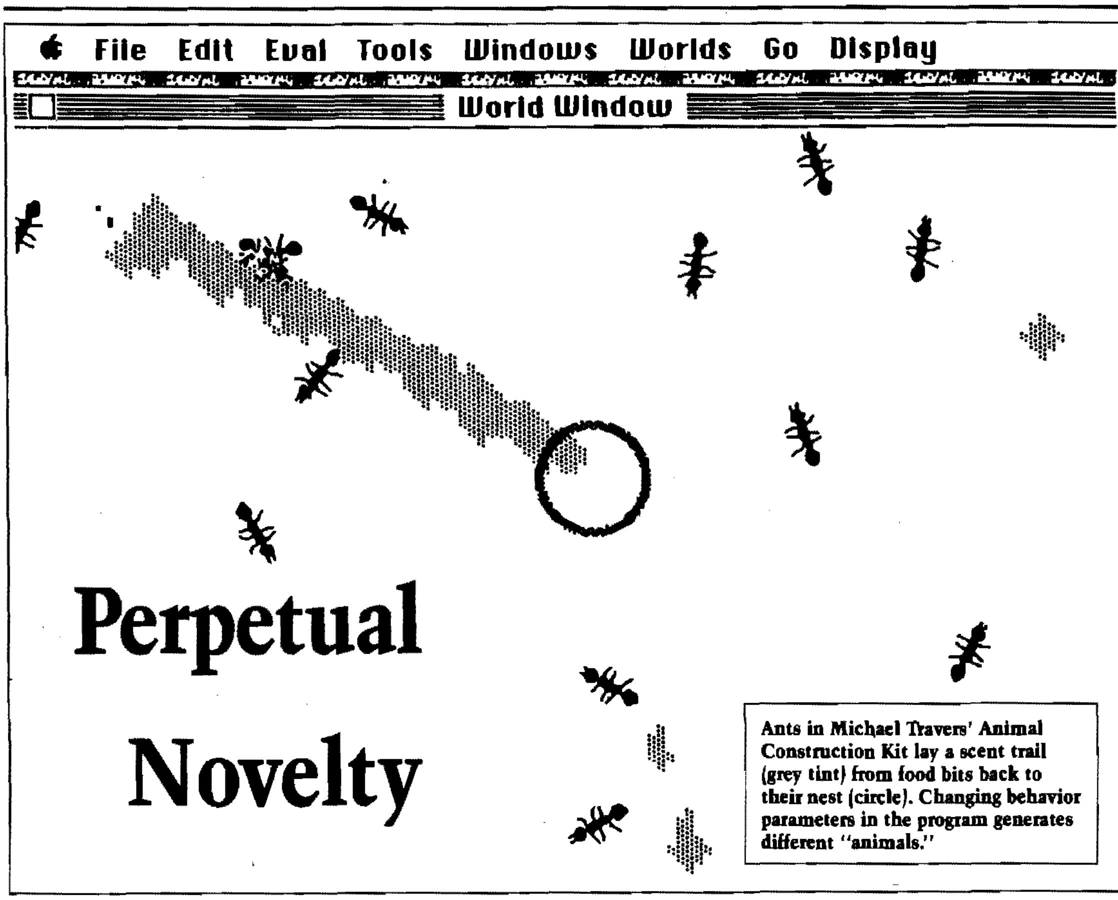


Perpetual Novelty

Ants in Michael Travers' Animal Construction Kit lay a scent trail (grey tint) from food bits back to their nest (circle). Changing behavior parameters in the program generates different "animals."

Selected Notes from the Second Artificial Life Conference

BY KEVIN KELLY

"Artificial life" is a catchy name for a wholesale Enlightenment in systems understanding. I've found the few, tentative experiments reported here to be revamping my ideas on ecology, psychology, politics, economics, and biology, not to mention life (and my life) itself. Others say the same. This movement began small at the First Artificial Life Conference (see WER *#59, p. 74) and mushroomed to 200 eclectic researchers by the Second, held in Santa Fe, on February 5-9, 1990.*

LIFE ON THE EDGE OF CHAOS

Chris Langton, co-organizer of the first and second A-Life Conferences, defines artificial life as "the attempt to abstract the logical form of life in different material forms." His thesis is that life is a process, or relationship, or logic, or complexity that is not bound to a specific material manifestation. He feels that even a mild a-life enables us to study natural life by deconstructing it in a way that we cannot do in nature, either practically or morally. Langton says, "The most important thing to remember about a-life is that the part that is artificial is not the life, but the materials. Real things happen. We observe real phenomena. It is real life in an artificial medium."

Langton lists four reasons to study/create/mess around with artificial life:

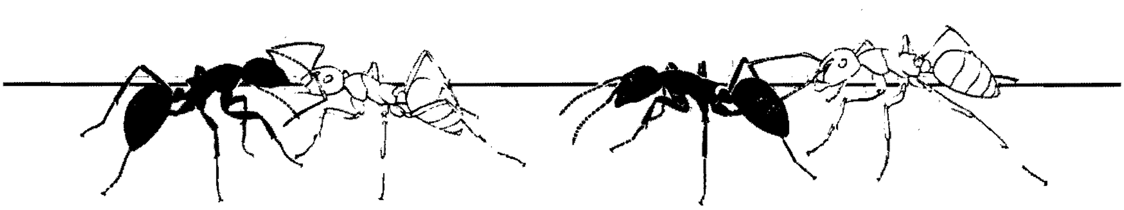
1) A-life gives us a picture of nature as a whole. (And other things as a whole, I must add.)

2) We need to study a-life because it is inevitably going to be with us. Look at computer viruses as an example.

3) A-life is a better way to engineer complex software — if you can't build it, you can evolve it.

4) A-life is a means to study biological life, which resists understanding as an historical case with no comparisons, and resists (practically and morally) altering a few parameters in a coldly scientific way.

In Langton's own work on mathematically replicating cells, the most interesting patterns live at a sharp, thin line between periodic, static (thus boring) routines and unpredictable, non-repeating chaos. This gave rise to his a-life creed that "life is lived on the edge of chaos."



