DOUBLE MAP SUPPLEMENT: THE ROMAN EMPIRE

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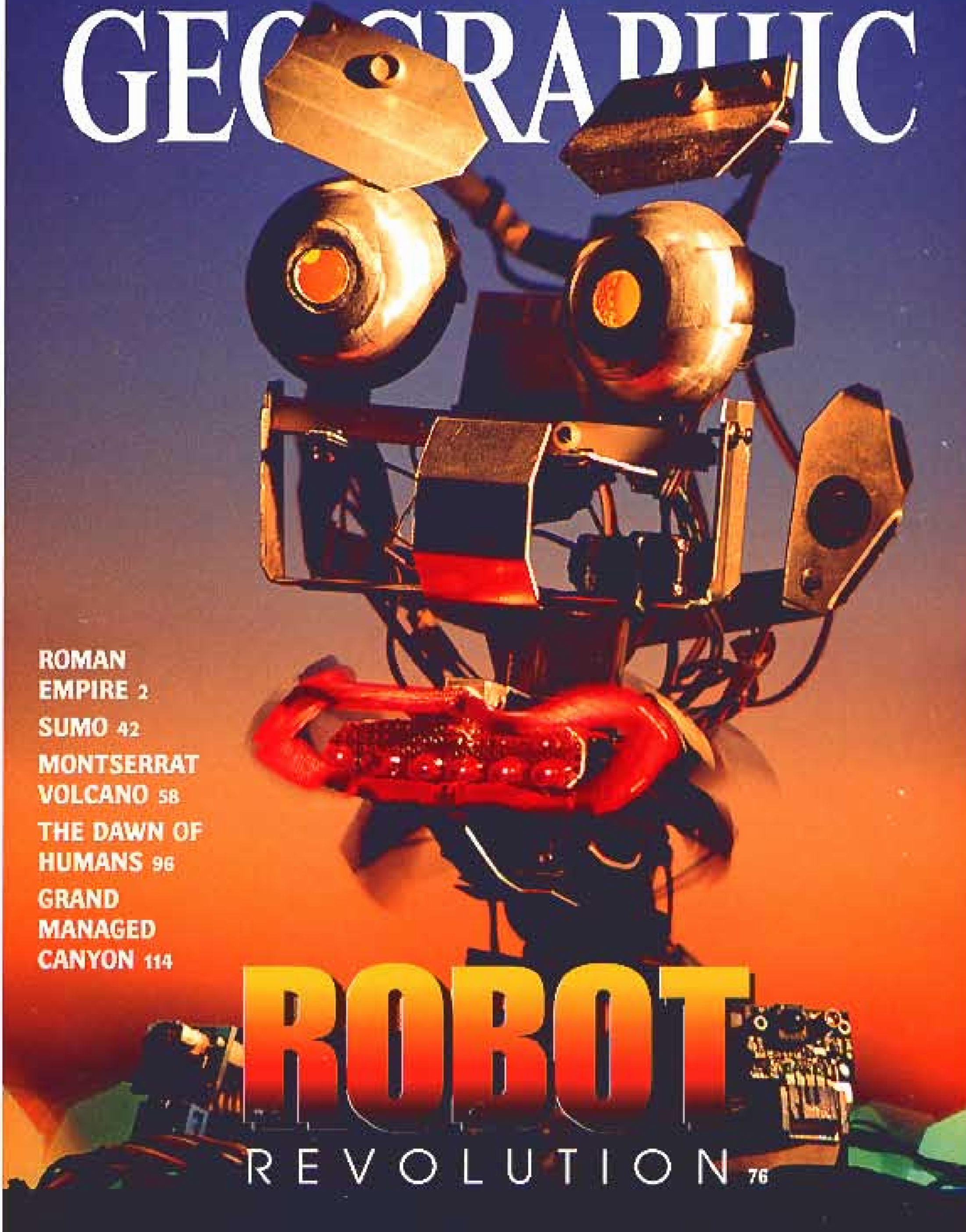

