Rehabilitating Biology as a Natural History

Takashi Ikegami

Adaptive Behavior 2009 17: 325
DOI: 10.1177/1059712309340855

Adaptive **Behavior**

Rehabilitating Biology as a Natural History

Takashi Ikegami
Graduate School of Arts and Sciences, University of Tokyo

1 Missing a Fundamental Theory in Biology

Our age is missing a basic theory of living systems. As biology has changed from a natural history to systemic science, we find ourselves in a flood of fine-grained data without having a basic theory to interpret it. We are therefore not in a better place to understand what life itself is in spite of many technical advances and ever more sophisticated analysis.
Basic theories of living systems have been proposed in the past by Alan Turing (1952), John von Neumann (1966), Walter B. Cannon (1963), W, Ross Ashby (1960), Nobert Wiener (1965) and Humbert Maturana and Francisco Varela (1980) most of them are from the era of cybernetics. By digesting their ideas and concepts carefully, we understand what kind of model and experiments we must study to develop a new fundamental theory of living systems. We should always ask very basic things repeatedly if we are to make biologically plausible models: When we are to do modeling, what should be a state of a system? What evolves temporally? What are the ir/relevant patterns? Should we take time steps discretely or continuously? Without going back to these fundamental queries, we will not progress in understanding biological phenomena. Biology is itself a new layer of description, what we call the middle layer description, different from the chemical or physical layers.

In other words, most research studies apply existing mathematical formulae to biology without doubting their plausibility and very few studies do the inverse: create a new mathematics from biology. Biological phenomena are certainly a mother of new mathematics not yet discovered. A purpose of artificial life, making abstract models and creatures, is ultimately to create the mother of new experimental mathematics from contemporary biology. In the light of this perspective, I respond to Webb's criticisms in the discussion in below.

2 Responding to Webb's Criticisms

Webb's article compares two kinds of models; one that is built with reference to a specific animal behavior and one that is built as an abstract possible form of life (called an *animat*).

There are serious criticisms in Webb's article, which I would like to address:

1. The animat model is simply too abstract and therefore unverifiable by experimental data, while models based on real-life animals can be justified empirically and therefore they contribute to understanding biology. Fantastic animat studies undermine any justification for its relevancy in biology.
2. We cannot say that more abstract models can make more general statements about biological phenomena compared with models that mimic specific behaviors of existing living creatures.

The first point poses a false problem with regard to artificial creatures. In other words, because an artificial model creature is a new non-existent creature, we cannot say the behavior is credible or applicable to living creatures or systems. This statement may sound

Correspondence to: Takashi Ikegami, Graduate School of Arts and Sciences, University of Tokyo, Komaba, Tokyo 153-8902, Japan.
E-mail: ikeg@sacral.c.u-tokyo.ac.jp

(2009), Vol 17(4): 325–328.
DOI: 10.1177/1059712309340855

plausible at first glance but the same criticism can be applied to models that closely mimic existing animals.

There may be a default hypothesis that people in artificial life (ALife) and adaptive behavior have in mind when making biological models. That is a "life = machine" hypothesis. It is clearly stated by Braitenberg (1986): the complex emotional or conceptual behavior of living creatures can be emulated by wiring adequate electric circuits inside the animat. This does not imply that the animat's behavior is predictable, but people assume that the behavior should be predictable given the artificial and simple nature of the creature. This creature should respond exactly the same way to the same stimulus during every trial.

However, we seldom see a typical stimulus–response relationship in these artificial creatures. Instead, a creature has a fluctuating unexpected behavior, which we often say is biological autonomy. Living creatures also have differing profiles and because of that there emerge many individualities and personalities. Living systems have potential adaptability by having individual experiences and learning capabilities based on their experiences. Amplifying the individual variances is a unique capability of living creatures. Therefore, a "life = variation generator" principle is a more adequate hypothesis in place of the life = machine hypothesis.

Thus ALife research hesitates to make an "accurate" model that emulates a specific animal behavior. Instead, ALife is trying to understand the mechanisms that create individual variety and adaptability, the very essence of living systems.

