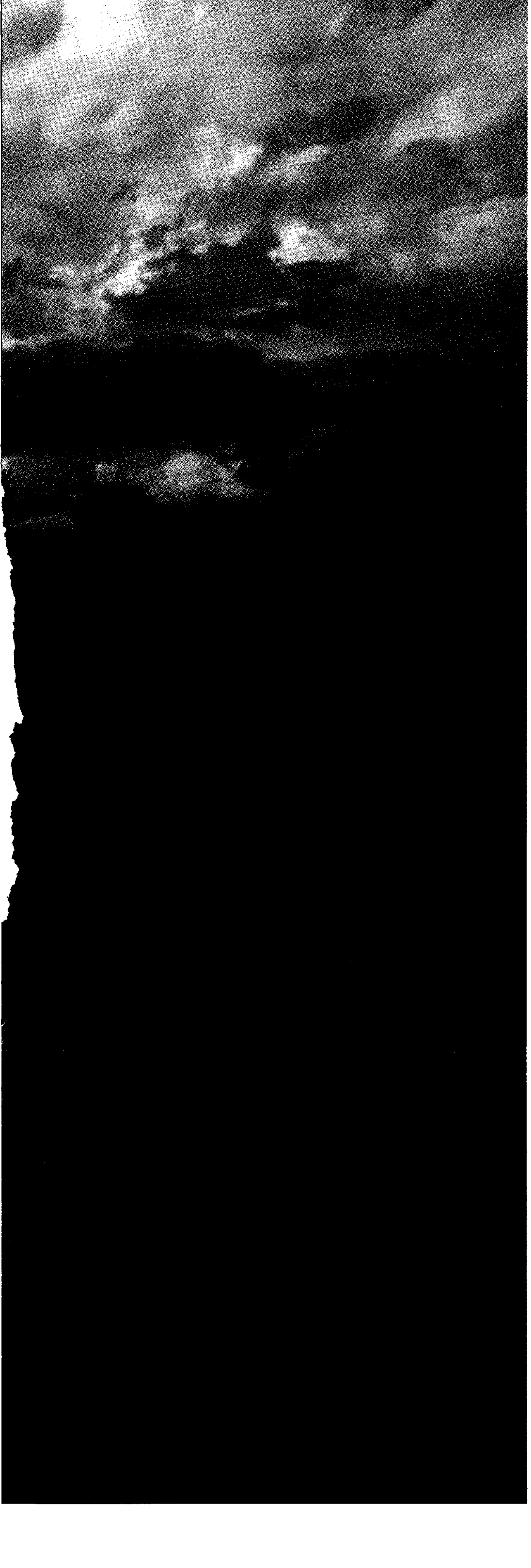

"We've got things in the computer capable of evolving, reproducing, metabolizing, things having complex patterns in space and in time. Are they not alive?" For a pioneer in the emerging scientific field of artificial life, that is the big question

INTERVIEW

CHRISTOPHER LANGTON

His first encounter with an artificial life form took place while he was at Massachusetts General Hospital. His job involved wheeling dead bodies between the morgue and autopsy room. One night about three A.M.—this was after he'd seen *Night of the Living Dead*—he and a co-worker were ferrying the latest corpse through a dank underground hallway lit by a single bulb. The body was covered with a sheet, all very *Frankenstein*-like, when suddenly the corpse started moving. It started to rise! The body. . .sat up! "And it made this roar!" says Chris Langton. "I turned to the guy next to me and he was gone. The double doors at the end of the hallway were going flap, flap, flap. . . ." No explanation ever did turn up. "People in the morgue liked to play jokes," he says. "You'd go to wheel a body, open up a drawer, and the body'd sit up. This one could have been planted, too."

Langton's second encoun-

PHOTOGRAPHS BY DAVID MICHAEL KENNEDY

NAME:
Christopher Langton

AGE:
Forty-two

PLACES OF WORK:
Complex Systems Group Theoretical Division, Los Alamos National Laboratory; Santa Fe Institute

LANGUAGES FLUENT IN:
C, LISP, BASIC, Pascal, FORTRAN, 6502 assembly language, PDP-7 assembly language, etc.

