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Life as it could be: Alife attempts to simulate evolution

By Nancy Forbes

Artificial life explores *natural life* by attempting to create biological phenomena in computers and other nonliving media. Alife also strives to introduce a broader, more universal understanding of life—accessible to new kinds of manipulation and testing—than that defined by traditional biology.

Looked at in this way, Alife represents the flip side of the empirical–analytic approach of most laboratory biologists, who start with a whole organism, deconstruct it into its component parts (for example organs, tissues, cells, genes, molecules, and so on), and then try to derive its fundamental principles. Most biologists would prefer to be able to simply reverse engineer life and synthesize real organisms, cookbook style, from their basic ingredients, but so far, this feat has eluded them.

Non-carbon-based life?

Biology is the exploration of life on earth. Despite its vast complexity and diversity this remarkable phenomenon given to us by nature nonetheless results from a series of historical accidents that occurred through a causal chain of events. Although the production of life on earth followed a path based on carbon-chain chemistry, some scientists legitimately question whether, on any other planet, life would inevitably have to develop this way. Couldn't silicon-based life or germanium-based life exist somewhere? While providing considerable fodder for science fiction writers, this question has arisen for traditional evolutionary biologists and Alife researchers alike. According to the latter, the study of carbon-based life here on earth constitutes a special case and gives necessary but not sufficient information for formulating the basic principles of life as shared by all living systems on all planets. To uncover these principles, they feel, it would be necessary to explore the space of all possible biologies, by studying many different life forms. But until aliens show up here on earth for this purpose, most Alife scientists feel that the artificial simulation of life can bring us closer to that goal.

Says the Santa Fe Institute's John Casti: "I think Alife will ultimately enable us to properly understand evolution and the workings of cellular machinery, mostly because it will offer us the chance to do the kinds of experiments that the scientific method says we must do—but cannot with the time and/or spatial scales of material structures like cells themselves."

Alife purports to shed light on our understanding of "life as it could be" by synthesizing it in artificial media, in the same way that chemical synthesis aided chemists in developing a fundamental set of laws in that field. A century ago, chemists' attempts to understand how matter behaved were limited to what they could glean from the analysis of chemical reactions they performed on readily available substances. "To have a theory of the actual, it is necessary to understand the possible," remarked Chris Langton, one of the founders of Alife, in the introduction to his first book on the subject.[1] However, by developing the capability to synthesize new chemicals not found in nature, scientists have not only greatly extended their empirical basis for study and their understanding of underlying theory, but have also produced substances such as plastic, rubber, and certain pharmaceuticals that have proved extremely useful to society.

Alife proponents generally consider the field to have arisen from the initial efforts of Langton, an autodidact who was preoccupied with these questions throughout the

Figure 1: A picture of a Golem project's computer-designed evolvable robot, which pushes itself along the carpet using the piston at the center. (Source: The Golem Project at Brandeis University).

seventies. The first workshop on Alife (the Interdisciplinary Workshop on the Synthesis and Simulation of Artificial Life), sponsored by Los Alamos National Laboratory, the Santa Fe Institute, and Apple Computer, officially gave "birth" to the field in September 1987.[2] You can find, however, precursors for this field in both Turing's and von Neumann's work on automata.

Alife for individual entities

Alife encompasses many disciplines, such as engineering, computer science, biology, physics, chemistry, sociology, and even economics. In his textbook on subject, Caltech's Chris Adami defines Alife research as a continuum with the simulation–emulation of individual entities at one end. As an example, he gives Karl Sims's simulation of the evolution of the form and movements of swimming behavior in virtual animals made from blocks, and how competitive behavior develops in these creatures.[3]

An analogous example in engineering would be the construction of adaptive, autonomous robots, which can interact with their environment, evolve, and learn from it—as exemplified by the robotic crickets developed by Barbara Web's group at the University of Edinburgh.[4] This method takes a *bottom-up approach*, in which developers construct a robotic system from simple elemental units that—through evolution, emergence, and adaptation to their environments—expand into more complex systems.