EVOLUTION IS PARALLEL LEARNING

What most interested me at this conference was how often participants made this equation: *evolution = learning.*

David Jefferson, from UCLA, showed the first of many ant worlds being premiered at the conference. During the week, another ant-world enthusiast quietly handed out tiny rubber ants ordered from the zany Archie McPhee mail-order catalog of rubber chickens and other novelties. Each day more and more conference participants were walking around wearing name tags crawling with carpenter ants under the plastic slip. By the end of the week, the ants had become the mascots of the conference.

Ants were independently selected by a number of researchers as ideal a-life models because they are such a handy and non-threatening example (unlike cockroaches) of simplicity-generated complexity. To cyberneticists, ants are poetic.

Jefferson created a computer-modeled world called Genesys to try out artificial evolution. His ant creatures are neural-net animals; they have simple algorithms, or rules of thumb, that tell them how to move or turn. The only resource they consume is decision (= computing) power. Their only goal in life is to find their way through a very complicated virtual maze. Since they have limited decision resources, they not only can't afford to make many wrong moves, but they can't spend too much time thinking about which move to make either. In other words, if they can figure out the few rules that get them through the maze without much thinking or error, they will succeed.

Jefferson introduced a way for the ants' algorithms to mutate, thus generating new strategies to get though the maze. He let the maze be a selection pressure. Those randomly generated ants that scored highest at getting through the maze were kept to be re-released into the maze next round. The winners were allowed to mutate slightly, and released again. This winnowing goes on for many generations.

The smartest randomly generated ant could only figure out how to get through two-thirds of the maze before running out of thinking power. But after 100 generations of evolution and sifting, a highly evolved ant could whip through the maze with a perfect score. The neat thing here is that it was not the humans but the artificial ants who developed the perfect rules of thumb.

This experiment was done with a fixed environment — the maze was the same the whole time. What would happen if you took this army of highly evolved ants and put them into a new maze? Jefferson and associates found they didn't fare well, particularly at first. After a while, the ants did learn how to go through better. But the surprising thing was that when a fresh set of randomly generated know-nothing ants was run instead of the highly evolved ants, the untrained ants reached perfect score sooner. The specialized ants weren't ever able to learn the new maze perfectly, at least in the finite number of generations run. It's the old classic lesson of the dangers of becoming over-specialized.

In ecology this is called the problem of local optimization, and it comes up often in a-life. Imagine if we were to generate a "landscape" for the adaptive abilities of an organism, played by you. The more highly adaptive you, the organism, are, the higher the elevation. This landscape will look rugged; there will be many mountains and hills because your adaptation potential depends on the outside environment. At any one time you are somewhere on this "rugged adaptive landscape" trying to climb to higher optimization. Sometimes there will be a peak that will stand high compared to the immediate area, but be lower than a really high peak someplace else. In order to get over to that other, higher peak you actually have to descend into a lower un-optimized state. It may be that you need to unravel so much of your expertise that it becomes impossible to do so, you being such an optimal organism. So you get stuck on a local high. If the environment shifts, you're doomed.

That's what happened to the specialized ants. They got caught on the local optimization of the first maze. "What this taught me," Jefferson said, "is that evolution is massively parallel learning." If you are caught not learning, you're dead. Learning means dealing with things you don't know about. It's about adapting to massive uncertainties.

How does an organism acquire generally adaptive behavior? Ahhh, that is the one of several Holy Grail questions in a-life.

LOGICAL LEGO ANIMALS

Mitchel Resnick from MIT showed his LEGO/LOGO animals. These are neat little toys made up entirely of LEGO blocks. But special LEGO blocks. Certain of the blocks have little brains. These smart LEGOs have chips built into them with metallic contacts for electrical connections. Different blocks have different functions. There are sensor blocks such as the ones that feel a wall. There's an "eye" block that detects visible light. One that sees infrared. One that notices whether it's level. Some that hear noise levels.

And then there are logic or cognitive blocks. There is a clock that causes a pause or delay. There is one called "AND" that gives a signal if a certain stimulus AND a certain other one are detected. There is one called "OR" that goes on if one OR the other stimulus is perceived. There's a flip-flop that says "do the opposite of whatever you did last time."

And of course there are locomotion blocks — little electric motors, gears and so on — that are off-the-shelf LEGO accessories.

Naturally what you want to do is build creatures with all these blocks, creatures that have the tiniest, dim brain. They do things like follow the light, or run from noises, or run to noises . . . whatever you cook up. They are for kids and professors.

No you can't buy them, yet.

THE DNA COMPUTER

Theoretical biologist Stuart Kaufmann says Darwin was right as far as he went, but that Darwin had no idea that complex systems of all kinds exhibit self-organizing properties, so that the details of how selection works were left blank by its discoverer. That blank is still the biggest hole in biological science today.

Kaufmann sees "life as an *expected* emergent property of self-organized systems." Coming from someone else this might be plain mysticism, but Kaufmann is primarily a mathematician and has numbers, increasingly backed up by simulations done by others, as evidence of his ideas. He works a lot with genetic algorithms, a method which considers "the genome as a parallel-processing network, with 100,000 genes turning themselves on and off." Viewing DNA as a computer, which he does, means that flipping it around and viewing a computer as DNA, which a-lifers do, is not such a crazy notion.

Chris Langton: "Nature has more computing power than we do."

If that isn't representative of a paradigm shift, I don't know what is.

IF YOU CAN'T BUILD IT, GROW IT

"Sex is a computational hassle." —*Norman Packard*

Early in his talk, Danny Hillis wanted to make sure there was sex in a-life. There wasn't much before his talk and he felt sex in a-life was important; he found it sped up evolution. Hillis' conclusion came from his investigations on The Red Queen System, an ecological model based on his own Connection Machine (see *WER* #54, p. 108). This supercomputer uses 64,000 processes in parallel (versus the one or two in most computers) to simulate an interacting world. Each organism in the Red Queen System is modeled by one dedicated processor. Therefore each organism can perform its own independent interaction with other similar organisms. The combined ecology of 64,000 reciprocating organisms is what makes the Red Queen System.

It is an evolving sexual world. The organisms are "sorting networks," virtual beings whose task in life is to perform calculations. Their fitness is scored on how well they solve numerical problems. Those performing best survive to pass their rules onto the next generation. Introducing sex speeds up the process of attaining fitness. Yet Hillis discovered something that speeds up the fitness process even more: parasites.

