Technology Recapitulates Phylogeny

Artificial Life Art

Kenneth E. Rinaldo

Abstract

The author discusses the notion of emergence, the result of a collapse of both scientific and artistic barriers that has contributed to the rise of artificial life art. A discussion of artists who use biology as model and computers as material will lead into a description of some current artificial life art works. The author finishes with conclusions about the work of art in relation to artificial life techniques and interactive art in particular.

In our age the primacy of machines—amplifiers of muscle—have been surpassed by the primacy of computers—amplifiers of the mind. The profusion of media that the computer has fostered has collapsed barriers between unique professions, and a postmodern emergence of new forms, artistic and scientific, seems to be blooming forth everywhere. Computers and their use in art are now more than ever creating dynamic relationships between the works themselves and the viewing, interacting public. While the physical manifestation of the machine made distinctions between the self and the machine clear, the computer and its manipulation of information and ideas make its separation from the self often less obvious. This is evident when it comes to World Wide Web and the hours one can spend melting into the masses of interesting information. Although the Web has allowed those able to tap into this dizzying array of databases an unprecedented information wealth, it has also created an abundance that cannot be completely trusted or thoroughly navigated. Still, the Web has framed a cultural moment that could aptly be called synthesis, where ideas can be shared rapidly across time and great distances.

Emergence[1] is the new paradigm for a global change encompassing this earth. Artists, scientists, theoreticians, and researchers alike are no longer solely concerned with fields of pure research to the exclusion of other perspectives; they are instead concerned with the convergence and sharing of knowledge from all fields. The British developmental biologist Mae-Won Ho, speaks of "a global phase transition" that is circling the earth and touching all disciplines and can be characterized as

> an emphasis on integration over fragmentation, on cooperation rather than competition, on dynamics and process in place of the static and mechanical, on nonlinear distributed interrelationships and emergent properties of collective wholes instead of linear unidirectional or hierarchical control of incidental parts. [2]

For Mae-Won Ho, this is acknowledgment both that we construct reality and that we are moving away from scientific reductionist views that separate humanity and the sciences from the natural. In the sciences, this synthesis includes the joining of quantum electrodynamics and chemistry, as well as the fusion of the biological sciences with mathematics, physics, and computers for the purposes of computational visualization. In the multimedia arts, it is difficult to find work that is not interdisciplinary in nature.

Physician-scientist Jonas Salk, in past discussions with Jacob Bronowski, speaks of this synthesis as the next cultural evolutionary step in the ascent of man in the cosmos. Bronowski speaks thus of the convergence of the cultures of science and humanism:

> The evolution of Complexity demonstrates that in the physical sphere, complexity proceeds from elementary particles to atom to molecule. In the biosphere, molecules, cells and organisms replicated themselves. In the Meta-biosphere, the human mind and human culture have evolved. [3]

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For Salk, this points to the merging of the cultures of art and science. This "Meta-biosphere" is evident in the fractured multiple views of postmodern art with new art forms that seamlessly utilize the profusion of scientific research, surplus scientific material, and artistic motivation. Walter Benjamin predicted that this profusion of new media would collapse distinctions between genres [4]. This is epitomized by the artist Laurie Anderson and her performances that demystify technology and its use, or Myron Krueger's research at the University of Wisconsin, participating in the creation of virtual reality. The Web has been a key player in fostering a free exchange of information that has unified the sciences and the arts as they move across ideological barriers. This free exchange has created a mix of forms which, like the primordial soup that allowed the first sparks of carbon-based forms of life, has fostered a strange synthesis know as silicon-based artificial life. In one recent Web search using the Alta Vista search engine and the key words "artificial life," I came up with 14,647 hits.

Fig. 1. The author's *Technology Recapitulates Phylogeny,* 1995–97 (18 in. x 4 ft. x 9 in.), with projection light showing (left to right) a circuit board on acetate; two human brain cells (the Purkinje cell and a pyramidal cell); and a construction made out of an aluminum basket, hollyhock root, tubefex worms, dish, and sensor circuitry.