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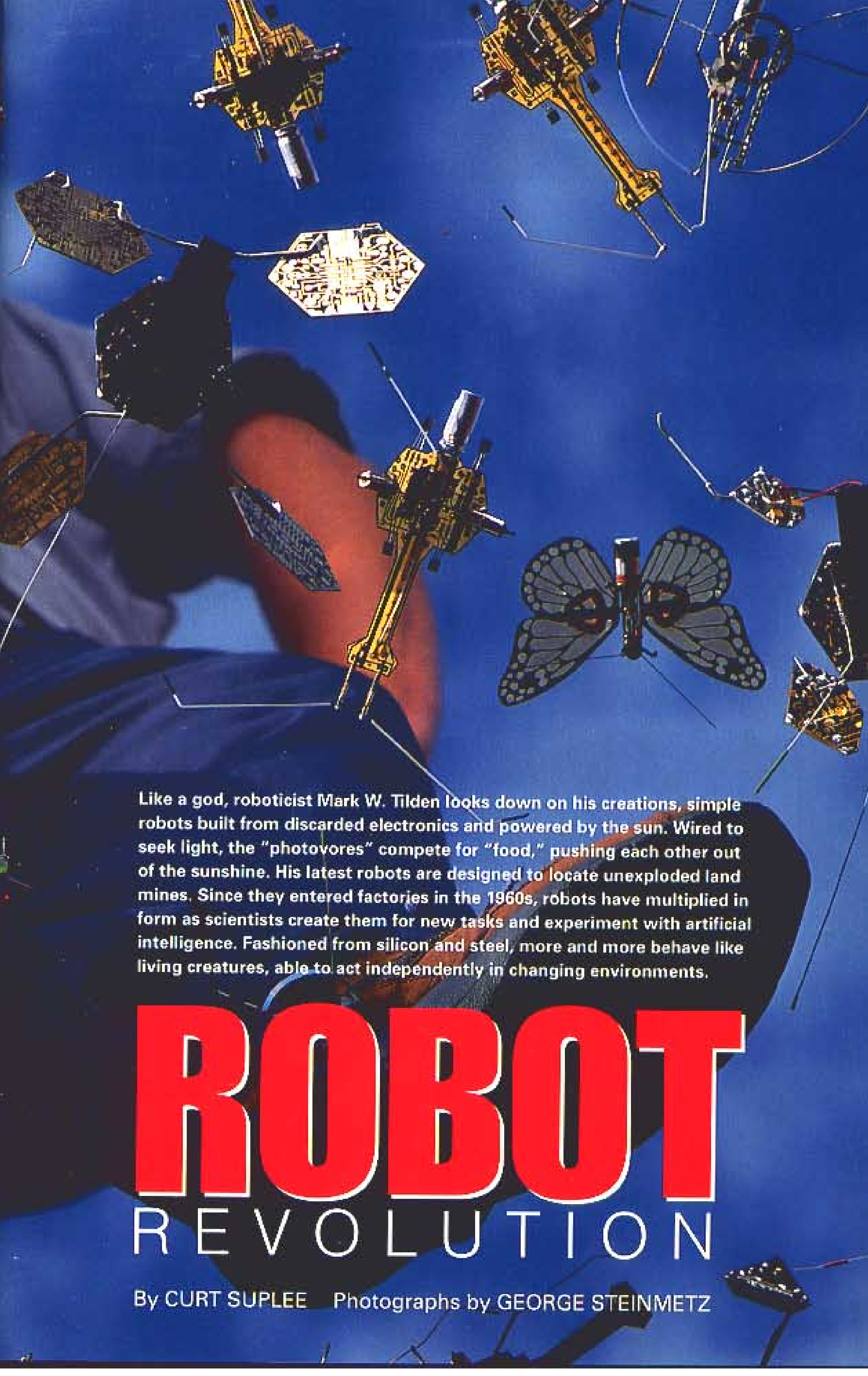


Like a god, roboticist Mark W. Tilden looks down on his creations, simple robots built from discarded electronics and powered by the sun. Wired to seek light, the "photovores" compete for "food," pushing each other out of the sunshine. His latest robots are designed to locate unexploded land mines. Since they entered factories in the 1960s, robots have multiplied in form as scientists create them for new tasks and experiment with artificial intelligence. Fashioned from silicon and steel, more and more behave like living creatures, able to act independently in changing environments.

ROBOT REVOLUTION

By CURT SUPLEE   Photographs by GEORGE STEINMETZ

Ping Faces Pong

Obedient to its operator, a master-slave robot in a Salt Lake City warehouse draws back its paddle in tandem with engineer Jon Price, whose motions are measured by sensors and relayed via computer. SARCOS, Greek for "flesh," matches most human moves in speed and smoothness but depends on a human brain for direction. "We do things so easily," says Price. "We don't realize what's involved in getting a robot to do the same thing."


SARCOS
15-5301-05
EMPTY

Robo Docs

Off the factory floor and into the operating theater, a modified industrial robot hangs poised over an obliging skeleton in Pittsburgh's Shadyside Hospital. During hip replacement surgery, ROBODOC drills a cavity in the femur (held by steel brace) so that the doctor can precisely fit an implant into the bone.

Flanked by a nurse and engineers, Dr. Anthony DiGioia uses another system, HipNav, to display the exact position of the pelvis and a plastic cup onto a screen so he can accurately place the cup into the socket. Experts predict that within ten years such technology will enter most hospitals.

Since the dawn of human ingenuity, people have devised ever more cunning tools to cope with work that is dangerous, boring, onerous, or just plain nasty. That compulsion has culminated in robotics—the science of conferring various human capabilities on machines. And if scientists have yet to create the mechanical sidekick of science fiction, they have begun to come close.