FAVORITE ARTIFICIAL LIFE FORM I:
Ed McMahon

FAVORITE ARTIFICIAL LIFE FORMS II:
Langton's cell simulation on the Connection Machine; Rod Brooks's insects at the MIT Artificial Insect lab

RECENTLY READ:
Mary Shelley's *Frankenstein* (for the third time): "I want to understand Frankenstein, to understand life from the perspective of the so-called monster."

ter was a little less spooky. Working in Mass General's Psychiatric Research lab as a systems programmer, he was trying to make one computer simulate the operational structure and functions of a second computer. These simulations, he realized, involved reducing a given machine's operations to a finite set of rules and instructions, a bunch of abstract logical relationships. Was there anything, he wondered, whose workings you *couldn't* simulate in this fashion? What was life itself, after all, but a lot of essentially dead materials organized so that, somehow, living processes emerged? If you correctly simulated the underlying pattern or structure of a living thing, Langton thought, wouldn't that simulation itself in some sense be alive?

His third encounter with artificial life also took place in a hospital, only this time he was a patient. In 1975, before entering the University of Arizona, he crashed his hang glider, breaking 35 bones, including both legs. As he regained consciousness, information patterns marched through his head, exploding like fireworks across his visual field. "It was as if they were self-existing entities completely taking over the hardware of my brain," he recalls. He spent the next five months recuperating and thinking about what he'd seen.

Years later Chris Langton established the field of artificial life as a distinct scientific discipline. In 1987, while a research fellow at the Los Alamos National Laboratory, he organized the first conference on artificial life. More than 100 scientists brought an entire menagerie of artificial animals. In addition to a smattering of robots, there were computer-based genes, ferns, flowers, worms, and bugs; there were schooling fish, flocking birds, and buzzing bioinformatic bumblebees; there was a warren of artificial foxes and rabbits in their own artificial ecology. The workshop was capped with an artificial life 4-H show: prizewinning entry, the ferns.

Two years later, even before receiving his doctorate, Langton helped organize a second workshop. Today artificial life embraces the study of complex adaptive systems in all their myriad forms: from prebiotic chemical evolution, to biological evolution, evolution of languages and cultural systems, to evolution of global economies. While some researchers try to get synthetic life going in chemical media, Langton prefers to work with computers. His latest project, which he's collaborating on with Kristian Lindgren (NORITA, Copenhagen) and others, attempts to computer-simulate a complete biological cell.

You can be as skeptical as you want about artificial life until you see that simulation. There in living color is a pulsing, undulating cell membrane, exactly what you might see watching cell division through a microscope: The cell wall puckers, pinches down on itself, and a second cell splits off. This is not a movie. The wriggling, dividing structure is a pattern generated by a program much the way DNA codons generate biological organisms. Somewhere in the bowels of the Connection Machine, a massively parallel supercomputer that sits a few doors away from Langton's Los Alamos office, exists the electronic analog of a living cell.

Says Langton: "We're going to try to capture a cell's behavior while it incorporates stuff from the outside—taking in metabolites and turning them into cell constituents—turns genetic code into entities that move around inside the cell and make it do things like divide, produce offspring with variants, and die."—Ed Regis

Omni: Can you define "artificial life"?
Langton: My first sense of it came around 1979 when I was trying to describe what I wanted to do for my Ph.D. It was then a way to study biological phe-

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nomena by building computer models of them, rather than by studying the real biological organisms themselves. It attempted to re-create in some other medium the processes important to life, and to study those processes in other mediums or in the abstract. Today I define artificial life as the study of artificially constructed systems that exhibit behaviors typically thought to be characteristic of real life.

Omni: Your focus is not the materials of life, but its basic structure?

Langton: The hardware of life is not really what life is all about. Biological things are wet and squishy, so we've come to associate life with wet and squishy stuff. But that's because we've seen life only in those materials. In fact, you can often separate the material from the behavior it exhibits and envision other materials that could exhibit that same behavior. What's important are the functional relationships between parts. I see no reason why you can't lift those relationships from the natural world and emulate them on a computer. You'd then have a realization of life in another kind of hardware.

