RAISING THE ROBOT'S I.Q.

Scientists are devising machines that can see, feel, hear, walk, make decisions, and reproduce themselves

by PAMELA WEINTRAUB

The setting is an ash-grey expanse on the moon surrounded by jagged ridges and craters. In the center stands a bustling factory manned by robots. Some of them scurry about on wheels, mining ore and transporting it to smelters. Others work in place, focusing television-camera eyes and flexing mechanical muscles as they assemble the newly smelted metal into spaceships, satellites, and, most important, new robots. Operating in a near vacuum, unprotected by any atmosphere from the lethal rays of the sun, the robots build and then operate additional factories that turn out more products. Eventually they design and construct a superior generation of robots.

This industrialization—and robotization—of the moon is one of a number of programs being considered by the National Aeronautics and Space Administration as the success of the space shuttle (page 18) expands NASA's vistas from the exploration of space to the utilization of it. NASA has always used machines—satellites, spacecraft, landers—that can be called robots because they interact with the environment. Similarly, industry applies the word to the one-armed welders and bolt-tighteners lately replacing human beings on many assembly lines. But now NASA, and industry, needs better robots, truly intelligent machines that can, at least to some extent, see, hear, feel, smell, communicate, move around—and make and carry out decisions. And science is taking steps to provide them.

A robot at the National Bureau of Standards uses its television-camera eye and sense of pressure to pick up an egg without breaking it

Recognizing that intelligent robots are essential to America's future in space, NASA expects to spend at least tens, and perhaps hundreds, of millions of dollars yearly on robot research and development by the mid-1980s. By the turn of the century, says Stan Sadin, NASA's deputy director of space systems technology development, smart robots could be exploring remote parts of the solar system and constructing satellites that collect solar energy and transmit it to earth.

Other scientists are trying to build intelligent robots that will mine the deep sea or perform rescue missions in nuclear power plants. The Air Force and the aerospace industry are gearing up to produce the "factory of the future," an automated airplane plant managed by computers and manned by blue-collar robots. And Stanford University plans to develop a robot with enough dexterity to assist a surgeon.

Says James Albus, director of robotics research at the National Bureau of Standards in Gaithersburg, Maryland, "It is not inconceivable that self-replicating robots may, sometime in the next century, develop into creatures that think and show emotions that are somewhat analogous to those of the human being. It is simply a matter of building sensory devices and computers of sufficient complexity. Robots may never look much like people, but they are evolving into a living species."

The 4,000 industrial robots in American factories today are not very advanced; See Threepio of *Star Wars* is nowhere near reality. Existing machines perform some repetitive tasks with more speed and reliability than human beings, and they can withstand fumes and heat. But, says Tom Binford, leader of the Robotics Laboratory at Stanford University in California, "they are nothing much more than three-thousand-pound idiots. After all, how much could a person do with his eyes, nose,