Analogs

"Technology recapitulates phylogeny" is both an observation I've made and a play on Ernst Haeckel's famous notion that "ontogeny recapitulates phylogeny" [5], that is, that the growth of the individual fetus in the womb (ontogeny) recaps certain stages through which human life itself has evolved (phylogeny). For example, during gestation, humans progress from a single cell through a stage in which the fetus has the rudiments of gills and a tail. Interestingly, even before Haeckel's ideas surfaced, Aristotle believed there was an analogical relationship between organic history and human development. Pre-Socratic thinkers like Anaximander, Anaximes, and Democritus postulated an analogy between cosmic history and human development. [6]

Technology Recapitulates Phylogeny is also the title of one of my artworks (Figs. 1 and 2; Color Plate B). When you approach this work, an infrared sensor mounted inside an aluminum basket switches on a light that illuminates and compares hollyhock roots, a circuit board in a frame, two types of human brain cells in smaller frames, sensor circuitry, and tubefex worms in a dish above the light. This piece juxtaposes treelike structures, a pervasive form that recurs at every scale in organic and now inorganic systems.

The tubefex worms that are the stars of this piece demonstrate one form of supra-organized tree structure in which single creatures combine to act as a single group. For example, suppose the worms send out exploratory tentacles over the edge of the plate from the central mass. They line their bodies up like striated muscle cells, and when you touch one worm at the tip of the tentacle, the whole mass contracts like a muscle. Five or six separate clumps may form in the dish like mini sea anemones, and when one clump reacts to a stimulus, the few worms that are invariably touching each other across clumps contract, and soon the whole plate has exploded with worms heading in every direction— a kind of primitive escape mode. Soon the worms have collected together again to act once more as a single treelike creature.

Tree structures act as super-efficient matter-, energy-, and information-distribution networks. They may appear as snowflakes, fingers on carbon molecules, branches of rivers, plant root systems, vascular and nervous systems, brain cell dendrites, circuit boards, very-large-scale integrated circuits, and telephone networks. Tree structures may also define themselves on a process basis as sequences of software code working through levels of logic.

In our time, with human cultural development so inextricably intertwined with and dependent on technology, our existence surrounded by a strangely comfortable embryonic sack of chips and wire, it is no wonder that a relationship between technology and phylogeny seems evident. Along analogical lines, market forces can be viewed as a strange commercial form of heredity in which a particular form of technology will be passed down to a later form, regardless of the drawbacks. This is evident with the standard QWERTY keyboard, which worked well in the era of manual typewriters in which it was developed, but which was passed down to electric and later to computer keyboards regardless of the more efficient designs that have surfaced for these newer systems. In biological systems, a species may have vestiges of semi-functional systems that served them in a previous environment but that do not serve them in the evolved environment— such as our appendix.

Strangely, there are now hybrid forms one cannot readily identify as being either technological or biological. For example, neural network computers composed of bacteriorhodopsin, a bacterial-based molecule derived from the chromophores (molecules that allow us to see color) in mammalian eyes, are used for storing images. Switched on (red) or off (green), these bacterial molecules are manipulated to store information in binary form. Or as another example, Dupont has recently created artificial spider silk—based on research into real spider silk production—that is rumored to be twenty times stronger than steel of the same width.

Still, I am not so interested in these specifics as in what seems to be an inevitable and overall evolution toward intelligent systems, both biological and technological. It seems humans are increasingly realizing the exquisite natural models available from carbon-based life forms. This would stand to reason, as biological forms have had a 3.5-billion-year head start to explore molecular variation. While genetics have permitted the passing of biological heredity from parent to child, what has truly distinguished humans from our past kin is not our 100,000-year-old biological selves (as indeed we reveal little biological difference from our ancient forebears), but instead the cultural memory that has followed humankind.