Robots constructed with artificial intelligence, on the other hand, employ a *top-down approach*, where developers start by targeting a complex behavior (such as walking up steps) and build the system with all the elements it needs to achieve this behavior. What's more, AI has traditionally focused on machines achieving complex, multifaceted human functions, such as chess playing, voice comprehension, or medical diagnosis. Conversely, Alife looks exclusively at natural behaviors, emphasizing survivability, evolution, and reproduction of the "creature" in complex, dynamic environments.

The Golem (*g*enetically *o*rganized *l*ife-like *e*lectro-*m*echanics) project at Brandeis University presents an even more fascinating example of engineered virtual life, involving robots that can actually design and build other robots.[5] Devised by computer scientists Hod Lipson and Jordan Polluck, the parent bots consist of a computer running an evolutionary algorithm that produces a design based on trial and error and a 3D printer that makes small plastic shapes. The offspring are small plastic trusses with actuators, propelled by motors and controlled by artificial neural nets (see Figures 1 and 2). Humans intervene only to attach the motors and connect the wires—the robots do all the rest, including telling the humans what to do.

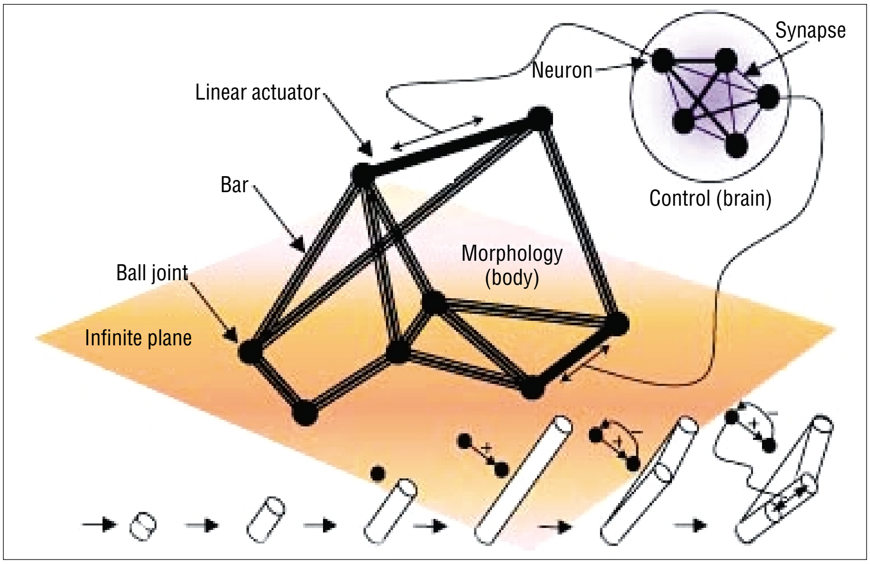

Figure 2. A schematic illustration of The Golem project's evolvable robot. Bars and actuators were used as building blocks of structure, and artificial neurons as building blocks of control. Bars connected with free joints can potentially form trusses that represent arbitrary rigid, flexible, and articulated structures and emulate revolute, linear, and planar joints at various levels of hierarchy. Similarly, sigmoidal neurons can connect to create arbitrary control architectures such as feed-forward and recurrent nets, state machines, and multiple independent controllers. Neurons were allowed to connect to bars, similar to real neurons that govern the contraction of muscle tissue.

Emergent behavior

At the other end of the Alife spectrum, Adami places the study of the emergent properties of living populations, which display properties that can't be seen in the individual units' behavior. (For example, in physics, temperature and pressure exemplify emergent behaviors that occur in large systems of interacting molecules. An individual molecule has neither temperature nor pressure by itself.) According to Adami, these living systems aren't amenable to a statistical description in terms of macroscopic variables, so he substitutes describing them in parallel to show emergent behavior. However, even the latter approach falls short because parallelism can't capture the self-organization seen in many living systems and because the resulting emergent behavior can often affect its members in nonlinear ways.[6]

Examples of this include swarm intelligence that emerges, for example, when wasps build large structures, such as nests, without each wasp really "knowing" what it's building.[7] Craig Reynolds' work on flocking birds, offers another example. Reynolds created a virtual flock of birds, called *boids*, which flew according to three rules:

- Always avoid collisions with your neighbors.
- Always try to fly at the same speed as your neighbors.
- Always try to stay close to your neighbors.