Coming soon: robots smart enough to build other robots

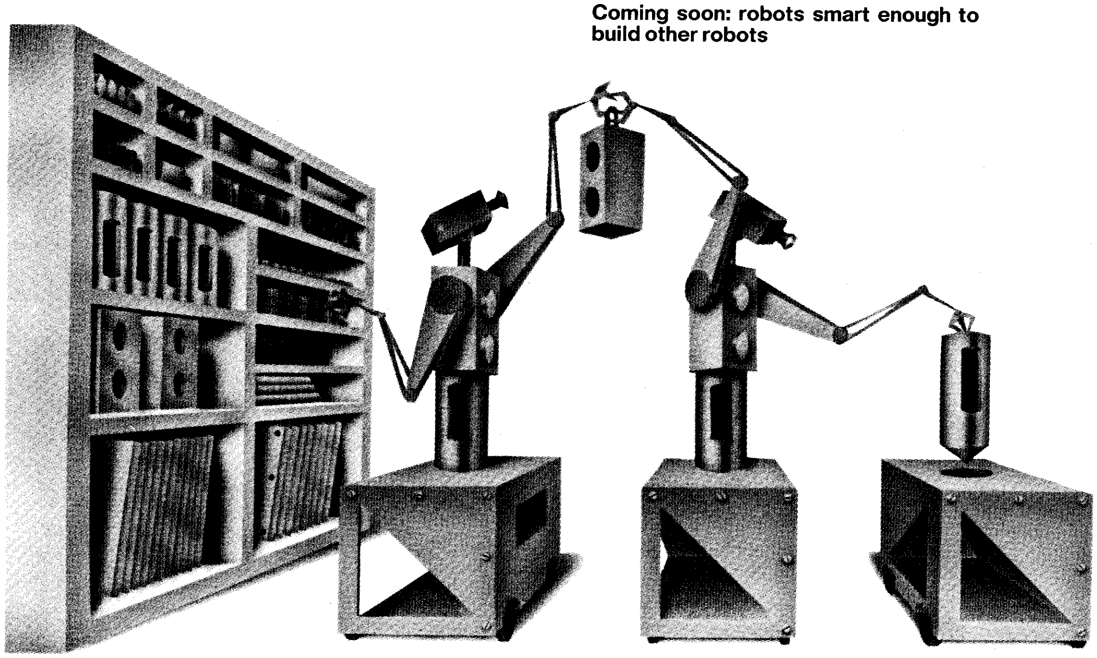
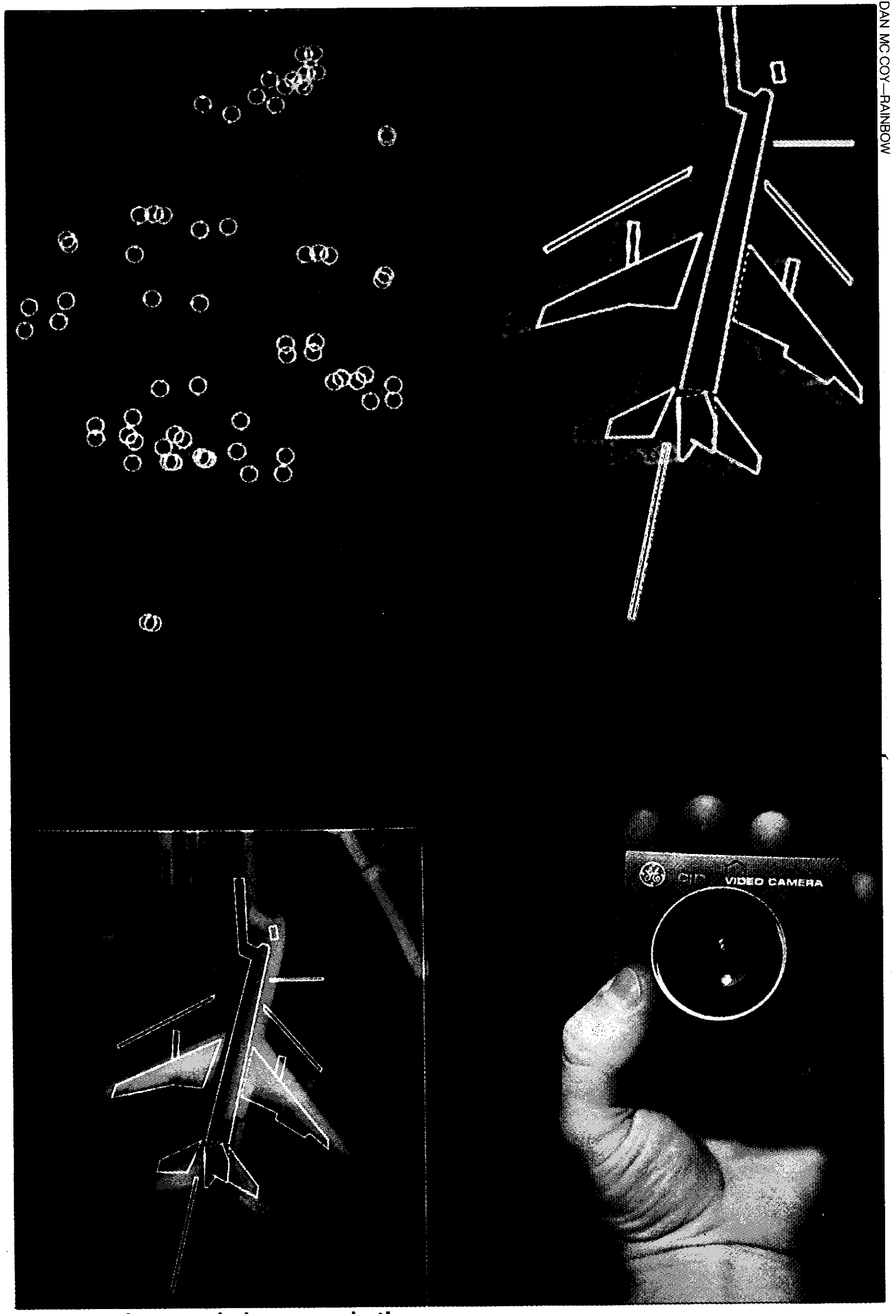


ILLUSTRATION BY MARK KAPLAN



DAN MC COY—RAINBOW

To recognize an airplane, a robot's camera eye transmits a picture of the plane to a computer, which simplifies the image to its basic shape (bottom left), then to a few essential lines, and finally to the most critical points

and ears plugged, his legs glued to the floor, and his entire body injected with the equivalent of novocaine?"