As a result, the modern world is increasingly populated by quasi-intelligent gizmos whose presence we barely notice but whose creeping ubiquity has removed much human drudgery. Our factories hum to the rhythm of robot assembly arms. Our banking is done at automated teller terminals that thank us with rote politeness for the transaction. Our subway trains are controlled by tireless robo-drivers. Our mine shafts are dug by automated moles, and our nuclear accidents—such as those at Three Mile Island and Chornobyl—are cleaned up by robotic muckers fit to withstand radiation.

PHOTOFEST

Endowed with ESP, Hollywood's 1954 Tobor ("robot" backward) attacked hostile humans and defended friends.

Programmed to react to movement, sound, and light, IT (opposite) mimics emotions: Here it smiles because people are nearby. Rodney Brooks, whose firm built IT, calls this "behavior-based intelligence."

Such is the scope of uses envisioned by Karel Čapek, the Czech playwright who coined the term "robot" in 1920 (the word *robota* means "forced labor" in Czech).

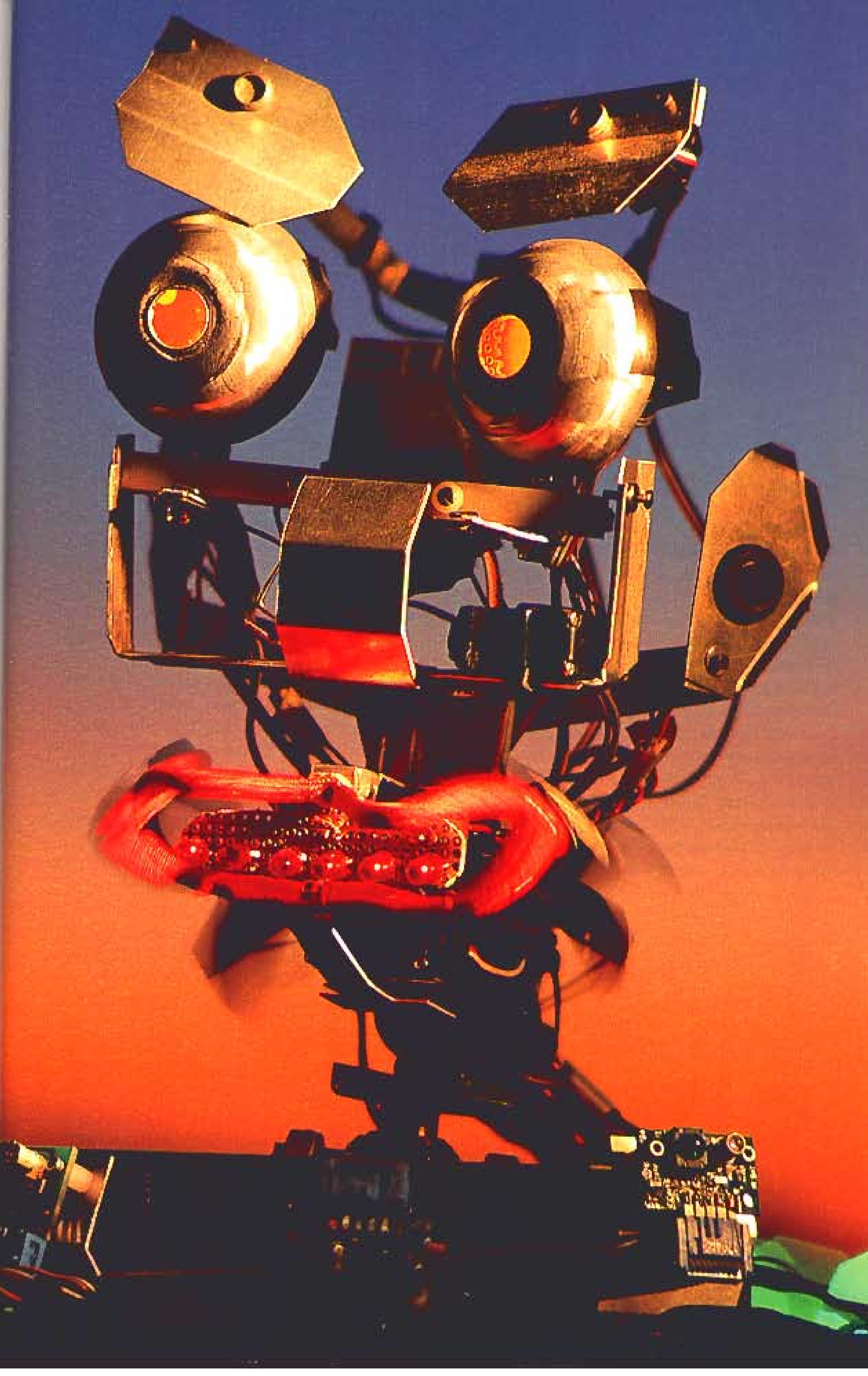
As progress accelerates, the experimental becomes the exploitable at record pace. This summer, about the time that NASA's autonomous Mars rover is to crawl across the red planet's surface, engineers will be testing a modified version of the technology on a down-to-earth chore: robots designed to mow 100 acres of alfalfa unattended. Solar-powered, self-steering lawn mowers are already for sale. The eventual demand for similar devices, says Dave Lavery, manager of a robotics program at NASA, could be four times as large as the present market for industrial robots—and there are some 650,000 of them at work worldwide.

