late research programs to optimize human living and working conditions in extreme environments, on Earth and in space.

"We need to broaden the connections and open dialogues," says Bell, "if we are really committed to an international future on this world, and others."

—*Leonard David*

Rodney Brooks

Big Visions with Tiny Machines

Someday, tiny robots will be as commonplace as microprocessors and computers are today, thanks to the efforts of artificial intelligence guru Rodney Brooks. His tiny machines, however, will do more than just scurry around the living room dusting furniture and turning off lights. They might one day explore the surfaces of other planets, riding atop the winds of Mars or hopping across the landscape of the Moon.

Brooks, a professor at the Massachusetts Institute of Technology, has worked with robots and computers all his life. Pondering the design of a robot is one of his earliest memories, the 36-year-old scientist says. As a teen in Adelaide, Australia, Brooks created wheeled gadgets that would clunk around or just follow lights. "They were pretty crude, but it was all neat at the time. I had a lot of problems with power sources," he confides. "But now that I look back it all seems pretty easy. At the time, though, there was a lot I just couldn't fathom."

After receiving a master's degree in mathematics from Flinders University of South Australia, Brooks realized that artificial intelligence was his real calling. So, in 1977, he transferred to Stanford, where he earned his Ph.D. in 1981 and eventually ended up at MIT's presitigious artificial intelligence laboratory.

"I'm someone who is intrigued by two things," he says. "How do we think, meaning what makes us human? And how can I make the coolest, neatest toys to make life on Earth more fulfilling and interesting? That's what motivates me."

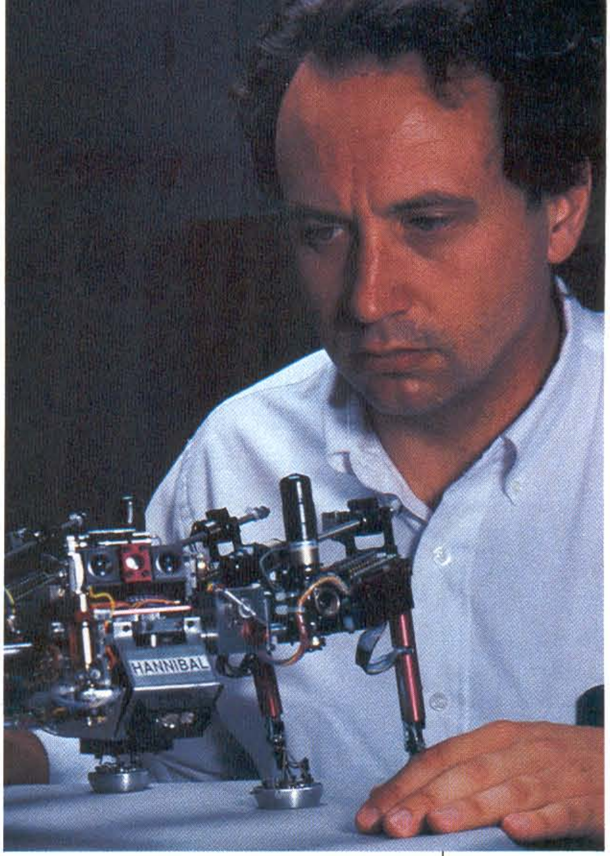
Brooks tackles problems in sometimes unconventional ways — hence his ingenious system, called "subsumption architecture," for instilling a sort of insect-like intelligence in his robots. Most researchers in artificial intelligence today strive to create a totally smart robot, one that mimics human intelligence using symbols and maps to interpret the environment. These robots then act on the information programmed into them. Brooks, on the other hand, programs his robots with basic instincts, such as "lift leg" or "move forward." The robot then decides the best course of action for each particular situation. "Attila," his latest robot, just *goes*—only worrying about obstacles when it encounters them. With no maps or instructions, the 3.6-ounce, six-legged robot feels at home anywhere, whether it is puttering around the house or exploring an alien landscape.

"These robots are amazingly versatile and complex," Brooks says. "People who want to make the machines totally smart end up with devices that don't do much. They get bogged down in their surroundings. I am interested in getting robots just to work in challenging environments and build capabilities to work with the environment."

The insect robots are ideally suited for planetary exploration. They are flexible and fairly cheap to make (certainly much cheaper than sending astronauts). Brooks envisions tiny robots carved out of a single piece of silicon — gears, instruments, and all. Robots of this sort could be tossed into the winds of Mars, traveling vast distances, but using very little energy.

"I can see having thousands of these critters all over a planet exploring for us," he says. "Now that's exciting."

