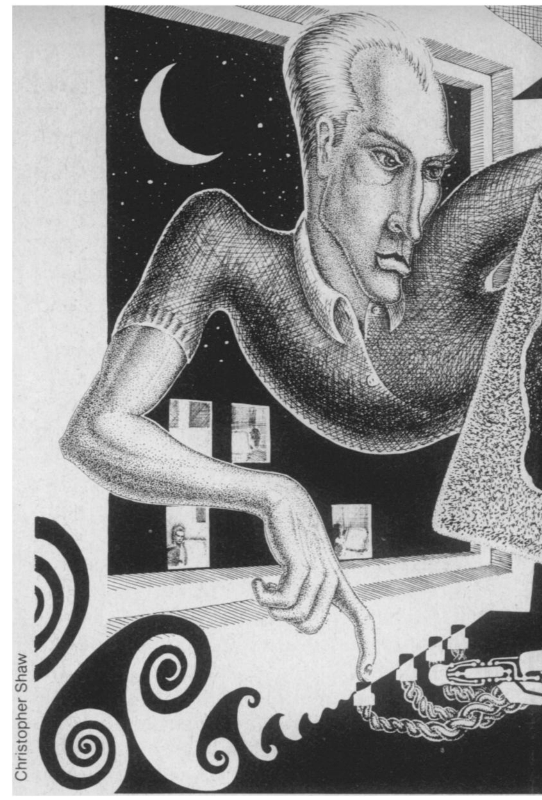
Inventing Life

To explore life-as-we-know-it, scientists simulate life-as-it-could-be



By IVAN AMATO

"We are not the end product of evolution," insisted computer scientist Christopher Langton at a gathering of several hundred scientists who didn't seem to need much reminding. They had just spent five days at the Second Artificial Life Conference in Santa Fe, N.M., exchanging reports of the viruses, proteins, cells, worms, mosquitoes, ants, crayfish, trees, ecosystems and other lifelike phenomena that have emerged, developed, foraged, competed, reproduced, mutated and evolved entirely within computers, test tubes or robots.

Many researchers in the fledgling field of artificial life (AL) see their lab-made and computer-dwelling creations as an encouraging first step toward the sublime feat of creating life itself, an achievement long attributed exclusively to divinity or primordial evolution. The day approaches, they suggest, when human beings will invent living things—artificial beings almost certainly unlike you and me, but alive all the same.

And at each step along the way, AL investigators will develop powerful tools for uncovering the complex dynamics underlying biological forms and functions, says Langton, who pursues his studies at the Los Alamos (N.M.) National Laboratory. By synthesizing lifelike behaviors within computers, chemical mixtures and other media, these pioneering scientists hope to provide a wide range of artificial biological phenomena that will broaden the empirical base of traditional biology — the Earth's living kingdom. Placing life-as-we-know-it within the larger context of life-as-it-could-be should extend biologists' ability to perceive how members of the natural living kingdom develop their physical shapes, respond to different environmental challenges, and evolve, Langton says.

But are these people seriously talking about someday making artificial *life* — the kind of laboratory progeny that might grow up, sustain itself, replicate and even evolve?

They are indeed.

"Within the next century," predicts physicist J. Doyne Farmer, "we will likely witness the introduction on Earth of living organisms originally designed in large part by humans, but with the capability to reproduce and evolve just as natural organisms do."

Farmer is exploring that prospect at the Santa Fe Institute, a scientific center that nurtures a multidisciplinary approach to studying complex systems such as life, weather, economics and geopolitical dynamics. He organized the February meeting with Langton, biologist Charles Taylor of the University of California, Los Angeles, and Steen Rasmussen, a Danish complex-systems theorist also working at the Santa Fe Institute.

"This is an end of one era of evolution," Langton suggested in his closing remarks at the conference. In the coming era, as he envisions it, artificial life forms will become increasingly important parts of an enlarged and redefined biosphere and will play roles in ever more facets of human life. Natural and artificial life will have to cooperate and develop symbiotic relationships with each other as they together develop a new human-machine culture, Langton says. It's only natural, he contends; change has always been nature's way.