Computers can certainly be considered as cultural- and memory-augmentation devices. As artificial intelligence researcher Hans Moravic observed, "cultural development proceeds much faster than biological development." [8] Structurally, computers continue to develop and seem to mimic the successive stages of development that less-evolved forms have gone through, progressing from single transistors (cells) to very-large-scale integrated circuits (neurons) to massively parallel neural networks (brains) [9]. Many would say that what is still lacking in computers are the body and sensory elements that would allow them to develop a form of consciousness. I believe we ourselves represent that body as a remote sense extension which rejoins with the computer as information processor and integrator. We further act as that body by continually researching, manufacturing, and modeling ever-faster hardware and software. Theorists also cite the Web as an expanded form of an emerging consciousness. Roy Ascott calls this form in which our minds and the information networks come together to create a new space of consciousness a "noetic network" [10].

In considering the relationship between Moore's law—which states that we double the number of transistors on a chip each 18 months—and current human brainpower, Hans Moravic concludes that there is a genetic takeover under way and that within fifty years computers will "take pride when they look back at us and refer to themselves as our descendants" [11].

Artists like Stelarc manifest these notions when they reference the body as "obsolete" and ask when body replacement parts and microrobots will colonize to improve the species:

> It is time to question whether a bipedal, breathing body with binocular vision and a 1400cc brain is an adequate biological form. It cannot cope with the quantity, complexity and quality of information it has accumulated.... it is only when the body becomes aware of its present position that it can map its post-evolutionary strategies. [12]

Precedents

As a group, artist have always been inspired by natural living systems. On the front end, one could relate figurative art and mimesis as a formal variant of natural systems modeling. With the computer and its control possibilities, artists would later look to process and change within biological systems for models. Many of these artists were inspired by Norbert Wiener, a mathematician out of MIT who looked to create cybernetic systems that attempted to get at the problems of computer control and communication by modeling natural systems [13]. These problems have found some solutions in the related fields of dynamical systems, chaos theory, neural networks, artificial intelligence, autonomous agents, and artificial life. The artists discussed below can be seen as direct precursors to the use of living systems as models for the creation of artificial life art.

In 1969, Nicholas Negroponte and the Architecture Machine Group at MIT created a work titled *Seek* that attempted to anticipate gerbils' objectives and thwart them by rebuilding a series of metal blocks to disrupt their nesting. Still, the software and its computer-controlled artificial environment were outsmarted by the gerbils as it seemed that neither scientist nor computer could adequately anticipate what the gerbils' objectives really were [14].

British artist Harold Cohen has utilized artificially intelligent programming out of Stanford University's Artificial Intelligence lab, seeing the machine as analogy for human mental processes. Cohen's computer is run by a program called AARON, which gives it the ability to draw two-dimensional works on paper based on rules derived from human perceptual behaviors [15].

Myron Krueger has built numerous versions of what he calls "responsive environments," which demonstrate computer perception and adaptation. Krueger envisions the aesthetic of the work arising out of the "collaboration between the artist, the computer, and the participant"—essentially, a network of response relationships with the environment [16].

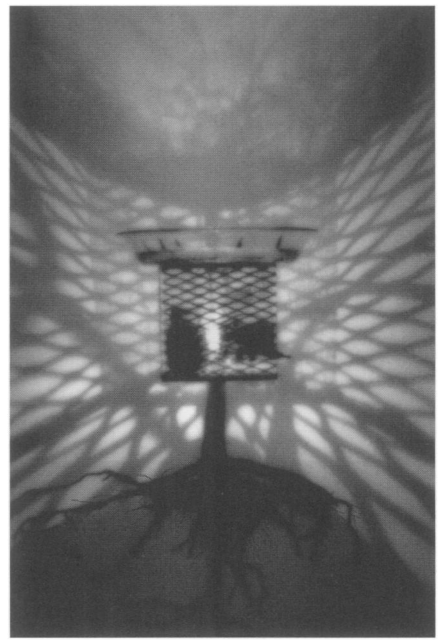

Fig. 2. A detail of *Technology Recapitulates Phylogeny* showing it activated by viewer presence, with a light projecting shadows of tubefex worms' supra-organization onto the wall and illuminating hollyhock roots below.