By introducing a second kind of organism to his small worlds, Danny found that the System exhibited many more interesting levels of organization and behavior. This new organism would live off the bounty of thriving prime organisms, weakening them, but not killing them off. To thrive, prime organisms now had two tasks: to solve calculations better, and to become less attractive to parasite organisms. However, because parasites were also evolving in the system, finding new opportunities to rely on prime organisms, this parasitism became a dynamic selection pressure keeping the whole System in flux. It's from this constant race to keep in place — the lament of the Red Queen in *Alice Through the Looking Glass* that it takes all the running she can do to keep in the same spot — that the Red Queen System gets its name.

Hillis sees a-life as offering a new interpretation of biology. He says the reigning dogma is that the "natural order" specifies certain roles for organisms in nature. Oak trees should be protected because they do this or that in a forest, and oak forests should be protected because they do this or that for a certain area. But you can't separate an oak tree from the forest, or a forest from a biome. He says ecologists and perhaps environmentalists are beginning to understand that "oak tree," "oak forest" are not only fluid and continually being re-invented, but that they are almost a phantom as separate individualities. Like Richard Dawkins, of *The Selfish Gene* and *Extended Phenotype* fame, Hillis says "ideas of independent genes are illusory." An "oak tree" includes all the parasites that keep it going evolutionarily, and vice versa. It's a perspective of ever-widening circles of symbiosis.

To my mind one of the most remarkable findings from the Red Queen System is Danny's graph of his organism/parasite's rise in fitness over time. On a run of a thousand generations, their fitness mildly increases, then zooms up precipitously, then levels off for a while, then zooms rapidly again, then levels off. Understanding fitness as adaptation, this graph is a spitting image of the recent theories of punctuated equilibrium in evolution promoted by Steven Jay Gould and others. By and large, they argue, evolution proceeds at a near-equilibrium pace, which is occasionally broken by intense periods of readjustment and rapid change. Hillis' evolutions showed the same — longer periods of equilibrium punctuated by shorter, quick spurts of increased adaptation of fitness.

Theoretical biologists drool over the prospect of messing around with synthetic evolution tools like this, but Hillis has real-world applications in mind, too — flying airplanes and such. Hillis sees evolving ecologies like this able to design things humans may not have the patience or inkling to solve. "We want these systems to solve a problem we don't know how to solve, but merely know how to state." The idea is to grow solutions. Set up a system that will evolve programs that will solve the problem you have at hand. Hillis: "Rather than spending uncountable hours designing code, doing error checking, and so on, we like to spend more time making better parasites." Better parasites means faster convergence of the prime rule-making organisms toward the fitness ideal — an error-free, robust software program. "I would rather fly on a plane that was based on software built by a program like this, than on software that I wrote myself, because it would be built in an environment with thousands of adversaries who specialize in trying to find what's wrong with it. Whatever survives that has been tested ruthlessly."

THE EVOLUTION OF EVOLVABILITY

What changes the rate at which changes occur? Does the agent of change govern changes in its own makeup? The biological way of asking that is: can the mutation rate mutate?

Peter Schuster models the way proteins assemble themselves from a string of units into convoluted three-dimensional shapes. Just one difference in the order of units in the string produces a drastically different protein form. One protein might be circle-shaped, the other, one difference away, cross-shaped. Schuster made a little world in a computer where deliberate mutations were randomly introduced into the string to see how the proteins they produce would adapt to the selection tests he set up. In formal terms, he applied selection pressures to the phenotypes (proteins) created by small mutations in the genotype (string units) to see if this small world would simulate evolution and learn to adapt. He reported that increasing the mutation rate would keep increasing how well the proteins evolved until a critical "error-threshold" when further evolvability becomes difficult. This suggests that mutation rates are optimized.

What changes the change rate is not the change rate, but the system as a whole.

FAST, CHEAP, AND OUT OF CONTROL

At the first A-life Conference there was a 4-H Contest for the best a-life creatures. This time there were few entries and the prizes were given somewhat cursorily. I can't even remember who won. But I do know who should have won. Without deliberation, I would have given the blue ribbon to Rod Brooks' six-legged insect robot.

Brooks runs the robot lab at MIT. He says that rather than try to bring life into a-life, he's trying to bring a-life into life. He wants to flood the world (and beyond) with inexpensive, small, ubiquitous thinking things. He's been making robots that weigh less than 10 pounds. The six-legged walker weighs only 3.6 pounds. It's constructed of model-car parts. In three years he'd like to have a 1mm (pencil tip-size) robot. He has plans to invade the moon with a fleet of shoe-box-size robots that can be launched from throw-away rockets. It's the ant strategy: send an army of dispensable, limited agents coordinated on a task, and set them loose. Some will die, most will work, something will get done. In the time it takes to argue about one big sucker, he can have his invasion built and delivered. The motto: "Fast, Cheap, and Out of Control."

Fast, cheap, and out-of-control robots are ideal for: 1) planet exploration, 2) collection, mining, harvesting, 3) guiding, 4) remote construction, say of a lunar base. A new movement in space exploration called "microspace" favors building featherweight space vehicles that are skimpy on mass and heavy in brains. There are currently designs for "lightsats," inexpensive communication satellites no bigger than a TV set.

As an example Brooks and friends built what he cheerfully calls "The Collection Machine" (not to be confused with Danny Hillis' million-dollar Connection Machine) — a robot that collects empty soda cans in an office space at night. It's ingenious. It operates according to the society-of-mind approach to a-life robotics. The eyes of the Collection Machine spot a soda can on a desk and guide the robot until it is right in front of the can. The arm of the robot knows that it is in front of a soda can because it "looks" at its wheels and says, "Gee, my wheels aren't turning, I must be in front of a soda can." Then it reaches out to pick the can up. If it is heavier than an empty can should be, it leaves it on the desk. When it takes a can it finds its way all the way back to its station to unload it, then randomly wanders again through offices until it spots another can. (A variation, called the Confection Machine, dispenses candy to people in exchange for them opening doors for it.) Not very efficient per trip, but night after night it can amass a great collection of aluminum. During the day it sleeps.