Other innovations promise to extend the abilities of human operators. Thanks to the incessant miniaturization of electronics and micro-mechanics, there are already robot systems that can perform some kinds of brain and bone surgery with submillimeter accuracy—far greater precision than highly skilled physicians can achieve with their hands alone. At the same time, techniques of long-distance control will keep folks even farther from hazard: In 1994 a ten-foot-tall NASA robotic explorer called Dante, with video-camera eyes and eight spiderlike legs, scrambled over the menacing rim of an Alaska volcano while technicians 2,000 miles away in California watched the scene by satellite and controlled Dante's descent.

But if robots are to reach the next stage of laborsaving utility, they will have to operate with less human supervision and be able to make at least a few decisions for themselves—goals that pose a formidable challenge. "While we know how to tell a robot to handle a specific error," says Lavery, "we can't yet give a robot enough 'common sense' to reliably interact with a dynamic world." That's why we don't have robots like the fabulous androids of *Star Wars* and *Star Trek:* humanlike creatures that can play Mozart or marbles and outthink their inventors.

Indeed the quest for true artificial intelligence (AI) has produced very mixed results. Despite a spasm of initial optimism in the 1960s and '70s

CURT SUPLEE, a science writer for the *Washington Post,* is the author of the Society's book *Everyday Science Explained.* GEORGE STEINMETZ, a frequent contributor, won a World Press award for his science photography.



Hovering above a mock town, CYPHER displays its surveillance capabilities at Fort Benning, Georgia. The robotic helicopter, developed by Sikorsky for military use, can take off, fly, and land by itself. An operator need only use a mouse to mark CYPHER's destination on a computer screen. One of a new breed of autonomous fliers, CYPHER, six feet in diameter, is smart enough to track a person and strong enough to carry a 50-pound load to a drop point 30 miles away.

when it appeared that transistor circuits and microprocessors might be able to replicate the action of the human brain by the year 2000, researchers lately have begun to extend that forecast by decades if not centuries.

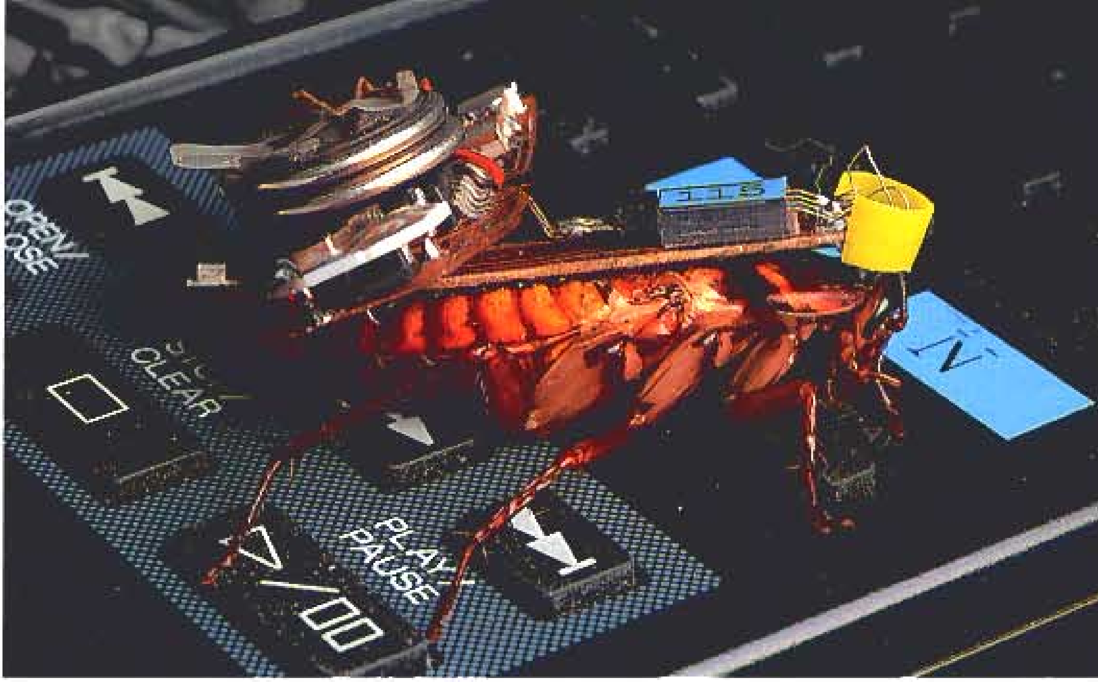
What they found, in attempting to model thought, is that the human brain's roughly one hundred billion neurons are much more talented—and human perception far more complicated—than previously imagined. They have built robots that can recognize the misalignment of a machine panel by a fraction of a millimeter in a controlled factory environment. But the human mind can glimpse a rapidly changing scene and immediately disregard the 98 percent that is irrelevant, instantaneously focusing on the woodchuck at the side of a winding forest road or the single suspicious face in a tumultuous crowd. The most advanced computer systems on Earth can't approach that kind of ability, and neuroscientists still don't know quite how we do it.