These three rules sufficed to create the emergence of flocking behavior. The boids flew as a coherent group and automatically split into two groups when encountering an obstacle, reuniting after it was passed through. This system demonstrates how a system of fairly simple elements—interacting with their nearest neighbors, with no central direction—can create cohesive, intelligent group behavior. In fact, the behavior of Reynold's boids precisely emulates what we observe in nature.

Life on Tierra

Somewhere in between these two extremes lies Tom Ray's Tierra project, which seeks to explore open-ended evolution in a virtual world, unfolding without any a priori human instructions. Ray modeled Tierra on the period in Earth's evolution known as the Cambrian Era, about 600 million years ago. The period began with the existence of simple, self-replicating organisms, which underwent explosive growth over time to result in the great species diversity known today.

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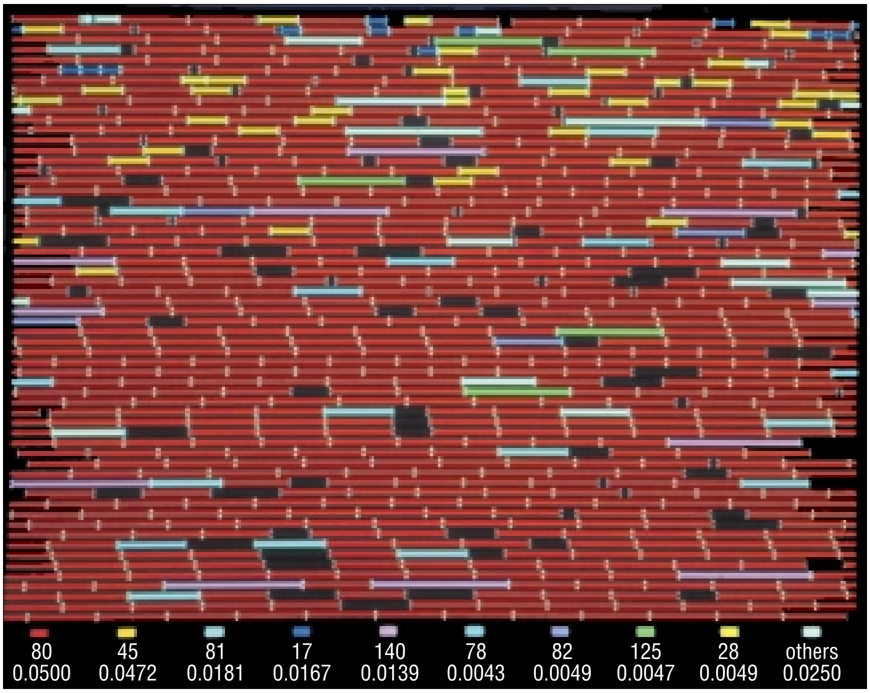

Figure. 3: An evolutionary race between hosts and parasites in a primordial soup of the Tierra program. Each image represents a soup of 60,000 bytes, divided into 60 segments of 1,000 bytes each. A colored bar represents each individual creature. Colors correspond to genome size (for example, red = 80, yellow = 45, blue = 79). In this image, hosts (red) are very common. Parasites (yellow) have also appeared but are still rare. (Photo: Marc Cygnus)

Ray wanted to investigate how self-replication eventually produced such complex, varied life forms. He started with a single organism called the *Ancestor*, the only engineered life form in Tierra. He then let the creature loose and watched to see what happened. After only one night, his virtual world was teeming with myriad creatures, displaying an amazing variety of form and behavior. These organisms and their progeny (the "organisms" are actually self-reproducing programs written in assembler language) competed for the natural resources of their world—that is, CPU time and memory. This provided the basis for natural selection to operate—some organisms die off and the fitter ones survive, adapt, and become more competitive.

