ELSEVIER

Artificial Intelligence 73 (1995) 371-377

Artificial Intelligence

Book Review

Christopher G. Langton, ed., *Artificial Life*[1]

Christopher G. Langton, Charles Taylor, J. Doyne Farmer, Steen Rasmussen, eds., *Artificial Life II*[2]

Christopher G. Langton, ed., *Artificial Life II: Video Proceedings*[3]

Stephen W. Smoliar*

Institute of Systems Science, National University of Singapore, Heng Mui Keng Terrace, Kent Ridge, Singapore 0511

1. The ill-defined vision of artificial life

A seductive name is often more confusing than informative to the imagination of the general public. Names like "catastrophe theory" and "chaos theory" (not to mention "artificial intelligence") never fail to attract popular attention but rarely direct that attention to the substance of their respective disciplines; and serious practitioners often wish those names had never been coined in the first place. Now we are confronted with "artificial life", whose origins can be traced back to the late Sixties when John Conway began work on his "Game of Life" [2]. This was simply an array of cellular automata whose two states were metaphorically dubbed by Conway "live" and "dead". Conway further pursued his metaphor by explaining the transition rules in terms of "birth", "death", and "survival". This metaphor was subsequently picked up by Christopher

* E-mail: smoliar@iss.nus.sg.

[1] (Addison-Wesley, Redwood City, CA, 1989); xxxi+655 pages.

[2] (Addison-Wesley, Redwood City, CA, 1992); xxi+854 pages.

[3] (Addison-Wesley, Redwood City, CA, 1992); 120 minutes.

SSDI 0004-3702(93)E0081-V

Langton in the course of his doctoral research at the University of Michigan [5]:

> Cellular automata provide us with the logical universes within which we can embed artificial molecules in the form of propagating, virtual automata. We suggest that since virtual automata have the computational capacity to fill many of the functional roles played by the primary biomolecules, there is a strong possibility that the "molecular logic" of life can be embedded within cellular automata and that, therefore, artificial life is a distinct possibility within these highly parallel computer structures.

The paper from which the above quotation was taken, entitled "Studying Artificial Life with Cellular Automata", appeared in the 1986 volume of *Physica D*; and in September of 1987, Langton organized "an interdisciplinary workshop on the synthesis and simulation of living systems" at the Center for Nonlinear Studies of the Los Alamos National Laboratory. The proceedings of this workshop were published under the title *Artificial Life* by the Santa Fe Institute as the sixth volume of their "Studies in the Sciences of Complexity". A second workshop was held in the city of Santa Fe in February of 1990; and *its* proceedings were subsequently published under the same auspices as *Artificial Life II*, along with a two-hour videotape.

While these workshops have now led to over 1500 pages of published material and two hours of video, I think it is fair to say that the discipline has yet to converge upon any unifying principles or themes. The workshops have been highly eclectic events, bringing together participants from disciplines which were often almost entirely unaware of each other. Yet while the resulting diversity is impressive, even the most enthusiastic reader cannot help but come away from some of the papers without wondering whether or not he has gone beyond the lunatic fringe.

One source of confusion likely to face the reader is that there are actually quite a few things happening in the name of artificial life. Consequently, for the sake of the readers of this journal, it will be desirable to sort out those aspects of artificial life which are related to artificial intelligence from those which are not. The next section will provide a brief review of the latter, where the areas of greatest interest are biology and the philosophical study of emergence. This will be followed by a more thorough discussion of three aspects of artificial intelligence which have been impacted by artificial life research: robotics, implementing Marvin Minsky's "society of mind" [8], and an evolutionary approach to learning. This exposition will be followed by some concluding observations.