Omni: What's the advantage of studying living processes in media such as computers?

Langton: Biologists would love to be able somehow to rewind the evolutionary tape back to certain initial conditions and run it again. You can do some of that with *Drosophila* [fruit flies] and *E. coli* [bacteria], but there's a lot you can't do. Simulations enable you to restart experiments from the exact initial conditions, changing just a single parameter and then seeing that parameter's effect on the resulting history. You could start off with the same exact situations but with different seeds in the random number generator, for example, to see the whole envelope of resulting histories.

Once you get genomes that pass on the information, mutations, recombinations, then you ask, What happens? The same thing? Or something different? Do you see punctuated equilibrium, long periods of stasis followed by brief periods of rapid change? Explosions of diversity followed by the filtering out of individual lines? Do you see extinctions? As people have gotten better and better at implementing these things, you see all that stuff.

Omni: So extinctions occur naturally, without the intervention of comets?

Langton: Right. Kristian Lindgren's little evolutionary models indicate it's plain as the nose on your face that you get extinctions. Clearly, the earth has been bombarded by big things having a huge effect, ruining the days of the local population. But most of the extinction record's structure is probably due to the natural dynamics of population evolution instead of externally imposed perturbations. This seems a natural feature of most evolving systems experimented with on computers. If we see extinctions in these simulations, it's natural to go on to ask, How much of the extinction record can we explain by natural evolutionary dynamics without invoking external catastrophes?

Omni: Is anyone in good mad-scientist fashion trying to create a living thing out of nonbiological components—in a petri dish, for example?

Langton: People at MIT recently constructed a chemical system in which molecules replicate by template synthesis, the way DNA replicates, only they weren't using DNA. This wasn't a computer simulation but was done in real "beakerware." They used certain kinds of adenosine triphosphate.

Gerald Joyce at Scripps Clinic Research Institute is trying to build what he calls an "RNA world" to address a fundamental problem about the origin of life: Current life depends upon a tightly coupled interaction between proteins, enzymes, RNA, and DNA. The tight coupling is that the DNA codes for protein synthesis, whose products themselves decode the DNA and mediate its replication. To get proteins you need DNA, but to get DNA you need proteins. How could this intricate interdependency have gotten started? The recent discovery by [Nobel laureate] Tom Cech that RNA molecules can function as enzymes points at one way out of the dilemma. Joyce is trying to construct a completely closed RNA world in which information-storing RNA molecules code for RNA enzymes, which in turn decode the information-storing RNA and mediate its replication. All without proteins. Another approach is to get the whole thing going in a strictly protein world. Some colleagues here at Los Alamos and at the Santa Fe Institute are working on that.

Omni: Would you regard these human-made chemical structures as alive?

Langton: There's no generally accepted definition of life. That's part of what we're trying to get at. The more of the phenomenology of life you're able to capture—in a computer or test tube—the more you're pushing into this gray area where it is hard to decide if they're alive. You know: Well, gee, they *look* kind of like life. Maybe they're not completely alive, but the only thing we have to compare them to is what evolved on this planet, this one example. We really need a class to see what's universal across that class and what's accidental in particular instances or members of that class. Any definition of life we might make based solely on our own experience of life on Earth will be too narrow.

Omni: But with a computer simulation you don't have a physical entity in front of you.

Langton: That's not such a big obstacle. It all depends on one's definition: Does your definition have any reference to physical properties or not? Scratch any biologist and he'll give you a list of things living entities ought to do: reproduce, metabolize, be a pattern in time and space, have complex organization, be capable of reproducing offspring that are slightly different and belong to an adapting and evolving lineage. In *The Growth of Biological Thought*, evolutionary biologist Ernst Mayr provides a classic list of properties that living things ought to have. But none are really tied to physical properties. It's all behaviors. Probably the biologist will say there's something else life has to do. He'll add something new to the list, make a qualification of how the entity has to go about these things. But we can make progress, even if we never generate something on the computer that biologists admit is alive, by forcing them to be more careful about what they mean when they say "life."