To prevent these digital beings from gaining access to the actual hardware of the machine they lived in like computer viruses, Ray made the entire Tierra program run on a virtual computer created in the software. Tierra's operating system basically performed four functions:

- allocation of memory to each organism, letting the organism have the exclusive privilege of modifying its own structure, to preserve its unique identity;
- allocation of CPU time to each organism so it could act;
- placement of each organism in a queue and—depending on life cycle, natural selection, and so on—killing organisms when they reach the top of the queue; and
- doling out random mutations in the binary string of each organism's program, thus causing some organisms to self-replicate imperfectly.[8]

Ray, currently a zoology and computer science professor at the University of Oklahoma, first attempted Tierra in January 1990. After over 500 million instructions, Tierra had created over 350 different sizes of life forms, 93 of which had survived to achieve subpopulations of five or more individuals. Tierra also generated hosts and parasites, and eventually a type of social organization with communities of genetically uniform organisms. Nearly every facet of natural evolution and known life-form behavior showed its face in Tierra, including competitive, exploitative, and protective behaviors.

Life among the Avidians

Inspired by Ray's work, Adami and Richard Lenski, a microbiologist at Michigan State University, began their own Alife experiments a few years later. Lenski had been conducting (and continues to conduct) wet lab experiments on evolution in his lab with E. coli bacteria, where a single experiment can span up to 24,000 generations—usually, a new one about every 3.5 hours.[9] After having read Adami's book, Lenski

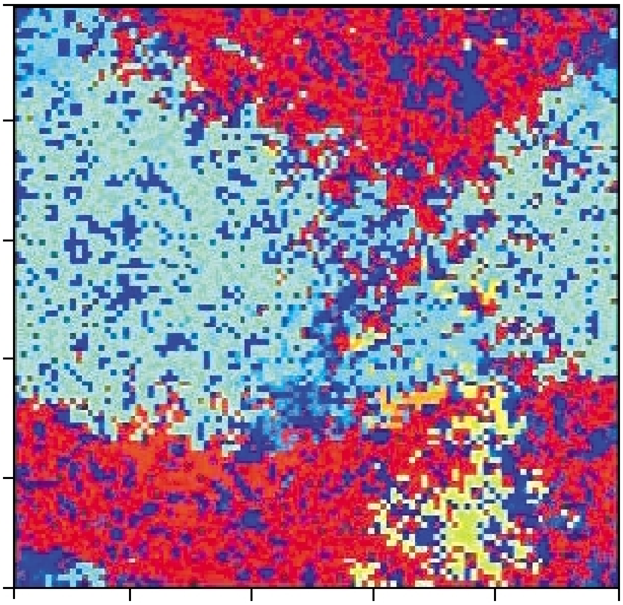

Figure 4. Example of an Avida lattice during a computer run at a reasonably low mutation rate. A different color is assigned each genotype that has more than three organisms of that type. Genotypes that don't reach this threshold are colored dark blue. The Avida world shown is toroidal, so each edge wrap is connected to the opposite edge of the figure. This picture was taken at update 3,100 of an 100 × 100 grid.

soon contacted him to learn more about Alife, and Avida—a new software program developed by Titus Brown and Charles Ofria, Adami's students—emerged.

Avida would not only enable digital life forms to evolve, but would subject them to experiments in evolution, such as inserting a particular type of mutation and seeing what resulted in the ensuing generations. The program typically ran for about 5,000 to 20,000 generations, taking only two to eight hours to complete. By comparison, similar experiments performed in vivo or in vitro in a lab could take days.

