

Digital Genesis: Computers, Evolution and Artificial Life

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Abstract

The application of evolution in the digital realm, with the goal of creating artificial intelligence and artificial life, has a history as long as that of the digital computer itself. We illustrate the intertwined history of these ideas, starting with the early theoretical work of John von Neumann and the pioneering experimental work of Nils Aall Barricelli. We argue that evolutionary thinking and artificial life will continue to play an integral role in the future development of the digital world.

Introduction

In *The Origin of Species*, Darwin introduced his theory of natural selection as an explanation of the complexity of the biological world (Darwin, 1859). Simply put, in a population where heritable variation exists in the characteristics of individual organisms, if one variety of a particular characteristic leads to enhanced reproductive success among those individuals that carry it, then, over time, that variant will become more common than others in the population.

The logic of Darwin's argument seems to apply to *any* system of entities which possesses the three fundamental features of *variation*, *differential reproduction*, and *inheritance*. The beautiful simplicity of this picture raises the alluring question of whether it would be possible to create virtual worlds instilled with these features, that might give rise to the evolution of complex digital life.

Digital Origins

The idea of applying an evolutionary process in a digital world dates back to the origins of the digital computer itself. Over the 1940s and 1950s the idea appears to have arisen, independently, as many as ten times (Fogel, 1998b, p.4).

The earliest substantial theoretical work in this area was developed by John von Neumann. In the late 1940s, he became interested in the question of how complicated machines could evolve from simpler ones (von Neumann, 1966). He was interested in self-reproducing machines that were robust in the sense that they could withstand some types of mutation and pass these mutations on to their offspring;

such machines could therefore participate in a process of evolution. Looking for a suitable formalism that was both simple and enlightening, von Neumann developed a two-dimensional cellular automaton framework in which to demonstrate his ideas.¹ Although the design was not implemented on a computer before his death in 1957, von Neumann's work can be regarded as the first attempt to instantiate an evolutionary process in the context of a modern, digital computational framework.

At around the same time, Alan Turing also considered the application of evolution to computers. In his seminal paper *Computing Machinery and Intelligence* he described a method of machine learning involving mutations (random or otherwise) to a computer program and feedback from a human experimenter (Turing, 1950). Turing drew explicit parallels between his proposal and the process of biological evolution. Intriguingly, he began practical experiments with this approach, although these apparently met with little success and were not reported in detail: "I have done some experiments with one such child machine, and succeeded in teaching it a few things, but the teaching method was too unorthodox for the experiment to be considered really successful" (Turing, 1950, p.457).²

However, it was not long until more substantial experiments with evolution on computers commenced. The first were conducted by Nils Aall Barricelli while working in von Neumann's group at the Institute of Advanced Studies (IAS) in Princeton over the period 1953–1956 (Barricelli, 1954, 1962, 1963). Barricelli employed a one-dimensional cellular automaton, where each state persisted from one time step to the next depending upon the state of other cells in

¹Von Neumann had originally thought of a more complex "kinematic" model, but arrived at the cellular automaton representation after a suggestion from Stanislaw Ulam (Beyer et al., 1985).

²Turing's first published thoughts on the idea of evolution as a search process in the context of machine learning appeared in a 1948 research report entitled *Intelligent Machinery* (Turing, 1948, p.18). The director of his laboratory at the time was none other than Sir Charles Galton Darwin, grandson of Charles Darwin. He was unimpressed by Turing's report, dismissing it as a "schoolboy essay" (Copeland and Proudfoot, 1999).

certain neighbouring positions such that cooperative configurations of states could arise. Among the phenomena he observed were: self-reproduction of certain collections of states (which he named “symbioorganisms”), crossing of material between two symbioorganisms, spontaneous formation of symbioorganisms, parasitism, and self-maintaining symbioorganisms (Barricelli, 1962).

In later work, Barricelli experimented with giving his symbioorganisms greater opportunities for evolving complex phenotypes. In particular, if two symbioorganisms attempted to reproduce into the same space, their genotype was decoded into a strategy for playing a simple game (called “Tac Tix”), and the winner was allowed to reproduce (Barricelli, 1963). Barricelli’s pioneering work was therefore very much focussed on replicating the dynamics of biological evolution in a digital medium, and in creating an “unlimited evolution” process in which complex digital lifeforms (“numerical symbioorganisms”) would emerge.³

Following Barricelli’s work at IAS, research on the application of evolution on computers has flourished. From the mid-1950s to the mid-1980s, the majority of this research effort focussed on using evolution as a practical tool for optimisation rather than the more lofty goals of Barricelli and von Neumann.⁴ Fogel (1998a) provides a good review of pioneering work from this period.

In the mid-1980s the field of Artificial Life was reborn, stimulated by a workshop in 1987 (Langton, 1989).⁵ This has led to a renewed interest in the kinds of ideas first explored by Barricelli, including attempts to create an open-ended evolutionary process in a digital medium (see (Taylor, 2013) for a recent review).

Digital Future

There has been renewed interest in the open-ended evolution of digital life but a convincing argument about whether or not such a system has been, or even can be created digitally, hinges on identifying a satisfactory set of criteria for judging its success. To date this has been elusive.

Many digital evolutionary systems generate an initial burst of interesting activity, but then seem to reach

³See (Galloway, 2011) for a good additional insight into Barricelli’s motives for his work, as revealed in material obtained from the IAS Archives. Barricelli’s term “unlimited evolution” is now more commonly referred to as “open-ended evolution” in the Artificial Life literature.

⁴Some examples of work from this period that *did* follow Barricelli’s goals more closely include (Conrad and Pattee, 1970) and (Holland, 1976).

⁵This developed into the biannual international ALIFE conference series, which is still running (along with an expanding number of regional conferences). An overview of recent work in this area is provided by Bedau (2007). At the same time, research on using evolution as an optimisation process continues to thrive.

a quasi-stable state beyond which no further qualitative changes are observed. Intuitively, these systems don’t seem to be open ended. This suggests that more features of biological evolution must be incorporated into digital worlds, beyond the three listed at the start of this paper that are the most obvious requirements for an evolutionary process.

We argue that a more principled, ecologically-inspired approach to modelling energy and matter is important, along with a more careful consideration of the “physical” dynamics of the environment and of the modelling relationship between organisms and environment (Dorin et al., 2008; Korb and Dorin, 2011; Taylor, 2013). Work on these topics is currently underway.

Looking forward, with the increasing importance in many application areas of systems that can autonomously learn and adapt, we see the close relationship between computers, evolution and artificial life only growing stronger.

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