James Seawright has created computer-controlled sculptures based on garden themes that are sensitive both to their environments and to each other and that offer visitor interaction. His desire is to create a "patterned personality. Just as a person you know very well can surprise you, so can these machines" [17].

Sculptor Robert Mallary has defined six levels in which computers can be integrated into the sculptural process and, by extension, into the virtual world of the computer. With the advent of artificial life, his last level is now upon us—the level where the computer "has achieved some kind of organic, self-replicating mode of existence" [18].

Learning

At this time, artificial life forms are being produced by artists, scientists, and researchers alike. These are forms that can learn and adapt to environmental changes; through the processes of natural selection, they can evolve as Darwin defined the term in 1859. In this section, I will define artificial life and discuss a few artificial life techniques. I will then discuss some of the works being produced and conclude with some issues raised by these works. The individuals mentioned do not by any means represent a comprehensive list of all the artists working with artificial life; they are just some of the artists I have had direct exposure to.

Chris Langton, who put together the first artificial life conference in 1987, has defined artificial life as:

> the study of man-made systems that exhibit behaviors characteristic of natural 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... whereas biology is largely concerned with the material basis of life, artificial life is concerned with the formal basis of life" [19]

While biology is the study of carbon-chain chemistry, artificial life could be thought of as theoretical biology, which looks instead to creating models of biological systems. Artificial life artworks could be considered as a subgroup of artificial life research in that most artists are more concerned with the creation of an aesthetic as opposed to testing theoretical biology. Which is not to say that the techniques utilized by artists do not result in real artificial life, or that artificial life researchers cannot find a visual or behavioral aesthetic in their research. Still, motivations often differ between the two groups.

Artificial life artworks seem to break into two clear branches along the lines of hard artificial life and soft artificial life. Hard a-life artists contend that they are really creating life, and soft a-life artists submit that they are creating simulations. From here they branch into many subgroups. There are physically manifested works that express themselves in the three-dimensional world of form, with the evolved behaviors showing up in the forth dimension of time. These are generally robotic and include senses that unify the systems to act and react in some special behavioral category. These are complex works to realize because they include not only the algorithms of artificial life but also the robotic systems and sensors to give them complex and adaptive behaviors within a real-world environment. These environments tend to be very uncontrolled and unpredictable.

Works that manifest themselves in virtual space seem to be more prevalent than physically manifested works, though many seem to have some input from the outside world that may start the simulation off or act to affect the simulation in some fashion. These works are able to generate virtual creatures within artificial worlds that have more specified environmental conditions and genetic predictability [20]. There are still other artists who have mixed both virtual and physical worlds with artificial life programming and environments.

One form of artificial life uses genetic algorithms. With genetic algorithms, researchers map a set of parameters into 0-1 bit strings and then map the bit strings into a desirable fitness function. The bit strings are then subjected to repeated computer cycles in which the fitness of each bit string is analyzed and evaluated against the fitness function, copies of the more successful bit strings are made in proportion to their fitness, and individual bit strings are altered by random mutations and mating with other bit strings. The most-fit bit strings are the ones that win.

Peter Beyles began producing music using genetic algorithms as an alternative to pure human design as early as 1991. He began with cellular automata [21] and is now employing genetic algorithms to realize original evolved musical compositions. Yves AMU Klein produces sculptural works inspired by octopus behavior and the growth of fungi, among other organisms. These works exhibit complex adaptive behaviors triggered by human inputs and other artificial organisms through evolving genetic algorithms set up by the artist. Karl Sims has used a Thinking Machines Connection Machine and John Holland's genetic algorithms to create *Panspermia* and other a-life works that create evocative and lifelike worlds.