Together, Adami and Lenski created a virtual environment where one initial bug was programmed to reproduce itself and mutate every 1,000 or so "births." The bug could also perform simple mathematical functions that the environment rewarded, by allowing those bugs to replicate at a faster rate. This helped push out the less competent bugs, forcing them to eventually die off—emulating natural selection.

"Today," says Adami, "we try to do experiments with both our virtual Avidians and E. coli in vitro to be able to compare the results." The researchers have found that the evolutionary principles seen in the computerized environment accurately mirror those found in nature, and that the "survivors" in their system appeared stronger and less affected by random mutations than less fit individuals. The experiment purports to put virtual results and actual ones on the same footing, to test how accurately Alife can replicate the workings of natural evolution.

However, Princeton evolutionary biologist Rob Knight feels this comparison requires more subtle treatment: "A major distinction in the Alife community is between *weak* and *strong* Alife. Weak Alife, which claims that simulations of evolving systems may help us understand biological life, is relatively uncontroversial, especially when the simulations relate closely to natural systems, such as Nilsson and Pelger's study of the evolution of eye morphology.[10] These [simulations] clearly provide valuable insight. However, experimental biologists tend to distrust computer experiments, perhaps unfairly, on the grounds that models often merely reflect biases programmed in at the start. Strong Alife, which claims that replicating programs inside computers really are alive, is far more controversial. This is partly because the examples of biological life we are all familiar with are orders of magnitude more complex and partly because the claimed similarities with biological evolution tend to be rather abstract."

Alife vs. life itself

The question of the nature and origin of life has preoccupied human thought since the dawn of time. It has been answered in turn by priests, philosophers, shamans, seers, mystics, scientists, and charlatans.

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Intelligent
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Data mining

Data mining e-business

Cornell University's Johnson Graduate School of Management (www.johnson.cornell.edu) has received a $200,000 grant from Intel to create an e-business database management laboratory. As part of a new program in e-business studies, students will use the lab to do their own data mining and interactive analysis of customers' behavior generated by Web-based businesses. When the Johnson School's immersion course on e-commerce debuts in January 2001, the lab will be fully equipped with workstations, servers, networking equipment, and software.

"The lab will allow us to offer a hands-on approach to learning about e-business," says Johannes Gehrke, assistant professor of computer science in Cornell's Faculty of Computing and Information Sciences group. "It will support a data management infrastructure of a fictional e-commerce company, including a Web server, an industry-strength database system, Web-database connectivity, and applications such as data mining."

Students will use the lab to construct and use large databases as well as to design and conduct Web-based surveys and primary market research for business clients. They will also develop models to attract more visitors to Web sites, keep them there longer, improve look-to-buy ratios, retain profitable customers, learn about customers' preferences, and personalize marketing offers.

"Cornell will be one of the first schools to have a laboratory specifically designed to introduce students to this technology and to allow faculty to conduct research with contemporary resources," says Richard Conway, leader of the e-business immersion faculty team and the Emerson Electric Professor emeritus at the Johnson School.

Cornell is one of five universities worldwide selected to receive Intel grants supporting e-business studies this year. The others are Carnegie Mellon, Harvard, and the University of Michigan in the United States and Tsinghua University in China.

All the religions and all the mythologies of the world have given it a central place in their belief systems, and only lately in the history of mankind has it become the purview of science—creationism notwithstanding. Given this import, it's not surprising that the idea of computers simulating life should elicit debate, controversy, and even incredulity.

On one hand, Alife represents a dynamic, new multidisciplinary field that continues to thrive and attract new followers. It has produced some remarkable research, and its scientists are making inroads in a plethora of disciplines, such as algorithm development, software, hardware, robotics, population biology, economics, and complex systems analysis.

However, some scientists view Alife with wariness, skepticism, and dismissal. When looked at as a simulacrum for real biology, many mainstream biologists feel it does not offer a legitimate vehicle for the study of living organisms or how they evolved. When asked for his views on Alife, chemist Stanley Miller, who in 1952 conducted the first experiment that simulated the primordial soup of the primitive earth and produced amino acids, retorted, "Running equations through a computer does not constitute an experiment!"[11] However, judging the merits of Alife solely on the basis of how well its answers stack up against those derived from traditional biology could distort and even diminish its accomplishments.