Omni: In principle, then, is it possible to have life inside a computer?

Langton: There's a strong and a weak claim about computer simulations of life. The claims are analogous to similar claims for artificial intelligence. The weak claim is that these are only computer models, tools to help you study real phenomena. The strong claim is that these processes can be more than simulations, that real intelligence and life could be embedded in the artificial material. The term *artificial* refers to the material, not to the life.

I believe the strong claim: To me material is irrelevant. Many different ways exist to realize any particular set of functions. Multiple realizability! This is the functionalist school of philosophy, either about intelligence or life. Some people argue: "Life can't be independent of material. Look at enzymes. So many of their properties depend on the chemical interactions and properties of the atoms involved in specific chains." Yeah, sure, but there are plenty of other ways to get complicated structure-function relationships. Clearly, you have to realize these functions in some sort of hardware, but the specific hardware is often irrelevant to the function itself. Because other materials also may be viable, computers could provide a sufficient material basis for life.

Omni: What arguments do those who deny the strong claim use?

Langton: A standard argument is that if you simulate a hurricane or thunderstorm on a computer, nobody gets wet. But they're missing an important point here. Simulations of something like wetness differ from those of something like life or intelligence in that wetness has very physical attributes. Wetness and liquidity are defined by physical properties, whereas life is not necessarily so defined.

Omni: Still, any example of a living entity is a physical thing.

Langton: Look, a computer is a physical thing, too. But a computer can exhibit a lot of behavioral properties, whereas as yet it can't exhibit a lot of physical properties. So certain physical attributes like viscosity will be hard to get on computers. I'm so much of a computationalist that I believe you can have real wetness in a computer. But you have to drop the specific physical attributes from your definition of wetness and define it solely in terms of behavioral properties. Tom Toffoli at MIT refers to certain classes of computers as "programmable matter." Some of my thesis research showed that this programmable matter can exhibit solid, liquid, and gaseous phases of behavior, just like real materials. So hardware can act wet. It all depends on definition and how you interpret observations. For me the altered definitions are much more powerful and useful than the older, more restricted ones.

Omni: Has anyone ever come out and said, "This artificial life stuff is nonsense. You should do something else"?

Langton: Well, yeah. On one of these radio call-in shows a guy who purported to be a scientist said, "There's no such thing. This is just a bunch of scientists trying to promote their careers. You can't have life inside a computer. It's not really life, but a sort of pattern of energy and magnetic molecules on a disk in a memory somewhere."

And I said, "Throughout your life you constantly change the cells in your body, but there's some pattern in space and time that persists. Your actual physical media are pretty transient." He had some counter to that. He just couldn't buy the whole thing.

Omni: Is everyone in the field trying to create life?

Langton: No. Lots of people are not studying life, not trying to make something alive when they're looking at an evolving population. They're studying evolution as a process. The term *artificial life* covers a lot of things that living things do.

Artificial life also covers the analogy between biological evolution and evolution of language and culture. In graduate school I had this epiphany—that words, sentences, and paragraphs were like genes. Language is like social DNA. The mechanisms by which language is transmitted, the basic mutations and recombinations of words and concepts, have analogs in biology. More broadly, social intercourse, whereby cultural information gets passed on from one generation to the next, does for cultural information what sexual intercourse does for biology. Social intercourse recombines cultural information packets, putting them in new contexts in slightly different ways.

Omni: People in artificial intelligence have made grandiose claims about producing human intelligence in ten years, and they've failed. Is there a lesson here for artificial life?

Langton: The problems in artificial intelligence proved harder than people initially thought. But the problem of life may be more solvable than the intelligence problem. We know a hell of a lot more about how cells work than how the brain works. We know next to nothing about how the brain works. I'm not claiming we'll have life within a computer within ten years. But this is mainly because we may not have a good definition of life in ten years, not because we'll be unable to do a fairly good job simulating the process of life on computers in ten years.