Many artificial life programs consist of populations of simple programs, with no specification controlling all the others. These programs react to local situations in an environment, or to each other, with no global behavior controller. This allows global behavior to evolve out of all the local interactions. Any behavior which arises out of such local interactions can be considered emergent. For example, the author and Mark Grossman have produced a set of three robotic arms, an example of a physically manifested work that reacts to viewers and to itself, displaying an inorganic flocking behavior toward sound but away from human bodies [22]. (See the author's article "*The Flock*" in this issue, starting on p. 405.)

At the 1998 International Society of Electronic Arts, held at the Art Institute of Chicago, I had the pleasure of experiencing Nick Baginsky's *Three Sirens*, a group of robots that use unsupervised neural networks to learn rules about improvisation and instrumental virtuosity [23]. They learn to control their motors and mechanical characteristics such that the feedback of the sound they make is further analyzed, and this layering of sound and feedback analysis results in a kind of free improvisation of neural-network-composed music.

Tom Ray has created Tierra, a platform for the study of the genomic evolution of artificial organisms at the University of Delaware and the ATR Human Information Processing Research Laboratories in Kyoto. The evolution of Tierra's machine-language computer programs proceeds without explicit direction or intervention from a human operator. Tierra represents a bottom-up approach to general artificial life simulation and could be considered a virtually manifested work, that is, one that exists within the box.

Another virtually manifested work is *Nerve Garden*, produced by Biota.org, a consortium of artist-researchers who have been creating a Virtual Reality Markup Language (VRML) testbed that allows users to plant a seed in cyberspace and begin an artificial life simulation. (See the article on *Nerve Garden* in this issue, starting on p. 389.)

Three animated creatures called "Woggles" are featured in *Edge of Intention*, created by Joseph Bates in association with twelve other researchers. In their onscreen world, the Woggles interact with each other and with a fourth creature that is controlled by a user. The autonomous Woggles display emotions through facial and body language expressions and develop complex interactions with both the visitor Woggle and the other Woggles internal to the artificial world [24].

Australian artist Jon McCormack has created *Turbulence*, a CD-ROM–based playback of virtual chimeras and synthesized forms created using artificial life algorithms.

Laurent Mignonneau and Christa Sommerer have created *Interactive Plant Growing,* a work in which five potted plants are used as input transducers to sense the visitor; and this input changes artificial life variables used within the program to grow virtual plants on the screen. This work is successful at unifying real-world interaction with a clear virtual manifestation of that interaction. Recently the pair have worked with Tom Ray in the production of *A-Volve*. [25].

Naoko Tosa has produced an artificial life artwork called *Neuro Baby* in which the participant induces a baby's head to react based on the tone of voice the system hears. Neural networks were used to decipher and understand these tones and to adapt by eliciting appropriate baby responses like crying or cooing [26].

Looking to the Future

Artificial life programming will certainly have more profound impact on the arts as hardware becomes more complex and we develop better artificial life software and algorithms that can be implemented to utilize this hardware power. Field programmable gate arrays (FPGAs) are one promising example of hardware that can be exploited for evolutionary techniques [27]. Researchers have already had some success utilizing a-life techniques to allow FPGAs to alter their connection instructions, thus allowing them to evolve a desired fitness

Perhaps the greatest potential for the arts and artificial life techniques is that they have presented opportunities for both artists and viewer-participants to develop true relationships with the computer that go beyond the hackneyed replicable paths of interactivity that have thus far been presented by the arts community. The word "interactivity" is often overplayed, perhaps because it demonstrates a kind of technical seduction even though there may not be a deeper aesthetic realization. In other words, finding a real poetry of interactive form and content has been too reliant upon simple button activation.

With artificial life programming techniques, for the first time interactivity may indeed come into its full splendor, as the computer and its attendant machine will be able to evolve relationships with each viewer individually, and the "inter" part of interactivity will really acknowledge the viewer-participant. This may finally be a cybernetic ballet of experience, with the machine and the human involved in a grand dance of each sensing and responding to the other. It will also allow new sculptural and virtual algorithmic manifestations that will far surpass our wildest imaginations.