"The hallmark of an intelligent robot," says Chuck Thorpe of Carnegie Mellon University's celebrated Robotics Institute, "is the sense-think-act cycle—and the 'sense' part is the most difficult."

It is in ambiguous circumstances that the human mind excels. And the paramount problem for AI is to model the way the brain holds a representation of the external world and modifies it on the fly to accommodate changing circumstances and shifting context. So far, however, the most avant-garde laboratories can't begin to get a robot to do what a 12-month-old infant does automatically—teach itself to balance, walk erect, and instantly tell the difference between a dark shadow and a hole in the floor.

Nonetheless, as information theorists, neuroscientists, and computer experts pool their talents, they are finding ways to get some lifelike intelligence from robots. One method renounces the linear, logical structure of conventional electronic circuits in favor of the messy, ad hoc arrangement of a real brain's neurons. These "neural networks" do not have to be programmed. They can "teach" themselves by a system of feedback signals that reinforce electrical pathways that produced correct responses and, conversely, wipe out connections that produced errors. Eventually the net wires itself into a system that can pronounce certain words or distinguish certain shapes.

In other areas researchers are struggling to fashion a more natural



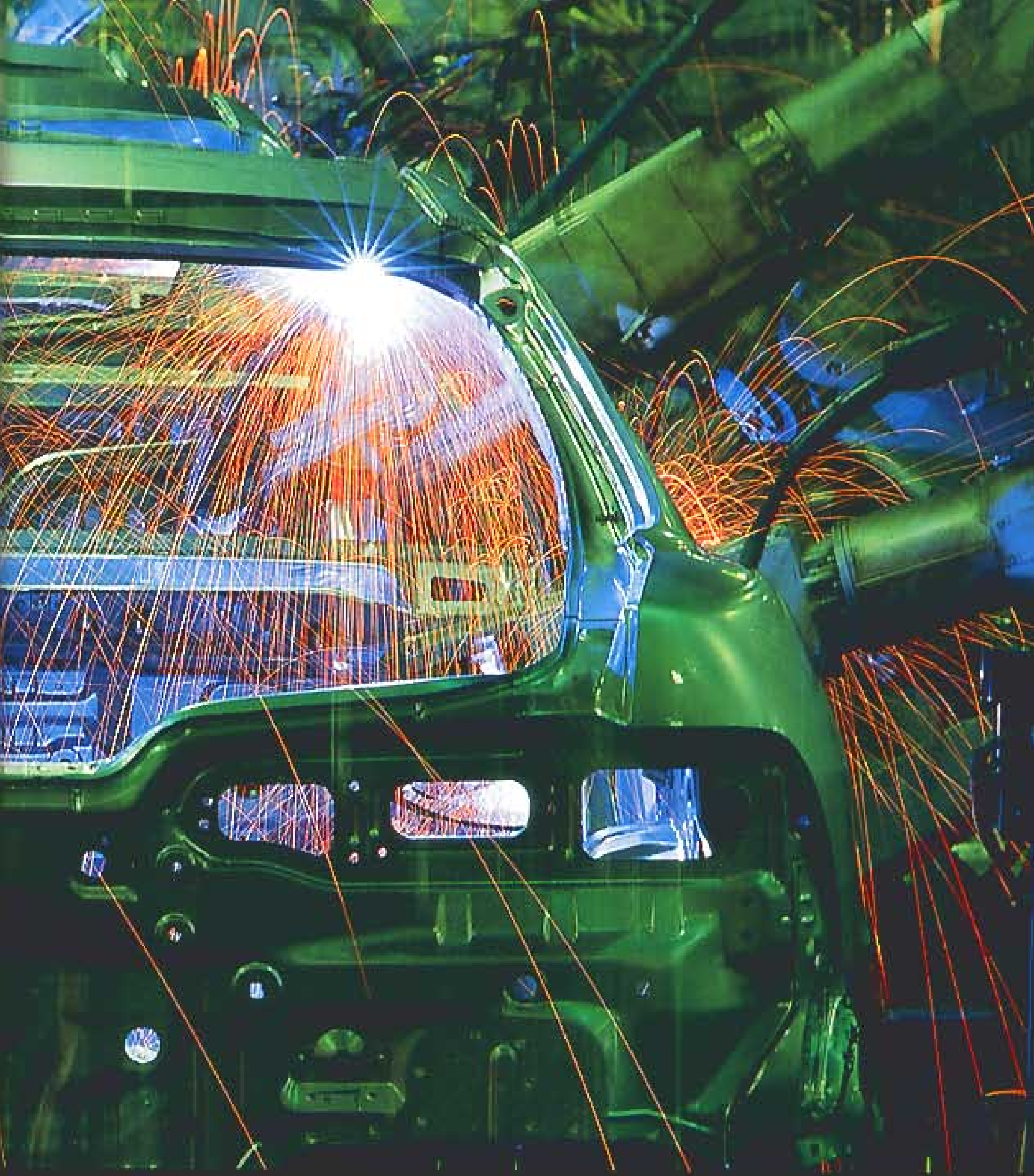
Fitted with a backpack microprocessor, a cockroach in Isao Shimoyama's lab at the University of Tokyo is ready to receive remote-control signals that will stimulate its nervous system, setting its legs in motion. Such "biobots" may someday help researchers understand how insects move, says biologist Robert Full of the University of California, Berkeley, where scientists are working to give robots with legs the same speed, stability, and grace.