Brooks has another small robot in mind that lives in the corner of your living room, or under the sofa, and wanders around vacuuming at random whenever you aren't home. You only notice how clean the floor is. A similar, but very tiny, insect-like robot lives in one corner of your TV screen and eats off the dust when the TV isn't on. A student of his built a cheap, bunny-sized robot that watches where you are in a room and calibrates your stereo so it is perfectly adjusted as you move around.

Brooks' most ambitious plan is to send a flock of tiny solar-powered bulldozers to the moon five years in advance of a proposed lunar base program. They can be built from off-the-shelf parts in two years, and launched completely assembled in the cheapest one-shot lunar-orbit rocket. Operating entirely by "local rules," without any communication from Earth, they will daily scrape away soil needed to level building sites. When the expedition arrives at the cleared landing, they will turn the robots off and give them a pat.

Brooks called for an infiltration of robots. He's been working on seeing how "dumb" you can make a robot and still have it do useful work. He gave the example of smart doors. For only about $10 extra you could put a chip brain in a door so that it would know you were about to go out, or it could hear from another smart door down the hall that you are coming, or it could notify the lights that you left on, and so on. If you had a building full of these smart doors talking to each other, they could help control the climate, as well as help traffic flow. If you extend that to all kinds of other apparatus we now think of as inert, putting fast, cheap intelligence into them, then we would have a colony of sentient entities, serving us, and learning how to serve us better.

His prediction for the future of a-life is that we'll have creatures living with us in mutual dependence — a-life symbiosis. They will be small, ubiquitous, hidden, and taken for granted. Their numbers will outnumber us, as do insects. And in fact, his vision of robots is less that they will be R2D2s serving us beers, than that they will be an ecology of unnamed things just out of sight, engineered with an insect approach to problems — Fast, Cheap, and Out Of Control.

IN WILDNESS IS PRESERVATION

For this one, you had to be there. David Ackley had misinterpreted the conference's request for video demos, and instead of slap-dashedly copying some last-minute computer screens onto a cassette, he produced an informative and hilarious tape, the best talk during the whole week. He would have had a standing ovation if anyone had any strength to stand up by that time. Myself and many others pressed him to make his video available commercially. It's the one I would recommend as the best initiation for those who have no inkling of what a-life is.

Ackley is a round guy, with a screen presence like David Letterman. In the video he invites us, the audience, to look over his shoulder as he explains his very graphic a-life world. His creatures have human faces. (No ants for him!) These humanoids run around in his world trying to acquire the usual things — resources, energy, and right answers. They bump into walls if they are not careful. They are winnowed out if they are wrong and don't get smarter. They have genes that guide their behavior, and they have mutations and crossover sex. They breed faster than rabbits. An all-nighter on Ackley's computer may take them to 300 generations.

As others have, Ackley found that his world was able to evolve amazingly fit organisms. Successful individuals would live Methuselan lifetimes (25,000 day-steps in his world), virtually immortal. These guys had the system all figured out. They knew how to get what they needed with the minimum effort. And how to stay out of trouble. Not only would individuals live long, but the populations that shared their genes would live long as well.

Noodling around with the genes of these streetwise creatures, Ackley discovered that he could make some improvements in their chromosomes that would make them even better adapted to the environment he had set up for them. He discovered a couple of ways to exploit resources that they hadn't taken up. So in perhaps the first act of virtual genetic engineering, he modified their evolved code and set them into his world. As individuals, they were superbly fitted and flourished easily, scoring higher on the fitness scale than any creature before them.

But Ackley noticed that their population numbers were always lower than the naturally evolved guys. As a group they were anemic. Although they never died out, they were always within the range of an endangered species. Ackley felt that if he ran his world for more than 300 generations, they might not last. So while the hand-crafted genes suited individuals to the max, they lacked the robustness of organically made genes, which suited the species to the max. Here, in a lab, in the home-brewed world of a midnight hacker, was the first bit of testable proof for hoary ecological wisdom: that what is best for an individual ain't necessarily best for the species.

"It's tough accepting that we can't figure out what's best in the long run," Ackley said, "but, hey, that's life!"

INADVERTENT LOW-LIFE

Eugene Spafford, computer security expert, gave a rundown on the current state of inadvertent a-life — the worms, viruses, bacteria, and other creatures on the loose in computer networks.

He started with some definitions:

Worm — propagates, or moves over networks. It may perform other actions beside replication.

Bacterium (or *Rabbit*) — merely replicates in known host.

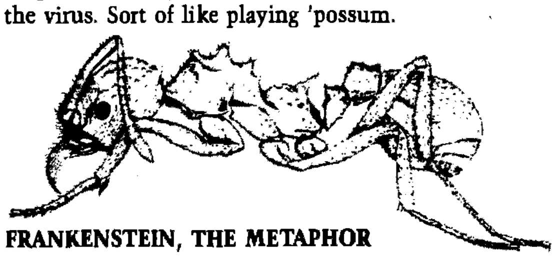
Virus — inserts itself into existing program. Cannot be run on its own. Spreads by replicating.

He now has records of over 115 versions or species of computer virus. Some viruses have become quite sophisticated. At least one pair of viruses (NVIR-A and NVIR-B on the Mac) have been known to "mate," by over-writing code, to produce a strain more virulent than either. There are also cases of viruses able to detect the signature of other viruses present on the system. These aggressive viruses remove the first virus, and then insert themselves. Removal of the first virus lessens the chance of the second being detected by human predators.

Other tricks abound. In response to more wary computer operators who try to wipe them out, some viruses will fake a re-boot by dwelling in the memory. Upon discovering the presence of these memory resident viruses, the human operator will attempt to kill them and clean the system by turning the computer off. Click. Blank screen. Operator turns computer back on. Fresh screen, fresh memory, no more virus.

Wrong.

The virus, anticipating these moves, has control of the system and merely mimics the effects of turning off the memory, without letting it really happen. While pretending to be erased, the memory is still alive and holding the virus. Sort of like playing 'possum.



FRANKENSTEIN, THE METAPHOR

"The movie Frankenstein is an albatross around the neck of artificial life." —*Doyne Farmer*

"But the book is great. It should be required for all a-life studies." —*Chris Langton*

EVERY COMPUTER AN INDIVIDUAL

Russell Brand described a puzzling case he and other computer-security experts encountered, and asked the conferees for their guess as to the agent. His thesis was that it is impossible to tell the difference between a human and a computer virus. By the end of his talk, almost everyone agreed with him.