One difficulty with some artificial life artworks is that the systems may not seem to be responsive to the changing environment, as the work demonstrates its own internal desires. This can make the work seem unresponsive or uncaring. Natural living systems manifest their complexity through their interconnected relationship to an ever-changing environment. Still, it illustrates a cultural moment in which the machine life may not need to be concerned with the human life. Other a-life artworks can be considered more collaborative in that initial conditions are set up by the artist or participant and then manifested by the system and the software. There seems to be an additional element of human selection involved in many works where the artist-researcher personally selects evolved elements that are considered aesthetic. So human interventions further act as a selective pressure in the evolution of the artificial life art piece.

Still, artificial life artworks raise questions about the originality of the work. Past artistic experience could be seen as a dialogue that artists would have with themselves and with the culture that surrounded them. In a case like this, who is the artist? The participant? The programmer? The hardware designer? Perhaps all of the above. Is artificial life work too reliant on easily replicable form or the excitement that it looks "natural"? Just the fact that it looks natural should not be enough to classify it as art. Since many of these works find distribution through the Web, and in so doing tend not to receive the associated criticism that would be evident in a gallery or museum environment, this issue of Leonardo is a first attempt to raise some of these questions. I believe the community of artificial life artists would welcome a critical dialogue.

The collapse of individualistic, reductionistic, hierarchical thinking has given rise to simultaneous world consciousness and therefore ideational plenitude. With this synthesis, humans are able to exploit models of living systems that demonstrate the possibilities for technology further recapitulating phylogeny. The hope is for a sustainable melding of our biological environment and the technotope. The new genre of artificial life art has already produced many exemplary poetic works, with still others evolving. I for one look forward to the day when my artwork greets me with a "good morning" when it has not been programmed to do so.

Acknowledgments

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References and Notes

1. In a nontechnical context, "emergence" is used broadly to describe the process by which new artistic and behavioral forms can bubble up to the surface in a culture rich with information and technology. It can also be considered a process of unpredictable development in which unexpected elements come into view because of the cross-fertilization of ideas that the information glut makes possible.

2. Mae-Wan Ho, "Reanimating Nature: The Integration of Science with Human Experience," *Leonardo* **24**, No. 5, 607 (1991).

3. Jonas Salk, "The Next Evolutionary Step in the Ascent of Man in the Cosmos," *Leonardo* **18**, No. 4, 237–242 (1985).

4. Margot Lovejoy, *Postmodern Currents: Art and Artists in the Age of Electronic Media* (Ann Arbor: University of Michigan Research Press, 1989) p. 278.

5. Steven Jay Gould, *Ontogeny and Phylogeny* (Cambridge, MA: Harvard University Press, 1977), p.187.

6. Gould [5] pp. 7, 13.

7. The QWERTY keyboard is so named because it represents the six letters at the upper lefthand corner of the keyboard. Originally, the QWERTY configuration was selected because it makes the keys less likely to jam when typing normal words on a manual typewriter. However, this configuration is known to be slower and less comfortable than newer designs on modern electric and computer keyboards.

8. Hans Moravic, "A Genetic Takeover Underway," in Christopher Langton (ed.), *Artificial Life,* Vol. VI (Redwood City, CA: Addison-Wesley, 1987) p. 168.

9. Very-large-scale integration, or VLSI, refers to a kind of integrated-circuit chip that incorporates from hundreds to thousands of individual logic gates. Currently they are used widely in the manufacture of microcomputers. Today's VLSI chips contain millions of transistors. Moore's law is dramatically demonstrated by a comparison between Intel's 4004 processor, which came out in 1971 and had 2500 transistors, and today's Pentium 11, which has 7.5 million transistors. VLSI means more calculations in addition to more speed. The Pentium 11 for can make 588 million calculations per second.

10. Roy Ascott, "A Glossary," on the Web at www.cooper.edu/art/techno/essays/gloss.html. In a noetic network, the information that is in the network and the information that is shared by the minds perceiving the network are seen as a collective and continous consciousness.