So roboticists (as they call themselves) like Binford are removing the plugs, freeing the feet, and providing their creatures with thumbs and brains. The most important first step, they say, could be the development of a practical robot eye.

Most visual robots undergoing tests in today's factories are limited because they see a flat, two-dimensional world. To give robots a sense of depth, scientists in the research lab are building eyes that see in three dimensions. One such robot sits on a table in a darkened room at the National Bureau of Standards. With a light shining from its fingertips and a television camera mounted atop its wrist, this mechanical arm scans nearby objects such as metallic cubes and cylinders. The camera transmits the image of any object illuminated by the light to a computer under the table. Applying simple geometry, the computer calculates the shape and location of the object, then tells the robot arm how to grip it and where to move it.

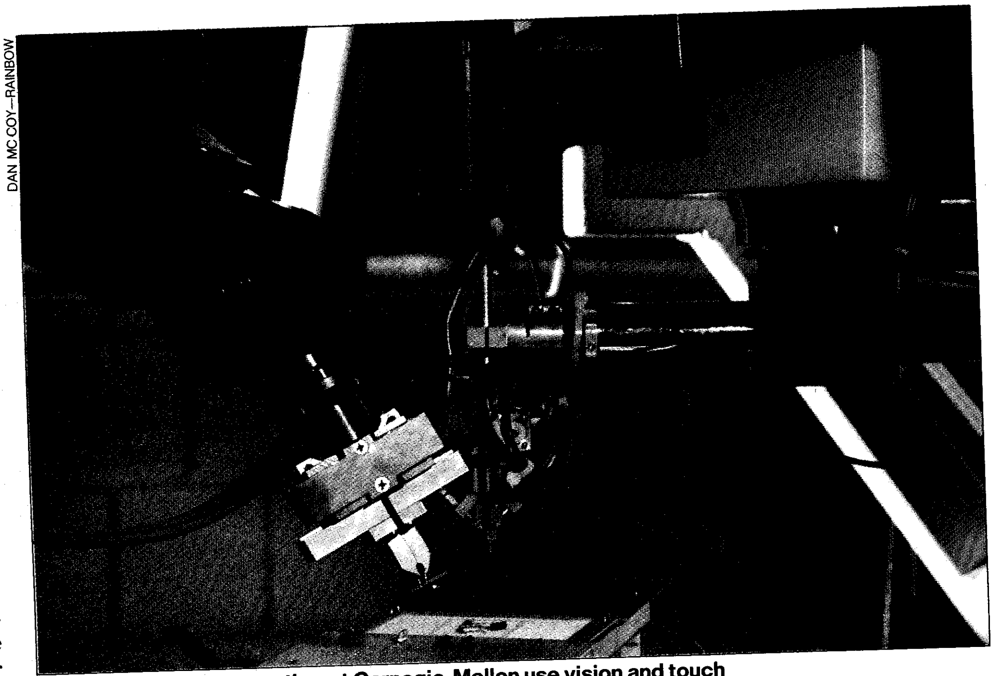
Robots that use light beams to see could do many factory jobs, but are otherwise quite limited. They can see only where the light shines, and for only a few feet. If a robot is to navigate through a cluttered office or build satellites in space, it must perceive complex, three-dimensional panoramas in stereo, using two eyes much as people do. Duplicating human visual perception and recognition is far beyond present capability. A human retina contains 150 million light sensors that send signals to billions of nerve cells. Human eyes combine the signals to detect depth, edges, curvature, and motion. Sent to the brain, the image is recognized through comparison with information stored in the memory.

Without aspiring to such complexity, scientists are working on systems that mimic human vision. Stanford's Binford is building a robot that uses two video cameras to see in stereo. The computer brain reduces the resulting image to a few crucial lines indicating the most important edges and curves.

