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# Artificial intelligence and synthetic biology: A tri-temporal contribution

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ABSTRACT

Artificial intelligence can make numerous contributions to synthetic biology. I would like to suggest three that are related to the past, present and future of artificial intelligence. From the past, works in biology and artificial systems by Turing and von Neumann prove highly interesting to explore within the new framework of synthetic biology, especially with regard to the notions of self-modification and self-replication and their links to emergence and the bottom-up approach. The current epistemological inquiry into emergence and research on swarm intelligence, superorganisms and biologically inspired cognitive architecture may lead to new achievements on the possibilities of synthetic biology in explaining cognitive processes. Finally, the present-day discussion on the future of artificial intelligence and the rise of superintelligence may point to some research trends for the future of synthetic biology and help to better define the boundary of notions such as “life”, “cognition”, “artificial” and “natural”, as well as their interconnections in theoretical synthetic biology.



## 1. Introduction

I would like to suggest a triple contribution that artificial intelligence (AI) can make to synthetic biology (SB) within the framework of embodied cognition. This contribution is on three temporal dimensions: the past, present and future. My claims are: that AI can help SB through the study of some *past* issues that we can rethink in a present-day way, particularly issues that are related to the origins of AI; that AI can offer something to SB as regards some particular *current* research on complex adaptive systems and superorganisms, which involves an AI treatment of biological systems, and vice versa; that AI can provide some insight into SB through present-day theoretical and epistemological research on AI *future* development, especially that concerning the notions of general AI and superintelligence.

Contributions from these three specific segments of AI development can concur to create a general framework within which it is possible to steer the efforts of SB in the building of synthetic biological parts, cells or even more complex organisms, with the aim of exploring the basis of cognition and cognitive processes. This is in the spirit of the origins of AI because the initial impulse of AI has not disappeared today and it has been totally recovered following renewed interest in past elements that come together in the current embodied approach to cognition. In Section 2, I outline what AI and SB are in general and what their aims are, trying to establish a common ground of interaction. In Sections 3 and 4, I deal with issues of early AI that may prove useful to current SB. In Sections 5 and 6, I address present issues of complex adaptive systems and biological systems that can help to create a fruitful interaction between AI and SB. In Section 7, I raise some issues regarding the future of AI that may be relevant to discussions on future research on SB. In Section 8, I draw conclusions and point out that AI can, by contributing to SB, also can gain something from SB.

## 2. AI and SB: an overview

Since its origins, AI has been aimed at simulating any feature of intelligence by a machine (the starting conjecture of Dartmouth's proposal on AI in 1955). Two very different approaches have been used to achieve this aim: top-down, centralized, control-driven, logical-based systems that model one or several specific intelligent features or cognitive process; bottom-up strategies that involve systems, in which low level agents interact with each other, or micro-entities simulate the behavior of parallel processing, giving rise to emergent cognitive phenomena. While the former is the traditional approach, the latter is more typical in the new AI of recent decades, which is strictly connected to embodied and enactive cognition. While the former is considered to be too engineering-driven and oriented to explain (human-level) cognition, the latter appears

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to be more suited to explaining cognitive features of entities provided with a body and a brain, and acting in an environment.

Both approaches are still alive (Russell and Norwig, 2010), have a long history and have interacted with each other, leading among other things to the development of in-between positions and outcomes (hybrid models and systems), as well as specific and autonomous sub-fields of research. These include artificial life (A-Life), which is one of the most important because it is rooted in cybernetics, and deals with simulation and creation of artificial living entities. A-Life is also closely connected with new trends in AI, including complex adaptive systems. New AI, however, is a more general approach and is involved not only with life, but also with cognition and cognitive processes. Most likely, AI is not a science, in the traditional meaning of the word, that is provided with a specific object, language and method (Matteuzzi, 2005). AI is a set of closely-related disciplines with different objects, languages and methods, but with a general aim and at least an abstract overall methodological feature: computational simulation and modeling. The history of its changes and trends is rich and justifies an attempt to find suggestions and ideas in AI that may enrich SB.

SB is somewhat different. Even if the idea and the expression are old,[1] it is only with biological and genetic engineering and DNA sequencing – starting in the 1980s – that true synthetic biology has become possible. SB has two general main trends of research: (i) designing and constructing new biological parts and systems; (ii) re-designing natural and already existing biological systems, or parts of these systems, for useful purposes. Both trends involve biology but their targets are quite different and imply different methodologies. While the latter uses a top-down approach to build new biological systems by integrating biological parts into an existing system by exploiting mathematical models, the former makes use of a bottom-up approach to design and construct synthetic protocells starting from biochemical building blocks (Freemont and Kitney, 2012). In the last 15 years the field of SB has split into specific subfields: bio-inspired and bio-mimetic SB; recombinant DNA applied to metabolic engineering; genome engineering; evolution; biological building using bio-bricks (Church and Regis, 2012).