The case involved abnormal behavior of a computer system. The system administrators noticed unofficial login attempts, messages left on the system, more over a period of time which were identical including a spelling mistake, then more machines infected without the spelling mistake, then an increasing number of messages left on many sites at exactly the same moment, and so on. A detective story. Who done it? A virus that misspells (on purpose to mislead?), or a human who can be more than one place at once, or a Conspiracy? The point Brand wanted to make was that they had no idea whether they were dealing with bugs or people.

The ending of the whodunnit is that it was a meme — an idea that passes itself around and infects people. In this instance it was a message that gave instructions on how to post in a "secure" area that was passed around by students, written on a piece of paper. That was why both the misspellings and the spreading simultaneous entries.

Russell Brand had some serious points, too. He made a very convincing case that you can do anything in a better way than by using viruses to do it. He took challenges from the floor (cheap way to distribute software, as a means of hi-tech warfare, etc.) and gave clever and witty replies to all of them. During this exchange, Danny Hillis asked if the proliferation of UNIX standard machines — most of the world's networked machines are UNIX-based — might be causing more viruses.

"Definitely," Brand replied. "In fact some people are deliberately staying with antiquated non-standard versions of UNIX in order to remain immune from these common infections."

"Then the problem we have with computer viruses," Danny said, "stems from the fact that all our operating systems are identical. The very thing that has made computing easy for the user — a standard system — has made it easy for viruses. There is a continuing move to standardization among machines connected by networks. So as long as formats like UNIX become a universal standard, we'll have awful problems with viruses no matter how many vaccines and quarantines you come up with. What you want in networked computing is a diversity of operating standards. You want each computer to have a slight variant of the standard, maybe one that is slowly evolving. It will still have many holes that can be exploited by viruses and so forth; it won't be any more immune to infections, but it will hardly be worth the time to try to infect just one machine."

Danny made me realize that we have monocropping in computers. The idea of having a computer with an adapting operating system, one that is slightly different from all others, is both romantic and frightening. This way the computer becomes more like a pet with individual character, and (this is the scary part) with unique likes and dislikes ("Sorry, I can't stand Pagemaker; do you have Quark?"). Just when computers were becoming manageable because they were predictable, we find that ultimately predictability will be their undoing. I find myself saying "hail to unpredictability!"

NETWORK ANTS

Rob Collins introduced another ant world. Each ant is 9K in a computer neural network. There are eight ants per colony, and 4,000 colonies in his world. Colonies reproduce, not ants.

The ants roam the world looking for food, which they are supposed to bring back to their colony nest to fuel reproduction. Like the other examples at the conference, the ants "learn" over generations to better find and compete for food. However, as in real life, individual organisms (which are colonies in the insect world) have their own quirky behavior. Collins found that even though the ants learned to range far for food very early, in some a-life colonies they never learned to pick up food right outside the nest, even after 240 generations. And there was one curious colony that played with their food, stockpiling it in one corner of the world instead of inside their nests. (I don't think they lasted long.) And occasionally some of the ants dropped food into the wrong nest. (This is not uncommon among real societal insects like bees.)

Party small-talk in the year 2050: "You can't imagine what my a-life pets did today!"

THE VELOCITY OF LIFE

One thing that a-life is about that few researchers have mentioned is time compression. Artificial-life models compress evolutionary time into human scale. This, of course, accelerates the rate of change in evolution. As a-life speeds up our own progress in evolving things, it will continue to accelerate the differences in time cycles that technology has introduced into the world. Whether the slow will govern the fast, or vice versa, isn't known, but the control of velocity is control of the system.

LITTLE BEASTIES: TABOO, QUARANTINE, OR INCUBATOR?

There was a panel discussion about the implications of viruses as an a-life form. One Harold Thimbleby from Scotland outlined a serious proposal to use a worm-like mechanism to distribute software updates. "LiveWare," he calls it. The engineered selective worm is broadcast out into the world; when it finds a receptive host it infects it with an updated version of information or software. The key here is that the worm is selective, only entering those systems that have deliberately allowed it, and passing over those which do not have the needed welcome signal. It is, in effect, a self-distributing system, since the sender has no need to know who or where to send his information to.

In rebuttal, Russell Brand pointed out the dangers of such

plans and continued to claim that "for any goal viruses are the wrong mechanism." Eugene Spafford also noted that so far "no computer virus has gone extinct." Panel member biologist Hyman Harthman dryly noted that before we dismiss them out of hand we should keep in mind that viruses and related organisms form the bulk of living matter on Earth. Furthermore, he suggested, there has been a recent "theory of speciation by infection," which says that interspecies viral infections are what spurs the movement toward distinct germ lines: the crossover code from viral infections helps speed evolution. If I understood him correctly, he also said that researchers have noticed that interspecies viruses moving in the germ line are a steadily increasing phenomenon in living organisms on Earth right now.

That was the closest that anybody would come to endorsing viruses as a legitimate research area for a-life form. The same amazing thing happened at the Hackers' Conferences. Not even there would anyone publicly defend experimenting with viruses. Privately, every hacker I talked with would say that viruses were fascinating conceptually, that they were important, if not inevitable, but that they were "wrong." Here, too, scientists would confess privately to me their fascination with virus code and their desire to try something. Occasionally they would describe a design for a virus that they had in mind and would like to check out, but "of course, I wouldn't do that!" Publicly, they sat mute while the virus bashers railed. I was seeing a 21st-century taboo arise.

Steven Levy, author of *Hackers*, who was sitting with me, was getting upset. "I don't understand. Here we are at a conference on the making of a-life, and the closest example that we have of that, computer viruses, nobody will even stand up for. If they can't deal with it at this stage, how are they going to deal with full-grown artificial life?" I felt equally disgruntled. Biologically, viruses are more important to what happens on Earth than dogs or cats. I wished Lynn Margulis, the microbiologist, were around to straighten these guys out.

My question to the panel that evening: Why not construct a National Computer Virus Research Lab, an a-life incubator, where there are large networks strictly separated from the outside so that this fundamental work can be done? Russell Brand's answer: "There probably is one already. But because it's dangerous [and socially taboo I will add] it is therefore secret." The CIA has acknowledged that is has done work with viruses. If the military continues to have the monopoly on computer viral research, then the direction of a-life research is in deep trouble.