2. Aspirations of artificial life (not related to artificial intelligence)

2.1. Biology

If one of the objectives of artificial intelligence has been a better understanding of what we tend to call "thought", then one may say that artificial life wishes to take on the more general question of life itself. This can be approached from a variety of points of view. One is to ask whether or not the manifestations of life on earth are the *only* such manifestations: Can you have life without the building blocks of carbon, oxygen, and hydrogen which are common to all life-forms on this planet? Another is to recognize that there are still major lacunae in our understanding of terrestrial biology, many of which can not be resolved by conventional experimental practices. Artificial life may be viewed as a potential laboratory tool for addressing questions which are beyond the grasp of those experimental practices.

Unfortunately, it may also be viewed as wishful thinking by highly speculative theoretical biologists and camp-followers with limited background in the life sciences. As a result there is precious little which would count as "hard science"; and the reader with a pedestrian knowledge of biology will be ill-equipped to judge the potential value of the "softer" contributions. Fortunately, one of the most concrete presentations is also very well written: " 'Non-Optimality' via Pre-adaptation in Simple Neural Systems", by David Stork, Bernie Jackson, and Scott Walker in *Artificial Life II*. This paper confronts the question of apparently "useless" synapses in certain life forms (in this case the tailflip circuit in the crayfish). The analysis invokes the principle of co-evolution: The circuit is a product of a previous evolutionary stage for which there were different criteria for fitness. However, those fit organisms led to changes in the environment which, in turn, led to new fitness criteria to which the organisms were then obliged to adapt. Such adaptation was not a matter of "optimizing from scratch" but one of seeking a path from a previously optimal state to a new one. Stork and his colleagues lucidly demonstrate how such a path could carry along vestigial remains of the previous state.

Most of the other biology papers are far "softer" in content. In his own contribution to the second volume, "Life at the Edge of Chaos", Langton continues his study of cellular automata by addressing which sets of state-transition rules are likely to yield automata with "life-like" behavioral properties (such as reproduction). However, Langton is clearly more at home with thermodynamics than with biology; and he does little to convince the reader of the biological implications of his investigation. Similarly, there are several papers concerned with the modeling of "autocatalytic sets", chemical mixtures such as the "primordial soup" [7] which has been hypothesized to be the source of life on this planet; but none of those models can yet explain the presence of the molecules common to terrestrial life forms (such as RNA).

2.2. *"Philosophy/emergence"*

An aspect of the second volume of proceedings which was not present in the first was that of philosophical speculation. Two papers were products of a panel discussion on the "Ontology of Artificial Life": "Aspects of Information, Life, Reality, and Physics", by Steen Rasmussen, and "Emergence and Artificial Life", by Peter Cariani. Rasmussen's presentation was extremely sketchy; but it is important to note his observation that "physics also gives rise to chemistry and biology, and through them, an observer participation, namely the emergence of life and later the evolution of man" (p. 769). This reduction of biology to physics was contested in Robert Rosen's paper, "What Does It Take to Make an Organism?" It is unfortunate that this opposing position never appeared in print. Cariani's paper, on the other hand, is more valuable for its expository discussion of three approaches to emergence: computational emergence, thermodynamic emergence, and emergence relative to a model. This analysis is potentially valuable in that it raises the possibility that studies which are concerned with computational emergence (such as Langton's work with cellular automata) may not necessarily impact the physical phenomena of thermodynamic emergence, which include the origin of life. However, it would be a mistake to view Cariani as a defeatist. Rather, his philosophical analysis clearly illustrates a need for focus which is sorely lacking in the biological contributions to these two volumes.

3. Artificial life and artificial intelligence

3.1. Robotics

From the perspective of artificial intelligence, robots are the most viable examples of artificial life, particularly those which are androids or emulations of other animal life forms. The second workshop featured a presentation by Rod Brooks with the humble title, "Real Artificial Life". Much of the substance of this talk can be found in Brooks' paper, "Intelligence without Representation", which has been published in this journal [3]. Nevertheless, it is unfortunate that *some* statement of these results did not appear in *Artificial Life II*.