Therefore, SB is a set of related disciplines – just as AI is – whose general aim is to obtain something living or that occurs substantially in living systems by manipulating biological matter. Both AI and SB exploit top-down and bottom-up approaches and both share a mathematical (SB) and/or logical (AI) conceptual framework and modeling in top-down approaches. Bottom-up approaches appear to be the common ground upon which AI and SB may influence each other. If SB wishes to deal with cognitive problems and develop proto-cognitive systems and systems with real cognitive processes, some AI bottom-up approaches, which I shall address in the next sections, are useful and fruitful. Bottom-up and bio-inspired AI approaches opened AI to the embodied and enactive approach. This is the new AI, which can influence SB approaches, insofar as its aims are shared by and benefit from SB technologies, methods and conceptual framework, to refine its biological inspiration and commitment.

## 3. Biology and early AI

Interest in biology has been part of AI ever since this field of research originated, even before the birth of the label "Artificial Intelligence". Turing, one of the acknowledged fathers of AI, especially of the traditional, symbolical and logical AI, was interested in biological structure in the very years in which he dealt with the epistemological and philosophical problems of AI by addressing them starting from the question "can a machine think?" (Turing, 1948, 1950). In an article from 1952, Turing outlines a theory of morphogenesis based on chemical substances that "react together and diffuse through a tissue", producing a structure (Turing, 1952). The main idea of Turing's theory is that chemical reactions in an embryo generate spatial patterns or forms. He was interested in the abstract idealized chemical model underlying morphogenesis, which he called "reaction–diffusion" model. It is a mathematical model that, according to Turing, can be simulated, tested and improved by computer. Turing was far ahead of his time and unsurprisingly his work has been considered as a forerunner of A-Life.[2]

A-Life is obviously not the same as SB. However, it is something that lies in the middle between AI and SB, because its methodology is strongly based on the synthesis of life-like behaviors and entities through computer and other artificial supports. Therefore, in some ways it is not just simulation: it is also realization of life (Langton, 1986). The question is quite simply whether life can be made artificially (Boden, 2006: 1322). But the general principle of extracting the logical form of living systems closely corresponds to Turing's ideas on morphogenesis and a mathematical theory of pattern formation from chemical abstract bases. According to Turing, pattern formation and differentiation are due to a breaking of symmetry[3] and uniformity that leads to new, different stable forms. Thus, providing a theory of morphogens and morphogenesis is basically providing a theory of what chemical reaction constraints, expressed with a non-linear differential equation, produce a new stable system.

The mathematical theory of embryology sketched by Turing is very interesting, especially in the light of his remarks on unorganized and self-organized machines of a work from 1948.[4] This paper introduces the idea of connectionism in a very similar way to the artificial neuron of McCulloch and Pitts (1943), and its main aim is to connect intelligence and learning. Turing speaks about models of artificial neural networks in terms of unorganized machines. These machines are formed by units (the abstract neurons) connected to each other and capable of having two definite states. The initial structure of neurons is random, which means the machine is unorganized, though the neurons can be trained through interference from outside. Two kinds of interference are possible: "there is the extreme form in which parts of the machine are removed and replaced by others. This may be described as 'screwdriver interference'. At the other end of the scale there is 'paper interference', consisting in the mere communication of information to the machine, which alters its behavior" (Turing, 1948: 419). The two kinds of interference can be seen as hardware replacement and software change, respectively. But this is too narrow a view. The two kinds of interference are not so different and the notion of interference closely overlaps, in present-day terms, the one of interaction (with an unspecified environment), though it may also result from a self-change process. Indeed, interference changes the machine. When interference is due to "internal operations of the machine" and affects the part of storage containing the instructions describing the machine itself, the machine is modifying itself.

Interference, in the sense of information communication and interaction, is a very interesting notion. It underlies the possibility to educate a machine, through interfering training. It is a very insightful and unprecedented anticipation by Turing of the idea of supervised training for improving the performance of a neural

[1] The phrase has been used for the first time by Stépane Leduc in "La biologie synthétique, étude de biophysique", in 1912.

[2] On the birth of present-day A-Life see Langton (1986, 1989). On Turing and A-Life see Copeland (2004: 507–513) and Boden (2006: 1261–1267).

[3] Symmetry-breaking systems in the sense of Turing (1952) are studied in current research on multicellularity (Lu et al., 2014).

[4] The two works (1948 and 1952) are different but connected, as Turing says in a letter to Young (8 February 1951); see Copeland (2004: 517).