PERPETUAL NOVELTY

John Holland came up with the most sophisticated artificial world I've seen yet. It's a disembodied, pictureless world; everything happens as numbers without graphic representation. Nonetheless it's come furthest in introducing many of the parameters that ecological systems of life have. Holland calls his world Echo.

In Echo, learning and eating are the same. Echo's creatures live in a grid-land, a wide-open plane divided into squares. They eat elements. In some squares there are fountains that dish out elements abundantly. Echo's creatures head toward these fountains to consume and be energized. The elements are short bits of code. While the bits of code are food, they also serve as the genes of each individual. [These beings really are what they eat.] For instance, imagine a creature growing genes made up of *a*s, *b*s and *c*s. In order to use *a*s in its genes it needs to eat *a*s. It can get *a*s from the environment by hanging out at the *a*s fountain and competing with other organisms for the limited amounts of *a*s, or it can prey on another organism that has *a*s in it and eat those, or it can have sex with an organism with *a*s in it, swapping needed code. The *a*s, *b*s and *c*s in a critter's body are added together to form short sequences like genes. The sequence of letters evoke a particular mathematical algorithm, which determines that critter's behavior in seeking out resources.

The competition for limited resources, the algorithms that learn over time, and the mutations brought about by sex, all contribute to a wonderfully dynamic ecology in Echo. In just the few short weeks that he has been running the world, Holland has noted some interesting traits.

In Echo, as in Core Wars [a duel of two computer parasites], the shorter chromosome wins. A short chromosome costs less to reproduce, it's quicker to make, so in a battle, it wins.

Recombination [sex] keeps one a moving target against predators and parasites. You can introduce more changes into an organism, without as much randomness as simple mutation.

Holland only mentioned the next one in passing, but I believe it holds great treasures for biology if a-life can prove it: "Selected mating is the origin of niches."

The other thing he was beginning to track was the food webs produced in these worlds. The consequences of food webs are hardly understood in the wild; having some models for comparison would be galvanizing for the field. And just to see what happens, Holland would like to make eggs and seeds.

Holland's goal is to design a system that will get complexity from natural selection, rather than from "artificial" selection as in, say, Richard Dawkin's landmark program Biomorphs. In Dawkin's system, the human operator picks out which mutation to breed [much as fanciers breed pigeons or carp], and then his program evolves it. Holland insists that the system itself define the criteria to breed. Or, in other words, that the selection criteria itself would be an emergent property of that world. [The terminology can get confusing here. Real pigeons are bred with "artificial" selection, while Holland's artificial computer critters will breed with "natural" selection. Heads up!]

He says he is after "a new mathematics of perpetual novelty. It is this perpetual novelty, and not equilibrium, that equals ecology."

SEEDS OF NUMBERS

Przemyslaw Prsuinkiewicz demonstrated how mathematical rules known as Lindenmyer Systems [L-systems] could be used to model the shape of plants. Very, very simple formulas could generate forms like leaves and bushes and tree profiles. By layering several L-systems at once, Prsuinkiewicz (I'll call him Prsu for short from now on if you don't mind) was able to mimic the leafing-out and flower stages of a wildflower. He did this in color. Then he did meadows full of them, each plant beginning as a tiny seed of numbers.

The major advance Prsu has contributed to the problem of growing an a-life form is to bring the element of time into the set of growth rules. While his earlier works superbly rendered a bouquet of flowers, or a patch of ferns, they weren't composed the way they actually grew. For example, a branch would be added to the stem, but in actuality an embryonic branch develops out of the stem as the stem itself is developing. If the stem is stunted so will be the branch hidden in it.

All growth turns out to be co-growth, just as all evolution is co-evolution. Co-growth is what the science of morphogenesis (how things grow) is all about, and why I think that a-life will finally be able to inform the incredible Looking Glass World of embryonic organisms — how does a cell know to become a hippo?

Prsu's film of growing a-life plants was riveting. There was the uncanny recognition of a time-lapse film of real plants surging upwards and out, unfolding themselves. His maturing plants and spiraling snail embryos gave off an aura that was decidedly organic. There was a grace on that screen that was neither human nor machine.

AN ANIMAL CONSTRUCTION KIT

Developed by Michael Travers at the MIT Media Lab, Agar: An Animal Construction Kit will "allow novice programmers to assemble artificial animals from simple components. These components include sensors, muscles, and computational elements. They can also include body parts such as limbs, bones, and joints. A complete animal construction kit will support the co-existence of multiple animals of different species."

As it is now, it is only an ant world. Travers runs a simulation of cooperative food-gathering using ant-like entities set into the Agar world. The human zookeeper puts out food anywhere, and the ants will try to find it. When they find food, they lay a chemical trace back to the nest so that the other ants from their nest can find the food quicker. The chemical trace "evaporates" over time, so sensitivity to the chemical trail is beneficial. The paths the ants take around obstacles are all emergent, not foreseen by program or operator.

The most important aspect of this project is that the parameters of the environment and the traits of the creatures can be easily modified to produce new creatures and new worlds.

BOTTOM-UP JUGGLING

Brian Yamauchi showed a video of a juggling seeing-eye-robot-arm that relies on "bottom-up" rules. The arm's task is to bounce a hanging balloon on a paddle. This very complex behavior (seriously) is implemented by a committee of lower "agents" (in Marvin Minsky's terms) that are in charge of a motor or a sensor or another subagent. Rather than have one big brain try to figure out where the balloon is and then move the paddle to the right spot under the balloon and then hit it with the right force, these tasks are decentralized, both in location and in power.

For instance, the problem of "Where is the balloon?" is divided among simple agents, each concerned with a simple question like "Is the balloon anywhere within reach?" — an easier question to act on. The agent in charge of that question doesn't have any idea of when to hit the balloon, or even where the balloon is. Its single job is to tell the arm to back up if the balloon is not within the arm's camera vision, and to keep moving until it is. A network, or society, of very simple-minded decision-making centers like these form an organism which can exhibit remarkable agility and adaptability.