3.2. Implementing the Society of Mind

One of the more perplexing editorial decisions of the first proceedings volume was the allocation of an explicit section to reports on projects at the MIT Media Lab. While the association between artificial life and media studies seemed tenuous at best, this decision resulted in the publication of one of the most interesting papers in the entire two volumes of proceedings: "Animal Construction Kits", by Michael Travers. The name of the paper, itself, should justify its relevance to artificial life. What is important for purposes of this review, however, is its contribution to artificial intelligence: This paper constitutes an excellent account of an implementation of a system based on the principles outlined in Minsky's book, *The Society of Mind* [8]. One reason for Travers' success may be that he is building upon the same foundation that inspired Minsky, Nikolaas Tinbergen's pioneering study of animal instinct [10].

Travers' system is called Agar, and it was developed as part of the work on the Vivarium Project at the Media Lab. Its long-term goal is to model the three-spined stickleback which Tinbergen had studied extensively. However, one of the more important contributions of Agar is the recognition that an effective implementation of a creature like the stickleback cannot be achieved unless one also implements a realistic world which it can inhabit. Thus, Travers' success can be attributed, at least in part, to his ability to come up with a suitable implementation scale for both his artificial creatures and the world in which they exist.

Travers summarizes the implementation of his creatures as follows:

> An Agar creature's behavioral control system is made up of entities called *agents*, loosely based on those described in Minsky's Society of Mind theory [8]. In Agar's implementation of the theory, agents are computational objects that can:
> - Execute concurrently,
> - Maintain local state,
> - Access the state of other agents through connections, and
> - Take actions automatically when environmental conditions are met.
>
> An agent is to be thought of as semi-autonomous. This means that an agent is not necessarily doing the bidding of some other agent or outside entity such as the user, but is responding to conditions in its environment, which can include other agents as well as the world. In this sense, an agent is similar to a production rule.
>
> An agent's *condition* can be stated as a boolean function of sensor predicates and other agents' activations. An agent's *action* can be an arbitrary behavior expressible in Lisp. ...
>
> Actions that an agent may want to perform include:
> - Activate or suppress other agents,
> - Activate a motor function,
> - Activate a script,
> - Remember the current activation state of other agents (K-line creation ...), and
> - Create a new agent or alter an existing one. (p. 429)

Agar was subsequently demonstrated during the second workshop. However, no paper was presented; and there was no follow-up document in the proceedings volume.

3.3. *Learning and evolution*

A major theme of the second workshop which was virtually ignored during the first workshop concerned the application of principles of evolution to learning. Five excellent papers were delivered during the workshop, all of which appeared in the proceedings volume along with some papers which had their origins as posters. Because these results are of particular interest to current work in artificial intelligence, I shall summarize several of the more interesting of these contributions.

"Interactions between Learning and Evolution", by David Ackley and Michael Littman, addresses a very fundamental question of survival:

> How can an organism learn in ... circumstances, where the only unarguable sign of failure is the organism's own death, and the reproduction process preserves only the genetic information, which is unaffected by any learning performed during the organism's life? (p. 489)

To answer this question, Ackley and Littman propose a new approach to learning algorithms:

> "Evolutionary Reinforcement Learning" [1] (ERL) provides one answer to this question. In ERL, we allow evolution to specify not only inherited *behaviors*, but also inherited *goals* that are used to guide learning. We do this by constructing a genetic code that specifies two major components. The first component is a set of initial values for the weights of an "action network" that maps from sensory input to behavior. These weights represent an innate set of behaviors that the individual inherits directly from its parents.
>
> The second component is an "evaluation network" that maps from sensory input to a scalar value representing the "goodness" of the current situation. By learning to move from "bad" situations to "better" situations—modifying its action network weights in the process—an individual achieves the goals of learning passed down from its predecessors. Whether those inherited goals are actually sensible or not is, of course, a separate issue; insofar as learning is a factor, each organism stakes its life on the *assumption* that its inherited evaluation function is reliable. (p. 489)

The idea of a genetic code which governs not only an organism's "behavioral hardware" but also the goals it has which must be satisfied through behavior places this work very much in sympathy with Tinbergen's perception of instinct and Minsky's interpretation of Tinbergen's work. Indeed, the relationship between behavior and goals is one of the more neglected areas in the current "Neural Darwinism" work of Gerald Edelman and his colleagues [9]. Ackley and Littman have presented a bold piece of experimental work, supplemented by an excellent display of results incorporated in the video proceedings.