Omni: What are the possible dangers of creating artificial life? Could these things get out of the box and start eating up the biosphere, unleashing unspeakable horrors on humankind?

Langton: Some of these horrors are already being unleashed, and not by people working in artificial life. Computer viruses, for example, are one of the things existing out there closest to artificial life. In several instances, one computer virus has overridden another, generating a virus nobody really wrote. This was a combination of two viruses, both viable, that spread around targeting the same sector of your disk.

Computer network technology is close to the point where you've got a big distributed system with powerful information processors at every node, with no central controller. These big nonlinear dynamic systems with spatial distribution have already thrown out examples of emergent phenomena where it's hard to figure out what's going on. Problems the Bell System had with some of their switching networks, where the whole system went down for several hours, may have been due to nonlinear interactions between switching stations. When they loaded in some new software, they had an emergent state come up that sort of locked out the whole system.

This is not a virus but an emergent property of the interactions of these programs talking to each other. The more you have autonomous decision makers that take in local data and make decisions affecting what other agents are doing, the more that medium is ripe for the emergence of complex, high-level phenomena. You can get all kinds of funny behaviors that crystallize out at the whole-network level that were completely unintended and unanticipated by the program designers.

The same is true for stock-trading programs, buying and selling programs: The system is ripe for chaos. Each computer interacts via the market, and other computers are looking at the same database, making local decisions that affect the database, too, but in a distributed rather than centralized fashion. This nonlinear dynamic system can in principle give rise to the spontaneous emergence of something with a lifelike dynamic.

So stuff is going to start happening out there. The only way we're going to be able to understand and control it, and not be swept under the rug by it in ways we don't understand, is to study it in these local, small-scale models.

Omni: Recombinant DNA research was constrained in the early days by guidelines designed to minimize possible dangers. Should the artificial life community do something like that?

Langton: The virus panel during our second workshop discussed the ethics and potential risks of working on these things. People working with computer viruses, self-reproducing programs, partial programs, program fragments, shouldn't turn them loose on the network. At the panel, Eugene Spafford [Purdue University] said people who create computer viruses and turn them loose on the network are the moral equivalents of those who'd dump a toxic biological virus into public drinking water. Some people don't yet realize it's a bad thing to do. These high-school hackers would never break into a hospital or take some AIDS virus and dump it into a reservoir. But they don't see that what they're getting their jollies with right now is in the same category. It will in principle have the same effect down the line. Anyway, I'm putting into the proceedings of the second workshop a list of things to avoid doing if you're working on computers.

Omni: But some of the very same virus panelists *defended* the rights of computer viruses to exist. What do you make of that?

Langton: I just can't dismiss those claims out of hand. But I'm also not going to run right out and protect the rights of computer viruses. We all murder life every day, all the time: We cut the grass, swat flies, poison ants. I don't poison ants so much anymore, now that I have a better appreciation for ant colonies, but I'm trapping mice in my house right now—they're eating me out of house and home.

The closer life is to us, the more rights we give it. It's a very anthropocentric, chauvinistic view. Only if it's like us does it have a right to life, otherwise we get to decide individually whether it lives or dies. Seems to me most people will consider computer-based life as pretty far away from us. But it's worth addressing philosophically: What are the moral rights of a process versus a kind of material? If we had a simulated human being in a computer that otherwise behaved and acted like you or me, would it have a right to electricity? Could we pull the plug?

Omni: So then, aren't you artificial life guys playing God?

Langton: [Long pause] Well, yeah, in a way. I have to admit it. In fact, someone once said to me, "Congratulations, I'm keeping track of gods, and you have joined the club. You're an official god in the club of gods because you have created a universe—one that exhibits interesting behaviors." But what does that mean, "playing God"? You can in some sense call artificial life "experimental theology." If you create certain sorts of universes, there's no way in hell—if I can use the phrase—you could know in advance what's going to come out of that universe. Dave Ackley [Bellcore] found this out after he'd gotten a set of some pretty sophisticated critters to evolve in his evolutionary model. When he figured out what he thought the fittest ones were doing, he decided to engineer something even better. And when he stuck his new, "improved" genotypes in there, they immediately just got eaten up by the other ones. What he hadn't taken into account were the ecological interactions among the creatures.