Yamauchi says, "There is no explicit communication between the behavior agents. All communication occurs through observing the effects of actions that other agents have on the external world." Keeping things local like this allows the society to evolve new behavior while avoiding the debilitating explosion in complexity that occurs with hard-wired communication processes. Keeping everybody informed about everything is how intelligence does not happen. Ignorance is sometimes bliss.

It has not been lost on certain astute observers that Yamauchi's recipe is an exact description of a market economy: there is no communication between agents, except that which occurs through observing the effects of actions (note that they see effects but not usually the actions) that other agents have on the common world. This led the Santa Fe Institute (host of the A-life Conference) to sponsor in 1988 a separate research program on "The Economy as an Adaptive Complex System."

INVENTING A SPINAL CORD

This five-minute video by Michael McKenna and David Zeltzer is an entirely computer-generated animation called "Grinning Evil Death": the story of how a giant six-legged menace from outer space invades Earth and destroys a city. The villain is a loathsome metallic cockroach who wriggles over the city in a very realistic (and repulsive) cockroach way.

The creature's video movements are painted by a kind of artificial spinal cord. You tell the head where to go, and the backbone part figures out how to move the feet. So there's this gigantic chrome cockroach, and the programmers say, "walk over those buildings," and the computer/cockroach figures out how the legs go and what angle the torso should be and then paints a movie of a giant chrome cockroach climbing over buildings. When it jumps down off the other side, a simulated gravity makes its legs bounce and slip realistically.

Walking, then, has been moved from the conscious to the unconscious. Steve Strassman, who is trying to write a program for a spinal cord, has a goal of encoding enough unconscious actions into a virtual being that one could merely give it an ordinary English-language script, and say, "Here do this." And it goes and invades a city without getting hung up on how it moves its six feet without tripping.

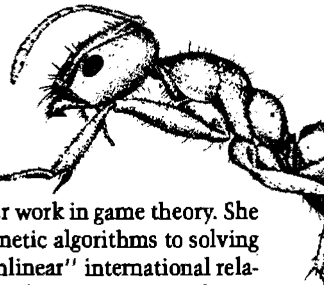
THINKING IN YOUR LEG

Belgian scientist Pattie Maes used Rod Brooks' six-legged walker as the experimental animal for teaching a creature how to walk using an agent-based, low-hierarchical system. In this case the thinking for the walking takes place near the two motors for each leg. The leg motors lift or not depending on what the other legs around them are doing. If they can get the sequence right ("Okay, hup! One, three, six, two, five, four!") walking "happens." As I understand it, setting the sequence is another job for an agent. Getting up and over obstacles, like a mound of phone directories, required adding some sensing whiskers to send ground information to the first set of legs. Since the other legs are watching the first legs, walking over obstacles happens. There is no one place in the contraption where walking is governed. There is no way for a motor, say, to determine whether it is walking or not. It knows only if it is moving its leg up and down. Sometimes when the legs are moving up and down the creature is stuck. Sometimes if everything is in harmony, the creature walks. But the parts don't know.

One of the major principles to be elucidated at the First A-life Conference was the thrilling notion that complex behavior in a variety of systems, from computer-grid worlds, to biological immunities, to synthetic ecologies, to global economies, could all be produced with what are called "local rules." Local rules guide the behavior of individual agents. These bottom-up heuristics say nothing DIRECTLY about what happens at further levels. If birds on the fly keep a certain distance between neighboring birds on the fly (a local rule), then they will exhibit a characteristic flocking behavior (a global rule), depending on what local rules they start with. Therefore, flocking (a global behavior) emerges out of local behavior. You can't get flocking by having each bird keep in mind the shape of the flock and try and do its part to keep it that way. It's too error-prone even if it was possible.

Visualizing the levels of emergent order which originate as grass-root rules and then cascade up, birthing self-organization at increasing scales of complexity, is the easy part. One can intuitively see how, with a clever choice of laws, local rules can govern global behavior. The hard part is understanding how global behavior can govern local rules.

The agent of the paddle doesn't know where the balloon is, the walking motor doesn't know if it is walking, the bird on the fly doesn't know the shape of the flock. Yet it became apparent at the Second A-life Conference that it wasn't as simple as that. The kind of perpetual novelty that John Holland talks about arises when there is a return communication between local and global. Somehow the global must control the local, difficult as it is to hit a moving target. Somehow the flock can aim itself to a destination, and sometimes over years, the flock will change its destination, or even, by evolution, what the aim of flocking is. All these changes entail the locally elected global power governing the local. Start with simple rules, get complex behavior — easy part. Get complex behavior to govern simple rules — very hard part. This is an important and final loop in an extremely recursive circuit. How this loop is kept flexible, rather than an ever-tightening noose, is, I bet, the theme of the Third A-life Conference.



NON-LINEAR GAMES

Stephanie Forrest does pioneer work in game theory. She has recently been applying genetic algorithms to solving arms-race problems, and "nonlinear" international relations, i.e. the chaotic real world. Using a model that parallels John Holland's work, she has been looking at how simulated countries can evolve their negotiation strategies for mutual benefit. In Holland's a-life world each organism determines its strength of defense, offense, reproduction; in Forrest's nonlinear international world, each country determines a similar three priorities: guns, butter, re-investment. Her initial results imply that in three-country worlds, the strongest position arises when the two weakest countries join as allies.

What is of interest here is that the allegiances are formed without prior prompting. It is an emergent property of a complex system. Forrest's earlier work with negotiating strategies (The Prisoner's Dilemma) and her current work point to "how cooperative behavior can arise in populations of autonomous self-interested agents in which there is no central authority." In worlds that seem to be propelled by Darwinian-described competition, how does cooperation ever arise? Richard Dawkin's explanation is that selfish genes make altruistic organisms. Forrest is suggesting other ways — that cooperation is a positive-feedback trait of adapting systems.

Remarkably it is the ants, again, who have some answers. Other than a-life fans and their ant worlds, the only other set of people seriously investigating the question of emergent cooperation are the real-ant fans — the sociobiologists. Ants exhibit rule-breaking altruism where one would not expect it — in pretty dumb and savage little beasties. They have systematic cooperation despite individual little-mindedness, and this is of interest to political scientists as we try to restructure a global economy. The Book of Proverbs (6:6) speaks truthfully when it says, "Consider the ant's ways and be wise!" Ants are, it appears now, the world's leading experts in nonlinear international relations. (See review, *The Ants*, p. 30.)