relationship between people and robots in the expectation that someday machines will take on some tasks now done by humans in, say, nursing homes. This is particularly important in Japan, where the percentage of elderly citizens is rapidly increasing. So experimenters at the Science University of Tokyo have created a "face robot"—a life-size, soft plastic model of a female head with a video camera imbedded in the left eye—as a prototype.

The researchers' goal is to create robots that people feel comfortable around. They are concentrating on the face because they believe facial expressions are the most important way to transfer emotional messages. We read those messages by interpreting expressions to decide whether a person is happy, frightened, angry, or nervous. Thus the Japanese robot is designed to detect emotions in the person it's "looking at" by sensing changes in the spatial arrangement of the person's eyes, nose, eyebrows, and mouth. It compares those configurations with a database of standard facial expressions and guesses the emotion. The robot then uses an ensemble of tiny pressure pads to adjust its plastic face into an appropriate emotional response.

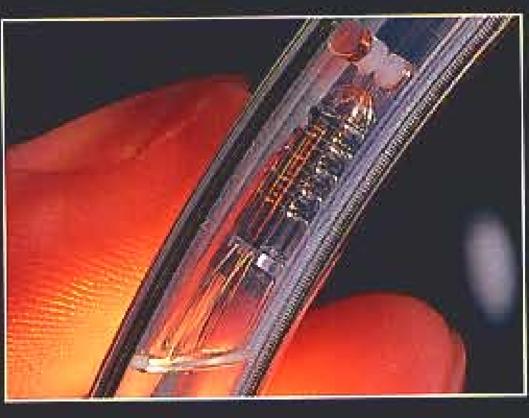
Other labs are taking a different approach, one that doesn't try to mimic human intelligence or emotions. Just as computer design has moved away from one central mainframe in favor of myriad individual workstations—and single processors have been replaced by arrays of smaller units that break a big problem into parts that are solved simultaneously—many experts are now investigating whether swarms of semi-smart robots can generate a collective intelligence that is greater than the sum of its parts. That's what beehives and ant colonies do, and several teams are betting that legions of minicritters working together like an ant colony could be sent to explore the climate of planets or to inspect pipes in dangerous industrial situations.

After a decade of setbacks AI enthusiasts are again growing optimistic. Though they are still a long way from replicating the complexity of the human psyche, few theorists now claim that machine intelligence is impossible. Meanwhile, the invention of less exotic devices is exploding in such profusion that scientists are having greater trouble defining the term "robot." Whatever form robotics eventually takes, we'll surely be living with ever smarter tools and toys in the century to come.

Driving Forces

Sparks shower a Honda assembly line as robotic arms weld auto bodies in Japan, the self-styled "robot kingdom." Quick to embrace industrial robots, Japanese companies became the world's leading manufacturers and consumers, harnessing automation to raise productivity and quality. To keep up, car companies around the globe installed robots, replacing some workers. Using a video camera for eyes, Navlab 5 (left) steers a van through a Pittsburgh tunnel at 60 mph, leaving Carnegie Mellon researcher Dean Pomerleau with free hands. Soon scientists will demonstrate a highway system featuring robotic cars that within 20 years could do all the driving.



Creepy Crawlers

Clinging to a sphere, a "spider" robot uses 16 legs to clamber over a gas tank in Tokyo, checking for cracks. Like their animal models, robots vary in size and shape as scientists adapt them to specialized niches.

