that living things may have found an easier solution. But the cell division and differentiation process used by multicellular organisms to replicate seems to me to be even more difficult, and I would offer the video [Conception to Birth – Visualized](#) (13) by Yale mathematician Alexander Tsiaras to support this. In any case, I don't see how we can claim to be close to understanding the origin of life when we are still not close to understanding how self-replicators could be designed.

References

1. Available from: https://en.wikipedia.org/wiki/Self-replicating_machine [Accessed 5th May 2023].
2. Dawkins R. *The selfish gene: 30th anniversary edition*. Oxford University Press, New York; 2006.
3. Available from: <https://youtu.be/gZwTcLeelAY>
4. Steele B. Researchers build a robot that can reproduce. *Cornell Chronicle*; May 25, 2005.
5. Available from: <https://en.wikipedia.org/wiki/RepRap> [Accessed 5th May 2023].
6. Jones R, Haufe P, Sells E, Iravani P, Olliver V, Palmer C, et al. RepRap – the replicating rapid prototyper. *Robotica*. 2011;29: 177–191. doi:10.1017/S026357471000069X

7. Lo T, Chien P, Anderson E, Alston R, Waltzer R. *Evolution and intelligent design in a nutshell*. Discovery Institute Press, Seattle, Washington; 2020.
8. Brown J. Team builds first living robots – that can reproduce. University of Vermont Communications; 2021.
9. Timmer J. Interesting research, but no, we don't have living, reproducing robots. ARS Technica; 2021.
10. Freitas R, Merkle R. *Kinematic self-replicating machines*. Landes Bioscience; 2004.
11. Von Neumann J. *Theory of self-reproducing automata*. University of Illinois Press, Urbana, Illinois; 1966.
12. Ellery A. How to build a biological machine using engineering materials and methods. *Biomimetics*. 2020;5: 35. doi:10.3390/biomimetics5030035
13. Available from: <https://youtu.be/fKyljukBE70>