11. Moravic [8] pp. 167–199.

12. Stelarc, *Metabody*, a CD-ROM produced by Cook Productions (date unknown).

13. Norbert Wiener, *Cybernetics and Society: The Human Use of Human Beings* (New York: Avon Books, 1950). Norbert Wiener is considered the father of cybernetics, the study of control and communication in animals and machines.

14. Cynthia Goodman, *Digital Visions: Computers and Art* (New York: Abrams, 1987) p. 40.

15. Goodman [14] p. 136.

16. Myron W. Krueger, *Artificial Reality* (Redwood City, CA: Addison-Wesley, 1983) pp. 49–54.

17. Goodman [14] p. 134.

18. Robert Mallary, "Computer Sculpture: Six Levels of Cybernetics," *Artforum*, May 1969.

19. Christopher Langton, *Artificial Life,* Vol. 1, (Redwood City, California, Addison-Wesley Publishing Company, 1987), p. 2.

20. Genomic predictability refers to the ability of the viewer to predict the behavior of an artificial life system after an initial input from the viewer. One that is more predictable would likely have fewer parameters of codified genetic variation and therefore mutation.

21. Langton [19] pp. 2, 28, 80, 105–108.

22. These robotic arms were based on Rodney Brooks' subsumption architectures. Subsumption behavior, also known as nouvelle AI or behavior-based robotics, is a technique in which the system is layered with behaviors that can arise if lower-level behaviors are satisfied first. The word "subsumption" refers to the process of arbitrating which behaviors should take precedence over other behaviors. See Joseph L. Jones, and Anita Flynn, *Mobile Robots: Inspiration to Implementation* (Wellesley, MA: A.K. Peters, 1993) pp. 5, 6, 15, 243.

23. *Der Prix Ars Electronica 93: International Compendium of the Computer Arts,* p. 113.

24. Kenneth Rinaldo and Mark Grossman, "The Flock," in *Visual Proceedings, The Art & Interdisciplinary Programs of SIGGRAPH 93* (New York: ACM Group, 1993) p. 120.

25. Laurent Mignonneau and Christa Sommerer, "Interactive Plant Growing," in *Visual Proceedings, The Art & Interdisciplinary Programs of SIGGRAPH 93* (New York: ACM Group, 1993) p. 164.

26. Naoka Tosa, "Neuro Baby," in *Visual Proceedings, The Art & Interdisciplinary Programs of SIGGRAPH 93* (New York: ACM Group, 1993) p.167.

27. Gary Taubes, "Evolving a Conscious Machine," *Discover,* June 1998, pp. 72–79. Field programmable gate arrays (FPGA) are a form of integrated circuit that can rewire their connections based on software instructions. Recently, researchers like Hugo De Garis (an Australian researcher living in Britain and working out of Japan) hava been experimenting with FPGAs and genetic algorithms to allow the hardware to rewire itself based on the evolving code.

Kenneth Edmund Rinaldo is a sculptor, theorist, teacher, and curator who creates multimedia works that look to the co-evolution of our natural and technological cultures. Seamless integration of electronic, mechanical, and organic elements assert this confluence, while the works are further influenced by the complexity of living systems, theories on artificial intelligence, and artificial life. His works have been shown at the Museum of Contemporary Art (Chicago, 1998), the Chicago Cultural Center (1997), the Home Show in Seoul, Korea (1996), the Dutch Electronica Arts Festival (1995), and Image du Future (Canada, 1992 and 1995). His works have been featured on The KNOW ZONE, a TV special on robotics (1995) and featured in *Wired* magazine (1994) and *Artificial Intelligence Expert* (1994). He has curated numerous exhibitions specializing in art and technology and produced numerous commissioned works. Born in 1958, he studied biology and ballet in New York till the age of 20. He has a degree in computer science from Canada College, a bachelor of arts from the University of California–Santa Barbara, and a master's degree in conceptual/information arts from San Francisco State University (1996). Rinaldo is currently teaching and producing new works at Ohio State University.