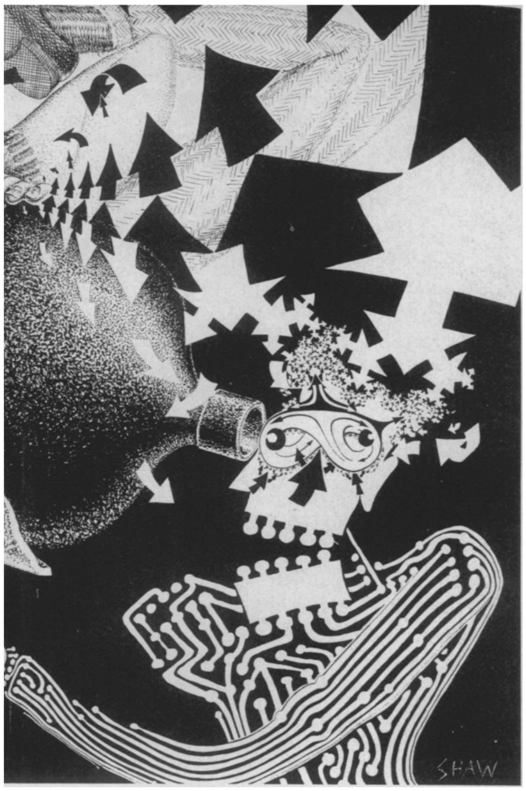
That may sound like cold comfort to many people, but Langton and Farmer assert that the genesis of artificial life is inevitable and that scientists therefore ought to think seriously about it now.

Hence the workshops. At the the First Artificial Life Conference, held in September 1987, participants began to outline the essential theoretical and practical challenges to creating lifelike systems and artificial life itself. A third conference is slated for the summer of 1992.

Some AL investigators speculate that artificial life may already exist. During the last few years, they note, electronic "viruses" and other cybernetic "bugs" designed by computer vandals have infected computer networks, perpetrating electronic mischief ranging from intermittent typographic graffiti to obliteration of sensitive data. These human-generated phenomena show hints of some remarkably lifelike properties, according to several researchers.

One type of "virus," for instance, consists of a small set of instructions that attaches to an existing program and then attempts to reproduce until the machine's memory is packed with copies, notes computer scientist Eugene Spafford of Purdue University in West Lafayette, Ind.

Another kind, more accurately called a "worm," enters computers through communications lines and then issues its own commands. These self-contained and highly contagious invaders can worm their way into still other computer pro-



Artist's interpretation of the collective message of the Second Artificial Life Conference.

grams, commandeering them, replicating and even manipulating the host computer into sending equally virulent copies to other computers on a network, clogging the systems into sluggishness or inaction.

Spafford also describes a pair of "bugs" that "mate" within certain computers to yield a new infectious agent that differs from its predecessors.

But are computer viruses *alive?*

"Almost," Farmer says. "Although computer viruses are not fully alive, they embody many of the characteristics of life. It is not hard to imagine computer viruses of the future that will be just as alive as biological viruses."

On the other hand, biologists don't even know whether *natural* viruses should be considered minimalist members of the living kingdom or miraculous machines of the molecular menagerie. So for now, the question of whether computer viruses are alive remains in remission.

What, then, do AL researchers mean when they talk about "life"? At what point would a computer virus of the future — existing as magnetic patterns on a floppy disk or as patterns of electronic activity within computer circuitry — truly qualify as a life form? And how could a flask of self-replicating polymers — another candidate for artificial life — be considered just as alive as the biochemical activity whirring inside biological cells?

"None of us quite knows what 'artificial life' means," admits theoretical biologist Stuart Kauffman of the Santa Fe Institute. But he adds that natural life has remained undefined for centuries without preventing biologists from discovering important secrets about it virtually every day.

Langton stresses that the products of AL research need not actually be alive to prove useful for studies of biological systems. All the same, the lack of a widely accepted working definition of artificial life, or at least some criteria for assessing whether a creation is living or nonliving, lands AL scientists in a philosophical swamp. How would they recognize life it it should appear?

AL researchers wholeheartedly acknowledge the problem. Many at the Santa Fe meeting presented their own working definitions of life, which often included the ability to reproduce, to interact with an environment, and to evolve or develop more complexity as one generation gives way to the next.

Not surprisingly, each of their attempts to cage the meaning of life in a functional definition fell short. Some definitions were so broad that they included nonliving things, others so narrow that they excluded some living things. Moreover, such speculative delineations carry the risk of fooling researchers into thinking they really are creating life when the behavior of their creations merely fits an arbitrary definition of the term. Yet even flawed or incomplete definitions have an important place in this field, providing a framework that can help prevent AL investigations from becoming a mere high-tech amusement.

Physicist Norman Packard of the Santa Fe Institute suggests that scientists may never come up with a universally acceptable definition of life, leaving AL researchers ultimately dependent on intuition to judge whether their computer or laboratory creations are alive.

The grand hope of many AL investigators — to create new life forms — pivots on the validity of a central assumption: The condition of life is inherent in the organization and dynamic patterns of matter and energy, and its embodiment does not depend on any particular kind of matter, such as the carbon-based polymers characteristic of life-as-we-know-it. In theory, by using computers, interacting sets of chemicals or other media to embody the operating principles of biological life forms and the functional relationships among the parts of such organisms, people should be able to create artificial systems that behave as natural organisms do.

"The dynamics of such artificial systems would be just as real as the dynamics in natural living systems," Langton contends.