Andy Ellington, a biochemist and engineer who studies evolution at the University of Texas at Austin believes the problem might lie with confusion over how we define life. Says Ellington, "The whole notion of life is somewhat specious. It is frequently difficult to draw meaningful scientific distinctions between organisms, viruses, and growing crystals. Thus, I have no problem with those who say that life inside a computer is 'real' life; the word is as ambiguous inside a computer as outside. From this standpoint, while creatures (or 'replicators') spawned by Alife couldn't adapt to a biological environment (imagine cellular automata in a rain forest), they can compete and adapt in a virtual one. So artificial life shouldn't be judged on the basis of whether or not it's as valid as biological life, but should be regarded as a completely separate entity, which a priori doesn't need to have the same underlying rules as biological replicators. What we need is a paradigm shift in the way we think about the concept of life."

Rob Knight agrees: "To be convincing, future Alife research needs to clearly define life and its characteristics, and show that Alife experiments can both recapture and extend the results of more traditional methods of inference about evolution."

However it's viewed, Alife has not only spawned some fascinating varieties of digital life, but also an exciting new field of research. Moreover, Alife has engendered a rich and provocative body of thought—whether you're for or against it—with the potential for generating an endless number of new ideas.

For further reading

Alife Bibliography: www.cogs.susx.ac.uk/users/ezequiel/alife-page/alife.html
The Alife Database: http://arieldolan.com/aldb/default.asp
Alife VII Conference: http://alife7.alife.org
***Artificial Life* (MIT Press):** http://mitpress.mit.edu/journal-home.tcl?issn=10645462
Artificial Life Online 2.0: http://alife.org
Boids Page: www.red3d.com/cwr/boids
Digital Life Laboratory: http://dllab.caltech.edu
The Ellington Lab at the University of Texas at Austin: http://ellingtonlab.org
The Golem Project: http://golem03.cs-i.brandeis.edu/index.html
Technosphere: www.technosphere.org.uk
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NASA robotics could help patients walk

NASA engineers and neurophysiologists at the University of California, Los Angeles, are creating a robot-like device that could help rehabilitate people with spinal cord injuries.

“We are developing a prototype robotic stepper device that, when complete, will be used as part of rehabilitation that can potentially help some people now wheelchair-bound take their first steps,” says Jim Weiss, program manager for collaborative neural repair at NASA’s Jet Propulsion Laboratory. “This system can do the work of four therapists and help monitor a patient’s progress in a controlled manner.”

The device will look like a treadmill with robotic arms and will be fitted with a harness to support the patient’s weight. The arms resemble knee braces that attach to the patient’s leg, guiding the legs properly on the moving treadmill. Although the robotic stepper is still in development and is not yet ready for use in rehabilitation, the device could be part of clinical trials at UCLA in about three years.

“Some rehabilitation centers around the world are starting programs that will allow therapists to train individuals affected with spinal injuries, stroke, and perhaps other neuromotor disorders to improve their mobility and stepping capacity,” says Reggie Edgerton, professor in the departments of physiological science and neurobiology at UCLA. “This robotic device could help therapists in those rehabilitation efforts.”

JPL robotic engineers have worked alongside therapists to develop the device, which has highly sensitive sensors that collect up to 24 different data readings of the patient’s activity. The device, connected to a computer, displays the information on the screen for the therapist to monitor.

According to Weiss, this same device could also someday be useful to astronauts and help them walk safely after prolonged periods in space, such as extended missions on the International Space Station.

The robotic stepper device is one of several projects in the Neural Repair Program at the UCLA Brain Research Institute (www.medsch.ucla.edu/som/bri) and JPL (www.jpl.nasa.gov). JPL and UCLA are actively pursuing efforts to commercialize the robotic system. JPL technically supported UCLA in filing a patent application in August.