

The logical Mechanisms of Life

“The designs found in nature are nothing short of brilliant, but the process of design that generates them is utterly lacking in intelligence of its own”. Daniel Dennett, NY Times 2005

Life-As-It-Could-Be: but, what is non-life-as-it-could-be?

“Artificial Life [AL] is the study of man-made systems that exhibit behaviors characteristic of natural living systems. It complements the traditional biological sciences concerned with the *analysis* of living organisms by attempting to *synthesize* life-like behaviors within computers and other artificial media. By extending the empirical foundation upon which biology is based *beyond* the carbon-chain life that has evolved on Earth, Artificial Life can contribute to theoretical biology by locating *life-as-we-know-it* within the larger picture of *life-as-it-could-be*. [...] [AL] views life as a property of the *organization* of matter, rather than a property of the matter which is so organized. Whereas biology has largely concerned itself with the material basis of life, Artificial Life is concerned with the formal basis of life. [...] It starts at the bottom, viewing an organism as a large population of *simple* machines, and works upwards *synthetically* from there — constructing large aggregates of simple, rule-governed objects which interact with one another nonlinearly in the support of life-like, global dynamics. The ‘key’ concept in AL is *emergent behavior*.” [Langton, 1989, pp 1-2]

“Artificial Life is concerned with tuning the behaviors of such low-level machines that the behavior that emerges at the global level is essentially the same as some behavior exhibited by a natural living system. [...] Artificial Life is concerned with generating lifelike behavior.” [Langton, 1989, pp 4 and 5]

The previous quotes indicate the goals of Artificial Life according to Chris Langton: the search for complex, artificial, systems which instantiate some kind of lifelike *organization*. There seems to be both a desire to obtain an actual artificial living organization, as well as obtaining some lifelike behavior. The first goal is more ambitious and related to the first definition of life introduced in lecture one, while the second goal is related to the second definition. The methodology to reach either of these goals is also in line with the notion of emergence mentioned in lecture one: from the non-linear interaction of simple, mechanistic, components, we wish to observe the emergence of complicated, life-like, unpredictable, behavior. Natural living organisms are likewise composed of non-living components. As pointed out in lecture one, the origin problem in biology is precisely the emergence of life from non-living components. The material components follow, and are completely described, by physical laws, however, a mechanical explanation of the overall living system is incomplete. Similarly, in Artificial Life, we have formal components obeying a particular set of axioms, and from their interaction, some global behavior emerges which is not completely explained by the local formal rules. Clearly, the formal rules play the role of an artificial matter and the global behavior, if recognized as life-like, plays the role of an artificial biology.

“Of course, the principle assumption made in Artificial Life is that the ‘logical form’ of an organism can be separated from its material basis of construction, and that ‘aliveness’ will be found to be a property of the former, not of the latter.” [Langton, 1989, page 11]

The idea is that if we are able to find the basic design principles of living organization, then the material substrate used to realize life is irrelevant. By investigating these basic principles we start studying not only biological, carbon-based, life — life-as-we-know-it — but really the universal rules of life, or life-as-it-could-be. Moreover, from a better understanding of the design principles of life, we can use them to solve engineering problems similar to those that living organisms face [Segel and Cohen, 2001; DeCastro and Von Zuben, 2005]. Several problems have been raised regarding this separation of matter from form, or the search

for a universality without matter [Cariani, 1992; Moreno et al, 1994], which will not be discussed here. What needs to be made more explicit is the relationship between the two distinct goals of AL.

Looking at emergent behavior, obtained from formal complex systems, in search of *interesting* behavior leads to a certain circularity. If AL is concerned with finding life-like behavior in artificial, universal, systems, we are ultimately binding life-as-could-be to the behavior of life-as-we-know-it by virtue of some subjective resemblance. This can hardly be accepted as the search for universal principles.

“They say, ‘Look, isn’t this reminiscent of a biological or a physical phenomenon!’ They jump in right away as if it’s a decent model for the phenomenon, and usually of course it’s just got some accidental features that make it look like something.” [Jack Cowan as quoted in *Scientific American*, June 1995 issue, “From Complexity to Perplexity”, by J. Horgan, page 104]

“Artificial Life — and the entire field of complexity—seems to be based on a seductive syllogism: There are simple sets of mathematical rules that when followed by a computer give rise to extremely complicated patterns. The world also contains many extremely complicated patterns. Conclusion: Simple rules underlie many extremely complicated phenomena in the world. With the help of powerful computers, scientists can root those rules out.” [J. Horgan, *Scientific American*, June 1995 issue, “From Complexity to Perplexity”, page 107]

“Artificial Life is basically a fact-free science”. [John Maynard Smith as quoted in *Scientific American*, June 1995 issue, “From Complexity to Perplexity”, by J. Horgan, page 107]

The problem is that Artificial Life must be compared to something, otherwise it becomes a factless manipulation of computer rules with subjective resemblances to vague ideas about the behavior of real life. Again, we are faced with many possible types of emergent complex behaviors, this time formal, but what kinds of these behaviors can be classified as “life-as-could-be”? What is the formal threshold of complexity needed? In the natural world we are able to distinguish life from non-life, biology from physics due to the known signatures of bio-chemistry. In the logical realm, we likewise need a formal criteria to distinguish logical life from logical non-life, artificial life from artificial physics. Only by establishing an artificial physics, from which an artificial biology can emerge, and a theory, or set of rules, distinguishing the two, can we aim at a proper science based on fact.

