Living Machines

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The Problem: Although artificial intelligence has been very successful and is present, largely unseen, in the everyday life of most people in the developed world, there still seems to be some things missing. Over the last fifteen years we have built behavior-based artificial creatures situated in the world like insects [2] and recently we have built robots with which we can have human-like social interaction [1]. But we never quite forget that these systems are machines and not alive. We build these models to better understand the biological systems, but the models never work as well as biology.

On the other hand scientists have gotten very good at modeling fluids, materials, planetary dynamics, nuclear explosions, and all manner of physical systems. We can put some parameters into a program, let it crank, and get accurate predictions of the physical character of the modeled system. But, we are not good at modeling living systems, neither in the small, nor in the large.

Motivation: Perhaps we are missing something fundamental and currently unimagined in each of our various models of behavior, perception, cognition, evolution, natural selection, morphogenesis, etc. If this turns out to be true then we will need to have some new ways of thinking about the issues of living systems if we are to make progress. This would be disruptive to all the sciences of living systems. As an analogy, suppose we were building physical simulations of elastic objects falling and colliding. If we did not quite undersand physics we might unfortunately leave out mass as a specificable attribute of the objects. Their falling behavior would at first seem correct, but as soon as we started to look at collisions we would notice that the physical world was not being modeled correctly.

What might the nature of this missing element be? One future possibility is that we will discover some aspect of living systems that is invisible to us right now. The current scientific view of living systems is that they are machines whose components are biomolecules. One can not rule out that we will discover some new properties of biomolecules or some new ingredient that we do not currently understand, that are necessary for the aspects of life which we observe. One might imagine that there is something on a par with the discover a century ago of radiation, which ultimately led to our still evolving understanding of quantum mechanics. This is now a firmly ingrained part of physics that was unimagined one hundred years ago–lots of good physics was done before its discovery. Note that even now quantum mechanics is an arena that is trying to be actively tamed in the service of fundamentally new classes of computation. Of course, relativity was the other great such discovery of the twentieth century with similar disruptive impact on our basic understanding of physics. Some such discovery might rock our understanding of the basis of living systems, and indeed their could be different such discoveries for various aspects of living systems, such as evolution, perception, etc.

Or it may be that what is missing is simply some "new mathematics". It may be that we do not require any new physics to be present in living systems. Rather it might turn out to be the case that we are simply not seeing some fundamental mathematical description of what is going on in living systems and we are leaving it out of all our AI and Alife models for that reason. This argument is played out in more detail in [3].

This project is an attempt to find this new mathematics.

Previous Work: There is of course a long history of trying to understand what it is that separates living from non-living matter. An insightful analysis of the nature of what an adequate theory might be like can be found in [4].

Approach: We have adpoted a three pronged attack on the problem.

1. We are building robots and trying to equip them with capabilities that living systems have, but which robots

have not previously had. These include self-repair, self-reproduction, energy self-sufficiency, growing bodies, and control adaptation to variable body morphology. In this work we demand a minimal competence from the robots, but that competence is not the primary goal–the primary goal is the exploration of the capabilities that all living systems have, but which robots have not previously had.

2. We are building large scale computational experiments to explore aspects of living systems that can not at this time be directly approached in hardware. These include self-organization of pre-biotic chemistry, self-organization of very simple neural systems in very primitive creatures, self-organization of physical structures based on tensegrity, and the evolution of physical attributes of creatures in complex environments.
3. We are trying to generalize our results in both the first two areas to be able to state mathematical theorems governing aspects of living systems. This work lags well behind the first two areas.

None of these approaches is completely unique. However, it is unique to have all three activities going on in a single research group. We are hopeful that the three activities will cross fertilize each other and lead to new insights.

Impact: This work has two potential sorts of impact. First, it may give better insight into how living systems work, so that they can be better analyzed and understood. Second, it may allow us to build new classes of machines with many of the desirable properties of living systems, including their robustness, their adaptability, and the minimal overhead that is required to fabricate them.

Future Work: This project is in its initial stages. There will be many changes to the specific problems that we work on as we refine the questions we are asking. There are however some interesting aspects of the problem that we have not yet addressed. For instance, we are still using conventional materials for our robots. In the future we intend to explore the use of different materials. We may also consider the explicit use of bio materials.

References:

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[3] Rodney Brooks. The relationship between matter and life. *Nature*, 409:409–411, 2001.

[4] Robert Rosen. *Life Itself: A Comprehensive Inquiry Into the Nature, Origin, and Fabrication of Life.* Columbia University Press, New York, 1991.