—*John R. Williams*



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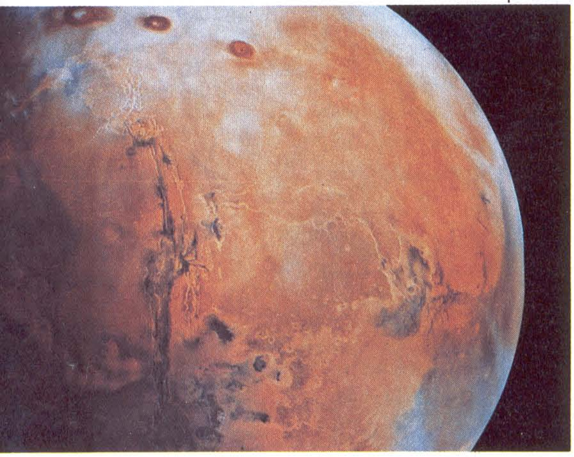
"I can see having thousands of these critters all over a planet exploring for us," says Rodney Brooks, pictured above with "Hannibal," one of his "insect robots."

NASA scientist Chris McKay's fascination with the red planet has taken him to the dry valleys of Antarctica—the most Mars-like place in the world.



CHRISTOPHER McKAY

Builder of Planets

In Edgar Rice Burroughs's "John Carter of Mars" series, huge, advanced industrial plants pumped oxygen into the atmosphere to make the planet livable. Today, terraforming Mars is within humankind's current capability, according to Christopher McKay. For over 100 years we have been using that same technology, unintentionally, to alter Earth's climate.

"The greening of Mars could take place without transporters, warp drive or photon torpedoes," says the atmospheric scientist and exobiologist at the NASA Ames Research Center in Moffett Field, California. "We wanted to look at terraforming in a serious way. It's more than just a science fiction concept."

Indeed, McKay's approach to terraforming Mars relies not on science fiction, but on science fact. Since the beginning of the Industrial Age, increased amounts of carbon dioxide and super-greenhouse gases, such as chlorofluorocarbons, have been introduced into our atmosphere. Some scientists and environmentalists argue that these gases are responsible for a warming trend that may lead to drastic changes in global weather patterns.

McKay's plan involves manufacturing huge amounts of chlorofluorocarbons, such as Halon, with material that exists on Mars. The gas could be spread into the thin atmosphere, where it would trap increased amounts of infrared radiation, thereby warming the planet.

As Mars heats up, carbon dioxide ice, which makes up much of the polar ice caps, should vaporize, adding gas that will further enhance the greenhouse effect. Later, when the temperature rises above freezing, water ice that makes up the remainder of the poles should melt. Carbon dioxide trapped in the frozen soil will also be released as the temperature rises. The result, if all goes well, will be a thicker, warmer carbon dioxide blanket. The entire process could take as long as 10,000 years.

At this point, with a temperature near freezing and an atmosphere about as thick as Earth's at an altitude of 20 miles, plants and microorganisms could be introduced. They would change the high carbon dioxide concentrations into oxygen, transforming Mars into a planet with a breathable atmosphere in 100,000 years.

Mars has not always fascinated McKay. As a child his interests ranged from being a firefighter, a teacher and a historian. A physics class he took as a high school senior fired his interest in pursuing science in college, and he attended Florida Atlantic University in Boca Raton. The real catalyst to study Mars came in 1976, when McKay was a graduate student at the University of Colorado and Viking touched down on Mars.

"When Viking landed and detected carbon, oxygen and nitrogen, but no life, I was immediately intrigued," he recalls. "The thing that struck me was 'the lights are on, but no one's home.' Everything is there for life to survive. Why is there no life?"

Speculating about life on Mars, McKay became interested in the red planet as it existed more than three billion years ago. Photographs of canyons and water-cut valleys suggest that at one time in the distant past, Mars possessed a warm, thick atmosphere capable of allowing running water. McKay believes ancient Mars was on the verge of blossoming into a living planet before it lost its atmosphere and froze over. He expects future explorers to find the Martian equivalent of stromatolites, the fossilized remains of blue-green algae that once thrived in the oceans of primeval Earth.

To form models on how life on other planets might exist, McKay and other NASA scientists have journeyed from the heat of the Gobi Desert to the frigid Siberian tundra and Antarctica. The dry valleys of Antarctica, the most Mars-like place on Earth, are simlar to dry lakebed features on Mars. In all these places, even in Antarctica's brutal environment of sparse water and frigid temperatures, microorganisms exist successfully. These hardy creatures could have survived on ancient Mars, McKay says, but they would perish on the planet's surface today because of the lack of liquid water.

Although McKay believes Mars is lifeless, he acknowledges in his writings that indigenous life may exist in an obscure environmental niche. This raises several ethical questions for terraformers, McKay says, the most important being 'should we?'

Introducing Earth organisms to the planet may mean a death sentence to Mars life, just like the introduction of European germs wiped out New World populations 500 years ago. Nevertheless, McKay feels that Mars should be terraformed. A kinder, gentler Mars, he suggests, could enhance the survival of any indigenous Martian species. If no native life exists, McKay believes that