To enable the robot to recognize these pictures, Binford is building a "world model," that is, an electronic memory that will eventually contain enough information to identify most physical objects or landscapes. That is no easy task. It is clearly impossible to make a model of each chair or tree in existence, or to take into account changes in an object's shape or position. Binford's goal is to construct abstract models of common objects, starting with those in his laboratory. He plans to use a single building block—a three-dimensional cone-shaped image that can be represented digitally in the computer's memory and programmed to appear on a computer screen.

Binford's seeing robot is painfully slow; it takes two or three minutes to recognize a simple geometric shape like a cube or a sphere. Why so long? Because the robot must sift through millions of bits of digital data to simplify the image and compare it with models in its memory, a monumental task even for today's speedy computers. But the computer of the future will work thousands of times as fast. Then the robot eye may begin to give its human counterpart a bit of competition.

Even eagle-eyed robots will need other abilities—a sense of touch, for example. With that in mind, researchers Danny Hillis and John Hollerbach, of the Massachusetts Institute of Technology, are building robotic skin made of thin sheets of rubber lined with wire. The sheets, piled one on top of the other, line the robot's fingers and hand. The top layer receives a steady flow of electric current from a power source on the robot. When the hand or fingers touch something, the sheets press together and the wires come into contact, allowing current to flow through lower layers. As pressure increases, additional wires come into contact and more current flows. Thus a robot hand connected to a microprocessor that measures voltage will feel the shape of anything much as people do with their fingers. Unlike other artificial skin, the M.I.T. version forms an image of what it touches. A robot touching a keyhole will see the keyhole in its computer brain, and that same image could appear on a computer screen.

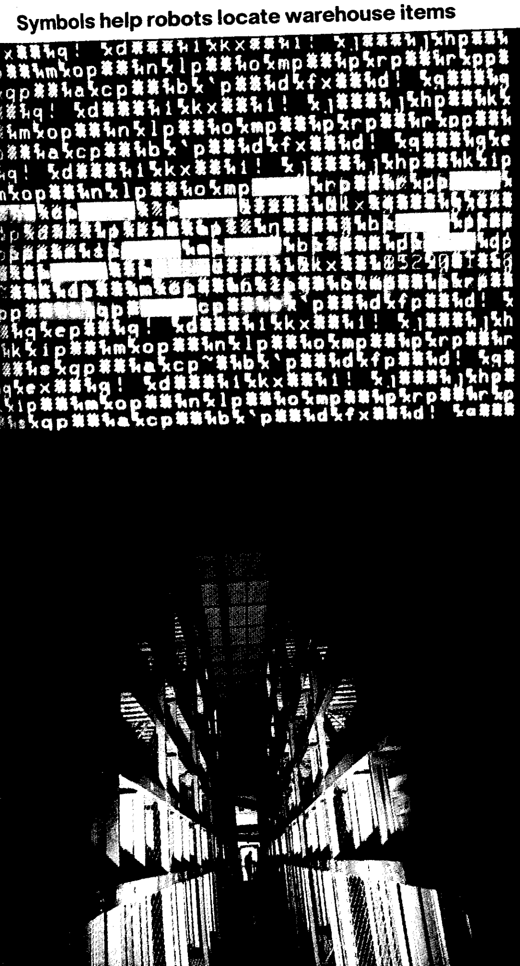

DAN MC COY—RAINBOW

Two robots working together at Carnegie-Mellon use vision and touch

Even more important than artificial skin are sensors that measure and control the forces exerted by a robot hand or arm. Some robots can respond to forces with the help of springs inserted in their wrists. But a robot with springy wrists cannot control the forces that it exerts. To solve this problem, one of the newest and most sophisticated force-sensors has recently been installed on a robot at the Charles Stark Draper Laboratory in Cambridge, Massachusetts. Built by engineer Donald Seltzer, the sensor looks like a diamond-studded bracelet encircling the robot wrist.

The diamonds are actually three lights that shine onto three tiny light detectors on the robot hand, according to project director Daniel Whitney. The hand is connected to the wrist by a joint made with three springy cylinders of alternating layers of rubber and metal. When the hand exerts force on an object, the cylinders contract, stretch, or twist, and the light moves accordingly across the face of the light detector, which sends the information to the robot's control computer. The computer can then calculate the force that the robot hand exerts, and give orders to the motors that drive the robot hand and arm. The robot at Draper can use its force-sensor to assemble parts or follow the contours of a curve, abilities that make it ideal for welding or painting.