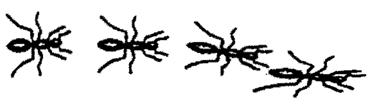
THE GENIUS OF RODENTS

John Nagle contemplated squirrels. Taking a cue from Hans Moravec at the CMU Robotics Lab, who suggests that current computers have an intelligence level of a snail, Nagle argued for aiming at the realistic goal of generating the intelligence of a squirrel. Rodents have about 1 gram of brain mass, which Nagle says is equivalent to a computer running somewhere between 100 and 1000 MIPS (millions of instructions per second). That level is not as impossible as human-level AI, but far more useful than the ant-level intelligence of your average Macintosh.

Squirrel-level intelligence will get us automatic character animation. Specifically, Nagle proposed a goal of reaching a level so that an a-life "squirrel does the right thing over periods of less than one minute." He said the hard things that a-life and AI folks tend to "abstract out" in order not to do, are actually the most important things. Going along with the Moravec graph of increase in computer power as a function of time, Nagle said we'll have squirrel-level artificial intelligence by the year 2000.

A young woman (one of the few present) stood up at the microphone at question time and told Nagle that he was full of it. She said that almost all the scientists dreaming about a-life any time soon were on cloud nine, that none of them had any idea of how complicated real biology was, that Moravec was out to lunch, that the work on retinas that he has been basing his projections on is shoddy, that she is a neurobiologist herself who happens to be studying the retina and Moravec hasn't got a clue to how computationally sophisticated just the eye is, that computer scientists like him underestimate the power of animal brains to the point of silliness, that equating MIPS with intelligence is one good example of how crippled the whole a-life movement is, and would he care to comment?

Nagle shifted uneasily and said he had a plane to catch (he did) and maybe someone else could answer her (they didn't).



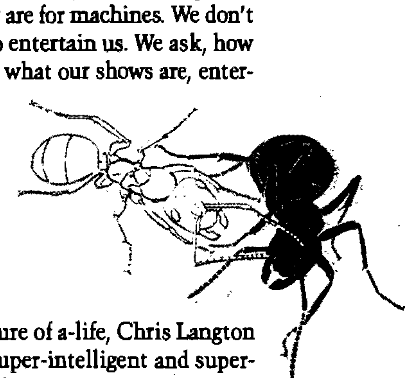
ENTERTAINMENT FOR MACHINES

On the last day of the conference Mark Pauline got his shock-wave cannon working. A solenoid on the cannon had broken on the plane flight, so during the a-life show-and-tell evening, the crowds had to be content to watch videos of past Survival Research Laboratories (SRL) spectacles. They were awesome and disturbing. One avant-garde video was a stark "documentary" of elaborate dinosaur-like machines involved in ceremonial rituals of sacrificing other machines to the machine god. These are not sleek Star-Trek machines, but rusty, smoldering, smoky, greasy, vibrating, mechanical monsters. They have gears and pistons, and sharp edges. They cut up or burn fellow machines with rotating propellers and grinding wheels. Their performances are modern-day Roman circuses of mechanical gladiators staged under industrial decay, searchlights, screeching loudspeakers, the crackle of fire, and the smell of diesel oil.

The idea is to do the shows with as little publicity or official approval as possible, have the audience get as close as they dare, and make the machines as fast, cheap and out-of-control as one can. For instance, take the Flame Thrower on Wheels. It used a Mack-truck V8 engine to run a huge blower that sucked up kerosene from a 55-gallon drum and ignited it with a carbon arc, spewing out a tongue of vicious orange flame a hundred feet easily. It was controlled by a little model-airplane joystick. Or take Pauline's description of his newest pet which he showed clips of: "This completed device is based on electromagnetic rail gun technology. Rather than firing a projectile at high speeds for kinetic impact effects or other droll, destructive military objectives, this device employs similar capacitor energy-storage units to liquefy a metal bar and magnetically eject the molten blob at about 200 mph. It appears to the eye as a comet-like beam that fragments on impact, tending to set fire to any nearby combustibles." As Pauline added. "This machine is SRL's answer to George Bush's call for a thousand points of light."

Nothing as kinetic was planned for the A-life Conference. A mere shock-wave cannon would do. A tube about five feet long is chained to an an electric hoist near the speaker's podium, and pointed over the heads of the 200 scientists. Hoses run to a tank of acetylene on the floor. When we see the blue warning light, we plug our ears. *Boooooooooom*. A terrific crack blasts the hall, blowing off all the papers, notes and hand-outs on the tables of the participants in the back row. The scientists scatter. A rain of dust and plaster bits showers down. The blue light goes on again. *Boooooooooom*. I am standing behind the cannon and actually see a wave go across the conference hall and hit the back balcony wall, where it shatters the plaster stucco. People are ducking now. Another blue light. Again, *Boooooooooom*. It's actually less a noise than a thump to the lungs. Pauline is enjoying it, an impassive face with a hint of a smile.

"Machines have something to say to us," Pauline says afterward. "When I start designing an SRL show, I ask myself, what do these machines want to do? You know, I see this old backhoe that some red-neck is running everyday, maybe digging ditches out in the sun for the phone company. That backhoe is bored. It's ailing and dirty. We're coming along and asking it what it wants to do. Maybe it wants to be in our show. We go around and rescue machines that have been abandoned, or even dismembered. So we have to ask ourselves, what do these machines really want to do, what do they want to wear? So we think about color coordination, and lighting. Our shows are not for humans, they are for machines. We don't ask how machines are going to entertain us. We ask, how can we entertain them? That's what our shows are, entertainment for machines."



ARTIFICIAL HUMANS, BIOLOGICAL MACHINES

In the closing panel on the future of a-life, Chris Langton asked, "When machines are super-intelligent and super-efficient, what is the niche of humans? Do we want machines, or do we want us?" Pauline responded, "Humans will accumulate artificial abilities, while machines accumulate biological intelligence. This will make the confrontation even less morally clear."

Somebody else on the panel: "You know Rod Brook's smart doors? Eventually we won't say to the door, 'open'; we'll have to say, 'open, please.'" ■