Indeed, several projects discussed and demonstrated at the February workshop seemed to support Langton's assertion. Using sophisticated computer simulations, some researchers showed how seemingly simple mathematical constraints can steer complex systems of particles — represented by colored dots on a computer monitor — to self-organize into discernible forms and behave in lifelike ways.

For example, Farmer, Kauffman and Richard Bagley of the Los Alamos National Laboratory outlined simulations in which protein-like molecules emerge in a simulated primordial soup (SN: 2/17/90, p.110). When the researchers alter the chemical rules by which these proteins cut and splice each other, the whole set of molecules either evolves so that it can replicate itself or veers into a decidedly unlifelike chaos.

On the hardware side of the simulation game, Tommaso Toffoli of the Massachusetts Institute of Technology in Cambridge reported designing a powerful new type of computer that he says should enable researchers to simulate living matter — such as evolving assemblages of cells — with unprecedented detail (SN: 2/17/90, p.103).

Many speakers showed off computer programs that mimic the individual and collective behavior of ants, mosquitoes, bees, bacteria, crayfish, plants and nerve cells. A number of these simulations undergo changes in which structures and behaviors of the "cells" or "creatures" — or even real color patterns on the computer monitor — become more complex, ordered or seemingly purposeful as a vastly accelerated form of evolution unfolds within the computer circuitry.

Robert Collins of the University of California, Los Angeles, demonstrated a simulation called ArtAnt, in which colonies of ant-like organisms live, compete and evolve over hundreds of generations within a common environment. Collins, a computer scientist, has simulated hundreds of thousands of ants that can sense and carry food and even leave their own "scent trails" to help fellow colonists find a food source. Successful colonies are those whose members bring back the most food.

Each ant has a simulated chromosome — a string of 10,000 or so bits — which governs how the ant responds to sensory input. The simulated chromosomes can undergo recombination or mutation, leading to offspring that respond more or less adaptively within the environment. During simulation runs, which take place in a state-of-the-art parallel computer called the Connection Machine and are displayed on a color monitor, successive generations in some colonies develop maladaptive behaviors such as wandering into the nests of other colonies. Others become better and better foragers.

The collective behavior appears only vaguely lifelike and looks very much like a computer game display. Nonetheless, this type of simulation reflects one of the most anticipated applications of AL research. Whether or not scientists ever create actual life forms, highly detailed simulations based on factual data acquired in the lab and field would allow biologists to study complex plant and animal behavior as if it were occurring in the wild – but with total control over weather, food availability and other environmental variables that affect the organisms' survival and reproduction rates.

Atmospheric scientists already wield such control in simulations that enable them to create hundreds of possible atmospheric futures, which unfold according to the global climate conditions the scientists stipulate (SN: 5/5/90, p.280). For an increasing number of researchers in a variety of disciplines, such powerful simulations offer a third scientific strategy – called experimental mathematics by some – lying somewhere between experimentation and theorizing.

Though computer studies dominate today's AL research, they do not hold a monopoly. At the conference, biochemist Gerald F. Joyce of the Research Institute of Scripps Clinic in La Jolla, Calif., described an example of artificial evolution involving a carefully assembled set of chemical reactions. He reported using chemical "selection pressures" to coax an actual ribozyme – a segment of catalytic RNA that cuts itself out of a longer RNA molecule – to evolve into a form that cuts DNA molecules instead. A paper on the work appears in the March 29 SCIENCE.

"Real artificial life" is how Rodney Brooks describes the robots he and Pattie Maes have developed at MIT. Brooks sees these creations as "robot beings that live in the world, have agendas and ongoing projects." One human-sized robot, called The Collection Machine, goes around the labs locating, picking up and disposing of 12-ounce beverage cans. Another, called The Confection Machine, tries to sell candy to people and uses the money to get nearby creatures – i.e., humans – to do things for it that it cannot do on its own, such as opening doors.

A smaller, six-legged robot, which Brooks says may serve as a prototype for an autonomous land rover on Mars, learns how to negotiate over and around objects in its path. Brooks and his coworkers have also have built a matchbox-sized robotic cockroach that avoids light and sound. As scientists learn how to make ever-tinier mechanisms, even armies of gnat-sized robots will become possible, Brooks says.

In opening the conference, Langton asked for a show of hands from non-carbon-based attendees; nothing nonhuman responded. Every computer simulation, robot or chemical brew unveiled in the week-long show-and-tell remains squarely within the realm of the nonliving.

Yet despite the absence of *bona fide* artificial life, Langton and Farmer argue that AL researchers have already begun to blur the distinction between natural and artificial organisms.

"Artificial life will flourish and go beyond anything we can imagine right now," Farmer predicted in his closing remarks. That prospect provides all the more reason, he and others warn, for investigators to work ethically and responsibly in order to prevent exploitation of AL research as an instrument of ill will.

The time may come, Langston muses, when computer-dwelling artificial creatures will become curious about their origin and will discover that the human creatures peering at them through the other side of the monitor had something to do with it. □