Symbols help robots locate warehouse items


DAN MC COY—RAINBOW

According to Raj Reddy, director of the Robotics Institute of Carnegie-Mellon University, in Pittsburgh, robots will eventually acquire a whole range of sensors. They will have ears that can hear a drill-bit breaking or recognize and understand the voice of a human manager, and chemical sensors that can smell smoke in the air or taste salt in sea water. But, he adds, "we are not limited to the human senses. Infra-red or ultra-violet sensors will be useful for seeing in the dark, and ultrasound or sonar may be valuable to robots laboring under the sea."

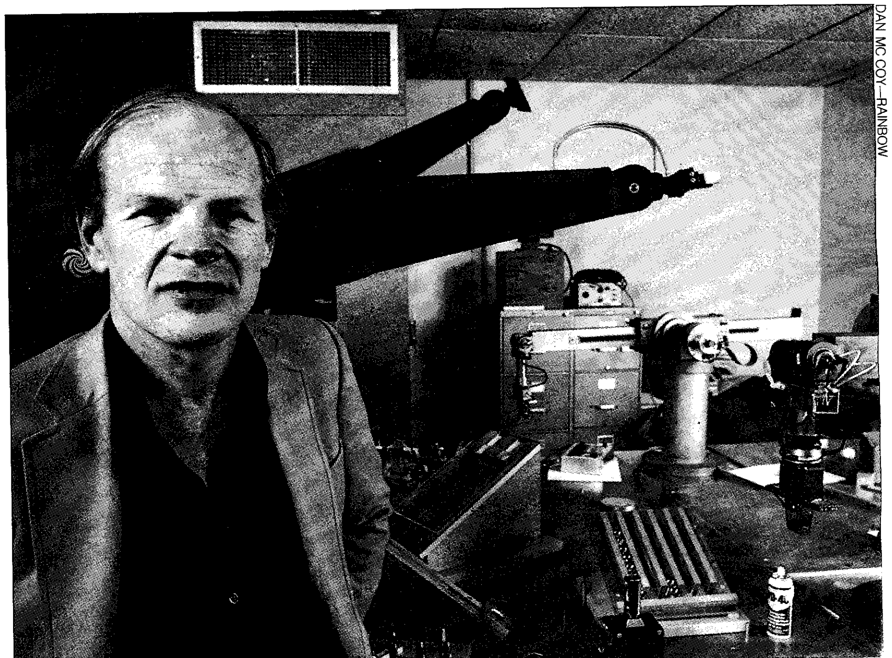
Hans Moravec, a young roboticist working under a Navy grant at Carnegie-Mellon, is building a robot that will incorporate most of these sensors and a set of wheels, enabling it to travel.

Moravec completed his first mobile robot last year while still a graduate student at Stanford. Unlike the primitive mobile robot that for a short time delivered mail at the Pentagon by following an electronic track along the floor, Moravec's could navigate an obstacle course guided only by its television camera eye. As the cart moved forward, the camera slid back and forth, photographing a roomful of chairs, wastebaskets, refrigerators, and cardboard cones that symbolized trees. The pictures were radioed to a large laboratory computer, which determined the position of the obstacles and radioed instructions to a receiver that controlled the robot's pram-sized wheels.

"The cart's major attribute," says Moravec, "was simply that it worked. It moved so slowly that it took fifteen minutes to travel three feet. All that time was eaten up by the large computer, which had to digest the enormous quantity of information sent to it by the robot camera." He admits that as of now radar might be more useful in robot navigation. But once 3-D computer vision speeds up, roving robots will be able to do more than avoid obstacles; they will be able to understand their environment and even change it.