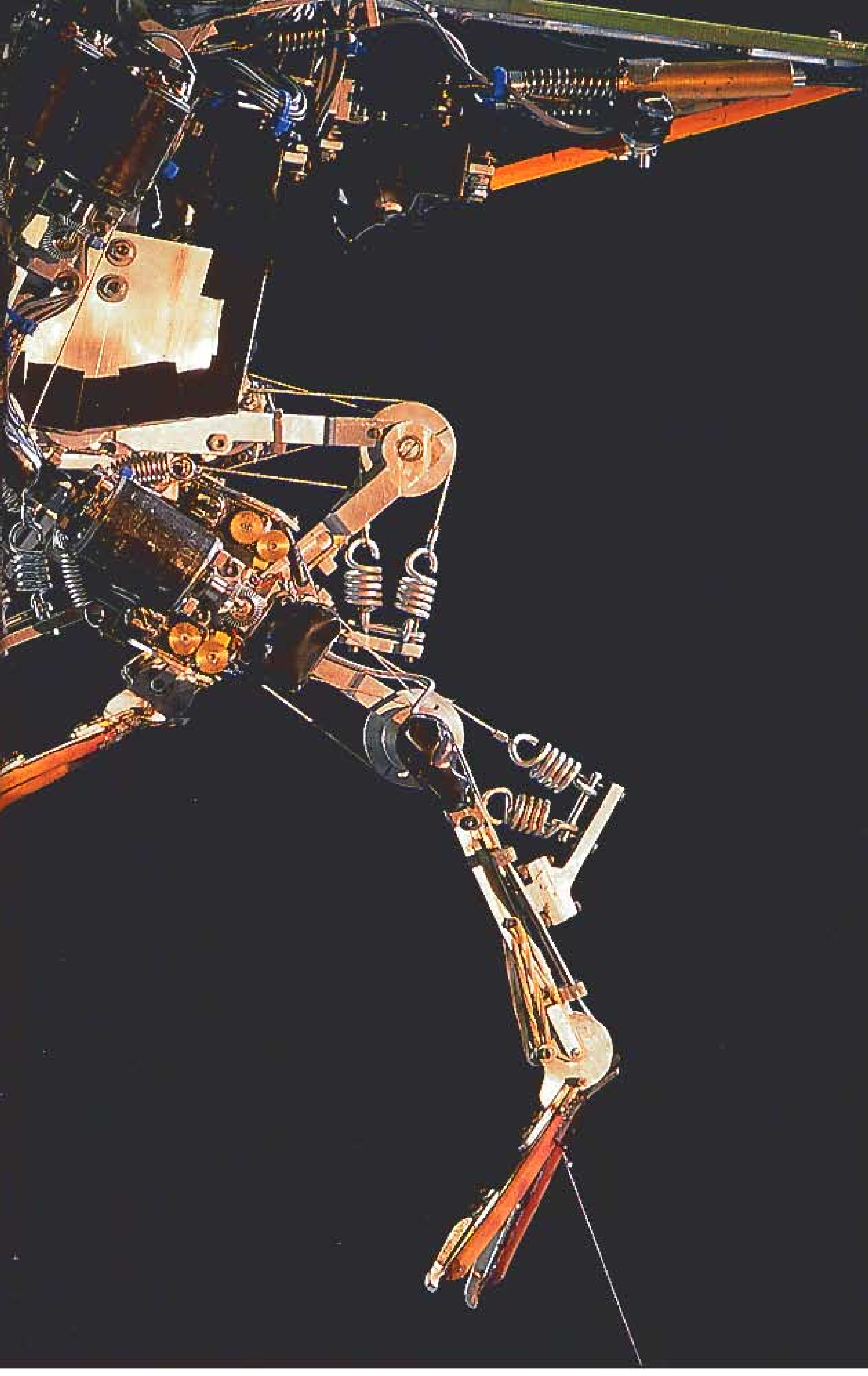
Experimental solar-powered "ladybugs" (top left), developed by Sanyo, use light-sensing eyes to turn toward the sun. A DENSO inspection robot (bottom left) contracts and expands like an inchworm, using minimal power to move through a tube.

As factories make smaller and smaller electronics, robots will shrink further, says DENSO researcher Nobuaki Kawahara, who says the future lies in micromachines.

Dynamic Dinosaurs

Frozen in flight, "Troody," a replica of a *Troodon,* balances between steps. Sixteen miniaturized motors—the equivalent of muscles—propel her forward. A series of springs adjusts to shifts of weight and speed as she mimics the quickness and agility of a real dinosaur. Wheeled robots are easier to build but limited in mobility, says Troody's creator, Peter Dilworth of the MIT Leg Lab. "The world is a complicated, three-dimensional place," he explains.