“Artificial Life must be compared with a real or an artificial nonliving world. Life in an artificial world requires exploring what we mean by an alternative physical or mathematical reality.” [Pattee, 1995]

The two goals of AL are usually described as *hard* and *soft AL* respectively. The first concerns the synthesis of artificial life from computational or material (e.g. embodied robotics) components. The second is interested in producing life-like behavior and is essentially metaphorical. To be accepted as a scientific field, ALife cannot settle for subjective rules of what constitutes living behavior. Indeed, whether we want to synthesize life or merely simulate a particular behavior of living organisms, we need investigate the rules that allow us to distinguish life from non-life. Naturally, the requirements for hard AL are much stricter, as we are not merely interested in behaviors that can be compared to real biological systems with looser or stricter rules, but the actual realization of an artificial organization that must be agreed to be living. Soft AL, may restrict itself to particular behavioral traits which need only to be simulated to a satisfactory degree.

Simulations, Realizations, Systemhood, Thinghood, and Theories of Life

“Boids are *not* birds; they are not even remotely like birds; they have no cohesive physical structure, but rather exist as information structures — processes — within a computer. But — and this is the critical ‘but’ — at the level of behaviors, *flocking Boids and flocking birds are two instances of the same phenomenon: flocking.* [...] The ‘artificial’ in Artificial Life refers to the component parts, not the emergent processes. If the component parts are implemented correctly, the processes they support are genuine — every bit as genuine as the natural processes they imitate. [...] Artificial Life will therefore be genuine life — it will simply be made of different stuff than the life that has evolved on Earth.” [Langton, 1989, pp. 32-33]

“Simulations and realizations belong to different categories of modeling. Simulations are metaphorical models that symbolically ‘stand for’ something else. Realizations are literal, material models that implement functions. Therefore, accuracy in a simulation need have no relation to quality of function in a realization. Secondly, the criteria for good simulations and realizations of a system depend on our theory of the system. The criteria for good theories depend on more than mimicry, e.g., Turing Tests.” [Pattee, 1989, page 63]

As Pattee points out, the bottom line is that a simulation, no matter how good it is, is not a realization. Nonetheless, it may still be possible to obtain artificial living organisms (realizations) if, from an artificial environment, we are able to generate, in a bottom-up manner, organizations which conform to some theory of life we wish to test. Howard Pattee [1989] has proposed that if emergent artificial organisms are able to perform measurements, or in other words, categorize their (artificial) environment, then they may be considered realizations. Some claim that computational environments do not allow for this creative form of emergence [see Cariani, 1992; Moreno, et al, 1994]. In any case, whatever artificial environment we may use, computational or material, we need a theory allowing us to distinguish life from non-life.

Related to this issue, and in the context of systems science, is the search of those properties of the world which can be abstracted from their specific material substrate: systemhood from thinghood. Systems science is concerned with the study of *systemhood* properties, but there may be systems from which systemhood cannot be completely abstracted from *thinghood*. Life is sometimes proposed as one of those systems [see Rosen, 1986, 1991; Moreno et al, 1994; Pattee, 1995]. The difficulty for systems science, or complexity theory, lies precisely in the choice of the appropriate level of abstraction. If we abstract enough, most things will look alike, leading to a theory of factless, reminiscent analogies, exposed by Cowan and Maynard-Smith above. If, on the other hand, we abstract too little, all fields of inquiry tend to fall into more and more specific niches with little communication amongst them. In the context of life, we do not want to be tied uniquely to carbon-based life, or *life-as-we-know-it*, but we also do not want *life-as-could-be* to be anything at all. The challenge lies precisely on finding the right amounts of systemhood and thinghood, as well as the interactions between the two, necessary for a good theory of life, real or artificial.

Further Readings and References

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- Segel, L.A. and I.C. Cohen [2001]. *Design Principles for the Immune System and Other Distributed Autonomous Systems*. Santa Fe Institute Studies in the Sciences of Complexity. Oxford University Press.

For next lecture read:

- Adami, C. [2006]. "Digital Genetics: Unraveling the Genetic Basis of Evolution". *Nature Reviews Genetics*. 7:109-118.
- Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall. **Chapter 7, sections 7.1, 7.2 and 7.4.**
- Ray, T. S. 1992. "Evolution, ecology and optimization of digital organisms". *Santa Fe Institute* working paper 92-08-042.

Optional: Part I of Flake's [1998], *The Computational Beauty of Life*. MIT Press.