Since I believe that it is not the individual behavior but the underlying variation generator that is more important for modeling, I claim that it is wrong to try to justify models by merely focusing on the typical animal behavior. In opposition to Webb's stance, a model that mimics a real animal has more chances of becoming meaningless to biology. Therefore, I think it is not a good idea to evaluate model behavior in terms of how much it can mimic a target behavior, but it should model the hidden motivation or cause of that behavior; for example, homeostasis is one such candidate (Ashby, 1960).

On the other hand, I think the second statement is right and an abstract model is not equal to a generic model in general. For example, the Ising model (the simplest magnetic spin model) is often taken as an abstract model of memory in a brain system (e.g., Hopfield's, 1982, model), but it is not a generic model for a brain memory. Another abstract model called the Sherrington–Kirkpatrick (SK) model (Sherrington & Kirkpatrick, 1975) is taken as an abstract model of spin glass states. Again this model cannot be taken as a realistic model nor an idealistic model; however, theoretical insights on the spin glass nature from this model are very rich and fruitful, for example, hierarchical organization of meta-stable states.

Therefore, an animat model can become powerful and useful in biology when it provides a rich insight into, or widens our scope of, real living systems, even if an animat itself does not mimic any existing animals. Therefore, we need an animat model that accounts for living creatures as in case of the SK model above. In this sense, Beer's animat is a good example of such an abstract model, but I am afraid its entailing concepts are not rich enough.

Let me comment on the opposite of the ideal limit described above that makes models on the most fundamental detailed levels. One such approach is molecular dynamics (MD), where only molecules and their electrostatic potentials are considered. Since any idealization or generalization has to do with neglecting realistic details, the MD approach is safely limited within its level of description. No assumptions need to be made about higher order entities, but rather any behavior that emerges in the system is to the result of molecule–molecule interactions. It is hoped that with increasing computational power, the MD approach can be scaled-up and used to explain many of aspects of living systems.

This MD limit is a realistic example of the type of modeling that seems at odds with the style of modeling employed by the ALife researchers. If we care too much about the accuracy of objects, then we are not able to compute even a single neural cell. A precise MD simulation of a single neural cell is far too difficult to compute. In such a situation, we need an adequate middle layer to describe life-like phenomena such as thermal dynamics. In addition to the 10^{23} molecules, we can describe the thermal property of a system with only four variables: temperature, pressure, volume, and the number of particles. But entropy must be introduced for making consistent thermal description of a system.

Using the thermodynamic formalization as an example, we need a middle layer for a living system where we can discuss the generic property and introduce new concepts such as entropy irrespective of the lower level structures and dynamics. Focusing on the middle layer is a prerequisite to making a model, whether it will be a biologically plausible or artificial life-like model. The theoretical contribution to biology is all about creating the middle layer.

We should bring a conceptual framework to distinguish the living from the non-living. Braitenberg's simple machine = life hypothesis creates a middle layer, which we appreciate. Many in artificial life, in particular Randall Beer, also focus on the middle layer description. But, unlike thermodynamic formalization, a living system is an ever-changing process. We need further elaboration for studying its self-organizing, self-regulating, and self-evolving properties by defining the middle layer (Ikegami, 2006).

3 Darwin's Earthworms and Oil Droplets

Charles Darwin studied earthworms to show how earthworms are intelligent and interesting agents (Darwin, 1881; Reed, 1996). They are not reflectively responding to the environmental changes but behave mindfully and show adaptability to dig holes and maintain the soil conditions.

Can we make a simple model for such earthworms? We may be able to make a model earthworm that replicates what Darwin observed with a real earthworm. However, this is not the point Darwin was trying to make. The earthworms' behavior can be determined by a simple neural circuit, but in the context of its environment its behavior becomes complex. The complexity comes from the interaction with the soil. No animal can be independent from the environment and only by changing it and assimilating into it can an animal live within the environment. This adaptability is what we seek to understand using our models.

However, this adaptability is difficult to understand from a Braitenberg's vehicle approach, since it lacks the notion of self-organization from the interaction between the earthworm and the soil. Such a viewpoint is often missing from both biologically plausible modeling and robotics research including animats studies.