It's difficult to overestimate the interrelationships of things that evolve in each other's presence. Subtle dependencies you weren't aware of are always there. This is why when you perturb any part of an ecological situation, it's difficult to predict the ultimate effect.

Omni: Do you ever worry that you're interfering with the natural order of things? Gaining forbidden knowledge?

Langton: What? This notion of artificial, in the sense of made by humans instead of nature, is a funny concept. Why do we degrade things we make by calling them artificial, as opposed to natural? We're part of nature, and what we do is part of nature. But we're not blind watchmakers, we're seeing watchmakers. Nature is not to be held responsible because there is no conscious entity capable of foreseeing consequences. We, however, *are* responsible for consciously, actively taking care to be sure we understand the consequences of building these things.

Omni: Are you skeptical that evolution is the only mechanism to account for the complexity of humans and biological organisms in general?

Langton: I wouldn't say I'm skeptical.

> "If we had a simulated human being in a computer that otherwise behaved like you or me, would it have a right to electricity? Could we pull the plug?"

There's much to evolution we haven't understood yet. Evolution is such a powerful, simple theory, it's just got to be right. But one thing we're learning from nonlinear dynamics is that evolution did not have to discover, painstakingly, all the components of some complex organismic structure of behavior. Aggregates of things interacting in nonlinear ways make for a situation pregnant with emergent dynamic possibilities. Nature's just going to be tripping over these possibilities right and left.

Like a kid in a candy store, nature probably has had a surfeit of possibilities to choose from rather than a difficult time working this, that, and the other things out. Evolution works with whole aggregates, large populations. Having variants on the plan—even identical things—in cooperation with each other generates zillions of different patterns of activity to select from.

Omni: When successful, will artificial life supplant natural life?

Langton: That depends on whether we decide to release living, evolving, autonomous machines with rights to existence into the biosphere. Right now to some extent we're populating the biosphere with all kinds of "unnatural" things: computers, robots, robot elevators, and trains. But trying to speculate about the future of artificial life is like trying to speculate about evolution. We'll design some initial things ourselves, but if artificial life really gets going, it's only logical to turn over the design process to evolution itself. Genuinely autonomous artificial life forms should have the capacity to evolve. And with that, they could give rise to intelligent, rational beings. They could give rise to *us*, implemented in a different hardware, or to *anything else*! I fully expect that they would.

Future life will probably involve symbiotic relationships between autonomous machinery, autonomous people, autonomous plants existing together in self-contained capsules. Analogs of the original protocells, these habitats will reproduce themselves as they spread through space.

Omni: The human-machine entity will be analogous to an individual cell?

Langton: Yes. That's how it happened in the past. Collections of molecules formed cells; a collection of cells formed more complicated cells; a collection of these more complicated cells formed multicellular organisms. When evolution takes a really big step, it's this jump from a collection of individuals at one level forming a single individual at the next level.

Omni: Let me ask again: What is the meaning of "artificial life"?

Langton: The larger meaning is that we can no longer point to ourselves and say, "We are alive, and those things aren't." Artificial life doesn't bring life down to the washing machine, the printing press, and car level. It doesn't degrade life; it upgrades machinery to our level. I now have a greater appreciation for the potential of machinery. I think machines can achieve the same state of this qualitative thing we call life. We can no longer consider ourselves special. Life is a property anything can have if it's organized correctly.

Omni: Why is there only one type of life on Earth: carbon-based life?

Langton: I'm not convinced it is the only kind of life. IBM, in some sense, is alive. Sociocultural institutions, in a way, constitute organisms in and of themselves. The conditions for life to emerge may be coming up all the time, all over the planet, but they just get eaten up by carbon-based life forms. That's the big advantage of being first on the scene: You get to wipe out the things that come after you.