Cybernetics and Systems: An International Journal, 32:443–458, 2001

0196-9722/01 $12.00 + .00

MAKING WAVES: THE PARADIGMS OF DEVELOPMENTAL BIOLOGY AND THEIR IMPACT ON ARTIFICIAL LIFE AND EMBRYONICS

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Dedicated to Alan W. Hunstad on his 16th birthday.

Artificial life ("Alife") is purported to subsume real life, but in practice *life-as-it-could-be* is not based on *life-as-we-know-it*, but rather on *life-as-we-don't-know-it*. In terms of developmental biology, this means that we have yet to decide which of numerous paradigms for the embryogenesis of organisms is correct, if any. Two paradigms are compared and contrasted: positional information and differentiation waves. These provide very different models for the nascent field of embryonics, the construction of computers and robots based on ideas from embryology. The behavioral component of Alife is usually thought about in terms of neural networks. Yet bacteria, single-cell ciliates such as *Paramecium*, and multicellular organisms, such as the ciliated placazoan *Trichoplax adhaerens*, have reasonably rich behavioral repertoires without nervous systems at all. It is therefore suggested that if Alife is to imitate and go beyond real life, then simulations of these organisms may be the place to begin.

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LIFE-AS-WE-KNOW-IT?

The basic premise of artificial life (ALife) studies is that one can transcend carbon-based real life via other media, such as computer simulations and robots:

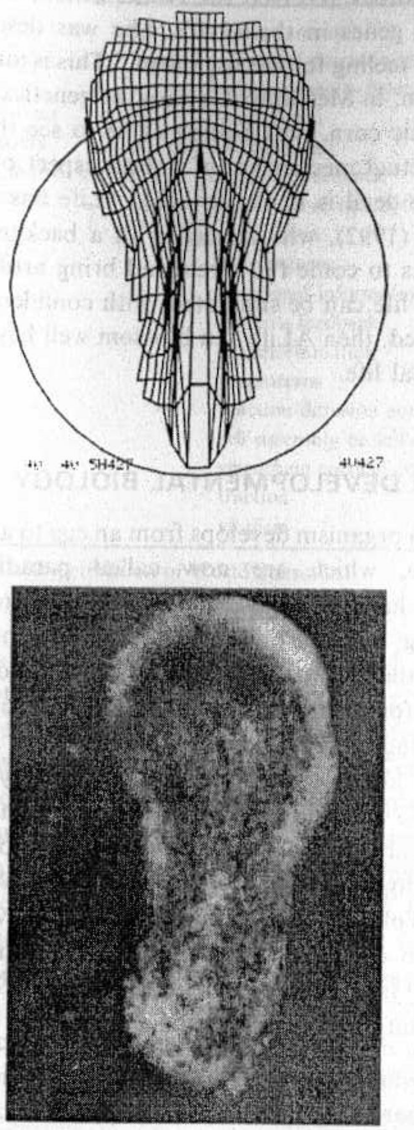
> "Artificial Life can contribute to theoretical biology by locating *life-as-we-know-it* within the larger picture of *life-as-it-could-be*" (Langton, 1989).

This sounds satisfactory, except for the fact that we have barely begun to understand real life, so we are actually faced with trying to make a superset starting from *life-as-we-don't-know-it*. We may, then, take the dim view that ALife is another case of the nearsighted drunk looking for lost glasses under a lamp post "because the light is brighter there."

In my own work, I have taken a different approach to the role of computers in understanding life. Once we have extracted what we guess as some essential feature of a living system, and reduced it to a set of components and their rules of interaction, then we can write a computer simulation embodying those rules. If the results of the simulation match the empirical observations, then the model has some chance of being correct. If not, we have to refine it or start over. Some 35 years ago Max Braverman, a hulky ex-Marine who studied delicate hydroid colonies, and I verbalized this in the following way (cf. Gordon, 1999). We had each shown that computer simulations with simple rules could imitate some of the complex morphogenesis of living organisms (Braverman, 1962, 1963; Braverman & Schrandt, 1966; Gordon, 1966). We knew full well that alternate models could generate similar looking results. So we declared that the time had come to find the actual mechanisms by which organisms constructed themselves.

This program was carried out with Antone G. Jacobson to work out the mechanism by which the open neural plate in salamander embryos changes from a disk to a keyhole shape (Figure 1).

Today's artificial life research, and its derivative, embryonics (Tempesti, Mange, & Stauffer, 1999), which aims to make better computers based on life, start from models of life that are unproven. Life-as-it-could-be becomes a subset, rather than a superset, of the possibilities that we could imagine. Can one really build Alife *in silico* from there?



(a)

(b)

Figure 1. Compression of (a) our computer simulation of the neural plate, which started as a flat circular disk of diameter 2.4 mm, with (b) an actual neural plate, removed from a salamander embryo. (From Figure 17 in Jacobson and Gordon [1976], with permission of John Wiley & Sons. See also Gordon and Jacobson [1978].)