Recently, we began to investigate a chemical experiment that produces a self-moving system (Hanczyc, Toyota, Ikegami, Packard, & Sugawara, 2007; Ikegami & Hanczyc to be submitted). Putting a drop of oil consisting of oleic anhydride into highly alkaline water, we see that the oil droplet becomes covered by the oleic acid generated from the reaction between oleic anhydride and the water at the oil water interface. Under the right conditions, we see that the oil droplet starts to move around in the aqueous solution. We hypothesize that the convection flow emerging inside the droplet sustains the chemical reaction on the surface of the droplet and this is responsible for the self-movement of the oil droplet. Depending on various conditions, the oil droplet shows a variety of motion styles as well as inter-droplet interactions.

This material system is a new form of artificial life animat, which Webb may say is interesting but nothing to do with biology. However, I see many properties in the oil droplet behavior that are relevant to biology:

1. The oil droplet adjusts to its own environmental condition and responds by starting to move.
2. A primitive form of chemotaxis emerges without specifically designing sensors or motors or linking neural networks into the system.
3. Many droplets together exhibit interesting behaviors that resemble dancing, chasing, and fighting.

These are observational descriptions that we must support by repeating the experiments and correlating behavioral properties of the oil droplets with their internal/external states. Some of these results are already qualified and will be reported elsewhere. For example, how a droplet starts to move and change its direction is replicated approximately by computing the Navier–Stokes equations coupled with the chemical reaction (Matsuno, Hanczyc, & Ikegami, 2007).

We note that this oil droplet model has a similar meaning to us as the earthworm to Darwin. And in this way we must keep an observational diary of droplet behavior and morphology in order to make a natural history of these chemical creatures. Although biology has made a transition from a natural history to a systematic science, observational science is still needed.

We discussed a middle layer description of a life system in the previous section. The middle layer description is only obtainable by making such observations. Either through computational simulation, robot manipulation, or chemical experiment, the exploration of potential behavioral patterns is necessary to build a new natural history of the artificial. This may sound paradoxical but animats are generating a natural history per se.

In this sense, we must say that Webb's criticism to the artificial life approach is from a narrow perspective. We need a fundamental theory to create a comprehensive natural history of both real and artificial creatures, and artificial life has a central role in exploring the complexity of its self-organizing, self-regulating, and self-evolving nature. My contention is that biology has to rehabilitate a natural history approach, which will support a new fundamental theory that includes animat behaviors.

Acknowledgment

I thank Martin Hanczyc for valuable comments and discussions.

References

Ashby, R. (1960). *Design for a brain* (2nd ed.). New York: John Wiley & Sons, Inc.

Braitenberg, V. (1986). *Vehicles: Experiments in synthetic psychology*. Bradford Books.

Cannon, W. B. (1963). *The wisdom of the body*. Peter Smith Pub. Inc.

Darwin, C. (1881). *The formation of vegetable mould, through the action of worms, with observations on their habits*.

Hanczyc, M., Toyota, T., Ikegami, T., Packard, N., & Sugawara, T. (2007). Chemistry at the oil-water interface: Self-propelled oil droplets. *Journal of the American Chemical Society*, *129*(30), 9386–9391.

Hopfield, J. J. (1982). Neural network and physical systems with emergent collective computational abilities. *PNAS*, *79*(8), 2554–2558.

Ikegami, T. (2006). *Life emerges in motion*. Seido Publ.

Matsuno, H., Hanczyc, M., & Ikegami, T. (2007). Self-maintained movements of droplets with convection flow. In *Proceedings of the Australian Conference for Artificial Life* (pp. 179–188).

Maturana, R. H., & Varela, F. (1980). *Autopoiesis and cognition: The realization of the living*. D. Rediel Pub. Co.

Reed, E. S. (1996). *Encountering the world: Toward an ecological psychology*. Oxford University Press.

Sherrington, D., & Kirkpatrick, S. (1975). Solvable model of a spin-glass. *Physical Review Letters*, *35*(26), 1792–1796.

Turing, A. (1952). The chemical basis of morphogenesis. *Royal Society of London Philosophical Transactions Series B*, *237*, 37–72.

von Neumann, J. (1966). *Theory of self-reproducing automata*. Urbana, IL: Univ. of Illinois Press.

Wiener, N., *Cybernetics: Or the Control and Communication in the Animal and the Machine. (MIT Press, 2nd Edition, 1965)*.