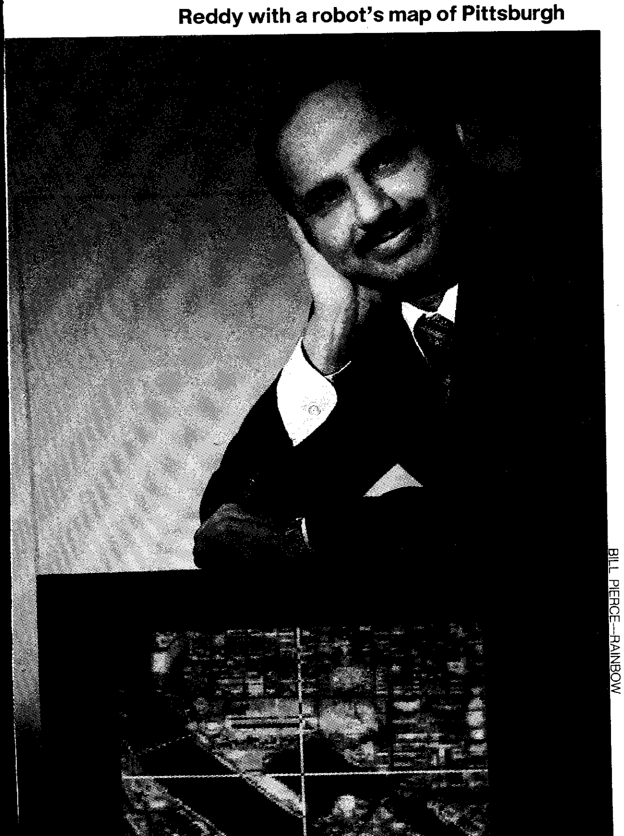
Moravec's second roving robot, which he says should be "pirouetting across the laboratory floor" at Carnegie-Mellon by the end of the summer, will travel ten times as quickly as the Stanford version. The reason: a powerful laboratory computer, built specifically to analyze visual information, works far more quickly than the one used last year; it sends instructions to twelve on-board microprocessors that rapidly orchestrate the motion of three sets of wheels. The new robot, two feet in diameter and three feet high, will look something like a wastebasket with a tilting, panning TV camera eye on top. Moravec says that future roving robots will gain speed and precision as computers continue to improve. They will have color stereo vision, a memory as extensive as the one being built by Binford, and two or three arms, each with muscle-like force-sensors and a sense of touch.

Even when laden with sensors, robot limbs will be relegated to heavy work on the factory floor unless they become as versatile as human limbs. Toward this end, Ken Salisbury, a graduate student at Stanford, is building a hand with three fingers, each of which is opposable to the other two and works much like the human thumb to grasp objects. Tom Binford is developing a robot that can coordinate two hands to perform a single task. Robert McGhee, a roboticist at Ohio State University, in Columbus, is building a walking robot with six legs; his next robot could have four legs and may be capable of working in a nuclear power plant or a coal mine. And Haruhiko Asada, of Carnegie-Mellon, is designing a fast robot arm driven by ultra light motors. The arm, which looks like a human limb, is far more agile and powerful than the conventional robot arm and consumes little energy. But it still weighs 280 pounds. Asada plans to use materials such as titanium, fiberglass, and plastic to build an equally powerful arm, weighing only 13 pounds.


DAN MCCOY—RAINBOW

Tom Binford in the Robotics Laboratory at Stanford University

Reddy with a robot's map of Pittsburgh


BILL PIERCE—RAINBOW

To endow robots with intelligence, scientists are depending upon the development, within a decade, of VLSI (very large-scale integrated circuit) systems, which will work at least a thousand times as fast and hold a thousand times as much information as today's best microprocessors. Then, says Raj Reddy, each robot eye, ear, and hand will have its own tiny but powerful microprocessor to sift through billions of visual points, analyze hundreds of voices, or determine the pressure on each finger and joint. The most important data will be sent to the robot's central computer, the size of a transistor radio, which will coordinate the entire machine.

"But being smart is not just a question of storing static information in a powerful computer," says Reddy. A smart robot must be able to adapt to changes and solve problems as they arise. To give the robot this ability, Reddy and others at Carnegie-Mellon are developing a set of techniques that will help robots make plans or find the means to accomplish a particular end. The Carnegie-Mellon group hopes to build an abstract, problem-solving model something like Binford's abstract model of the visual world. Reddy explains, "If a robot is exploring Mars and comes to a canyon it has never seen before, it can attempt to find an alternative path by relying upon its sensors and a set of general instructions on how to maneuver past obstacles."

Robots will start off with a simple set of skills, Reddy adds. In five years, those working in space, for example, might be able to fly from the space shuttle to a satellite, guided by their own brain power. But when it came to the more complex task of repairing the satellite, a human supervisor would have to radio instructions to the robot brain. In ten or fifteen years, Reddy believes, space, sea, and land robots can be more or less autonomous, smart enough to build complicated structures or navigate rugged terrain.

"There are two illusions about robots," Albus says. "One is that they are already here. The other is that they'll never be here, that they are the stuff of science fiction and will never have a significant impact on the real world. The real world of robotics is a funny thing that takes place between those two extremes." Indeed, robots intelligent enough to design a new, superior race of robots may be a long way off. Even so, 50 industrial robots made in Japan have recently begun to reproduce themselves, building new robots round the clock. Some human help is still needed; about 25 people assemble parts that these deaf, dumb, and blind factotums are too stupid to handle. So far. ■