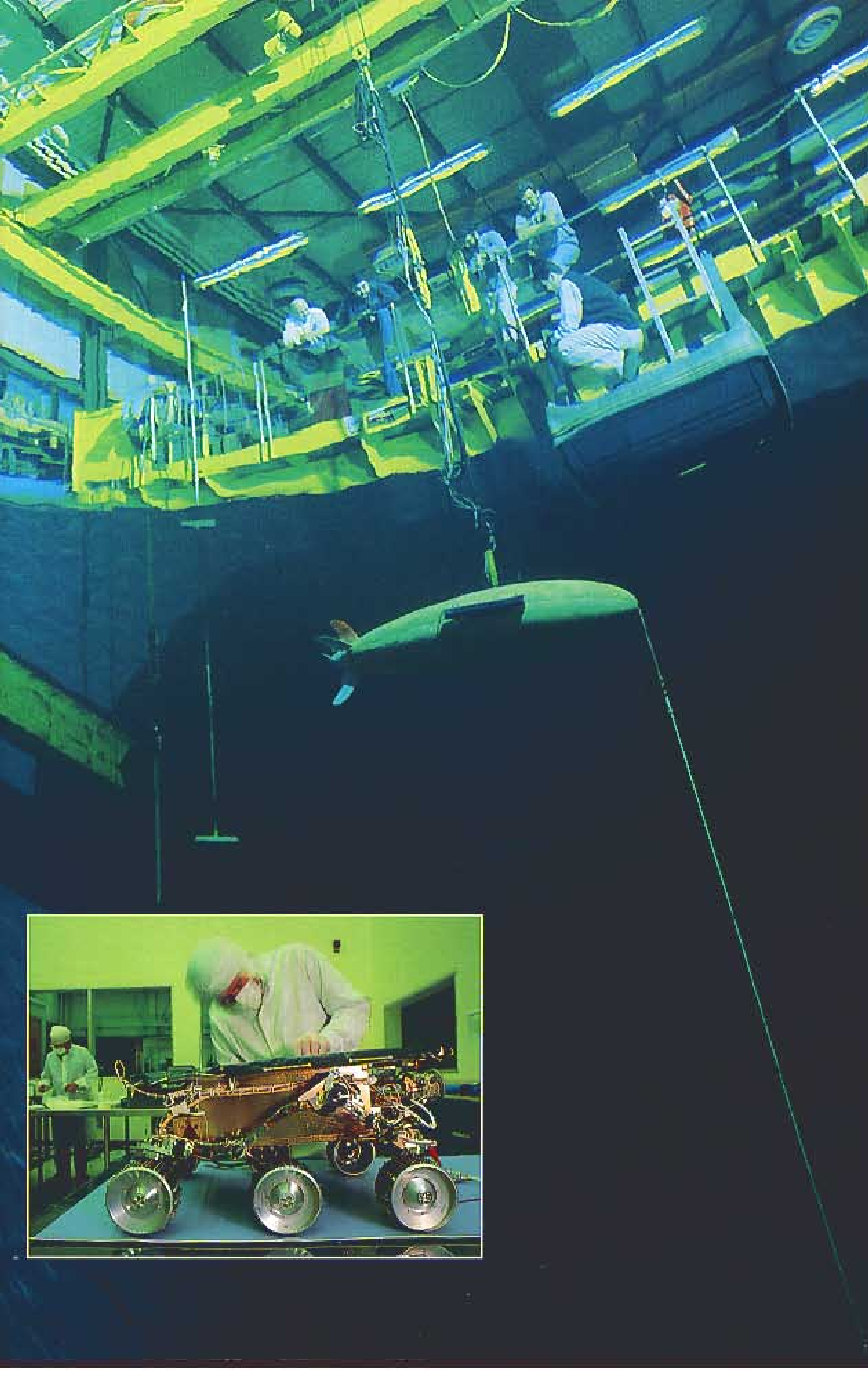
Strapped in a telemetry suit, puppeteer Barry Crane (below) prepares to guide the arms of a *Tyrannosaurus rex* about to chase the heroes of Steven Spielberg's *The Lost World* into a waterfall. Crane and five others from Stan Winston Studio controlled the face, head, neck, limbs, and torso of the nine-ton beast, transforming a master-slave robot into a movie character.



Sea and Space

Solo submersible, an Odyssey IIb hangs suspended in a Newport, Rhode Island, acoustic test tank several months after mapping tidal mixing off Vancouver Island. Unlike other unmanned underwater vehicles, the Odyssey IIb is tetherless, making it cheaper, faster, easier, and safer to operate, especially in deep or icy waters. MIT Sea Grant researchers envision networks of such robots, equipped with onboard intelligence, roaming the ocean to gather data for relay to scientists on shore.

A six-foot-long prototype lunar rover (below right) parks on a slag heap where Carnegie Mellon researchers check its ability to guide itself over rough terrain. Plans call for Earthbound "tourists" to steer the rover once it reaches the moon. The vehicle is smart enough to ignore bad drivers. The Sojourner microrover (far right) undergoes final preparations at the Jet Propulsion Laboratory in Pasadena. Sojourner, scheduled to land on Mars on July 4, was built to gather information on soils and rocks. In touch with Earth just once a day, the rover, capable of covering 46 feet a day, will pick its own course, driven by tiny solar-powered motors.



Future Shocked

Arcing from a Tesla coil, 1.8 million volts shoots through a Christmas tree, down a cage holding physicist Austin Richards, and into the floor of artist Christian Ristow's San Francisco warehouse. Later in this performance a claw destroyed the tree. "There's a certain thrill in viewing raw power unleashed," Ristow says. "There's something shocking about a machine that appears alive."

Some futurists speculate that robots may one day replace humans as Earth's dominant creatures. Nikola Tesla, who invented radio-controlled machines as well as the coil, foresaw the impact in 1919. "Teleautomata will be ultimately produced," he wrote. "Their advent will create a revolution." □