The artificial life team at UCLA is represented by several papers, the most interesting of which is "AntFarm: Towards Simulated Evolution", by Robert Collins and David Jefferson. The project is basically concerned with the study of a colony of artificial "ants". The issues are "simulated evolution of complex behavior in complex environments, the evolution of cooperation among closely related individuals, and the evolution of chemical communication" (p. 579). Of greatest interest is the extent to which this work has been guided by attempts to model the actual behaviors observed in ant colonies.

Communication receives more specific examination in another UCLA paper by Gregory Werner and Michael Dyer, "Evolution of Communication in Artificial Organisms". Werner and Dyer populate a world with artificial male and female organisms in order to investigate the evolution of mate-finding strategies. Not only do effective strategies emerge from their model; but also subspecies develop which communicate through different "dialects". While Collins and Jefferson began from the position of observing life and trying to explain the behavior they saw, Werner and Dyer have explored a particular objective of life which may ultimately provide new ways of looking at the "real thing".

4. Conclusions

The "bottom line", then, is that there *is* much of substance in these volumes which may interest members of the artificial intelligence community. There is also much to encourage wild speculation, and whether or not any of that speculation may ultimately benefit the study of artificial intelligence remains to be seen. Resources such as the published work of Edelman [4] seem to offer evidence that the time is ripe for a more fruitful interaction between artificial intelligence and biology. However, on the basis of these two volumes, it is unclear that "artificial life" will provide a foundation for that interaction. Furthermore, because these volumes have been relatively poorly edited, they do not provide a particularly good introduction to the literature for readers who might wish to learn more about potentially relevant biological issues. Perhaps this means that the time is not yet quite right for artificial intelligence to turn to biology for inspiration. For now, unless the next workshop brings a bit more focus to the discipline of artificial life, its impact on artificial intelligence is likely to be rather peripheral.

References

[1] D.H. Ackley and M.L. Littman, Learning from natural selection in an artificial environment, in: M. Caudhill, ed., *Proceedings of the International Joint Conference on Neural Networks, IJCNN-90-WASH-DC*, Washington, DC (Erlbaum, Hillsdale, NJ, 1990) 189–193.

[2] E.R. Berlekamp, J.H. Conway and R.K. Guy, *Winning Ways for Your Mathematical Plays* (Academic Press, London, England, 1982) two volumes.

[3] R.A. Brooks, Intelligence without representation, *Artif. Intell.* **47** (1–3) (1991) 139–159.

[4] G.M. Edelman, *Neural Darwinism: The Theory of Neuronal Group Selection* (Basic Books, New York, 1987).

[5] C.G. Langton, Studying artificial life with cellular automata, *Phys. D* **22** (1986) 120–149.

[6] D.B. Lenat and J.S. Brown, Why AM and Eurisko appear to work, in: *Proceedings AAAI-83*, Washington, DC (1983) 236–240; also: Artif. Intell. **23** (1984) 269–294.

[7] S.M. Miller and L.E. Orgel, *The Origins of Life on Earth* (Prentice-Hall, Englewood Cliffs, NJ, 1974).

[8] M. Minsky, *The Society of Mind* (Simon and Schuster, New York, 1986).

[9] G.N. Reeke Jr et al., Synthetic neural modeling: a multilevel approach to the analysis of brain complexity, in: G.M. Edelman, W.E. Gall and W.M. Cowan, eds, *Signal and Sense: Local and Global Order in Perceptual Maps*, The Neurosciences Institute Publications (Wiley, New York, 1990) Chapter 24, 607–707.

[10] N. Tinbergen, *The Study of Instinct* (Clarendon Press, Oxford, England, 1989).