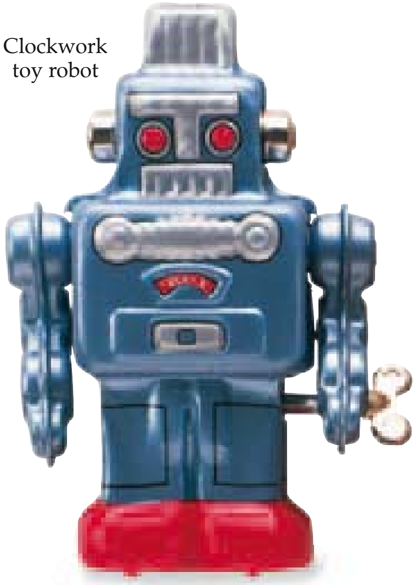
Eyewitness
ROBOT

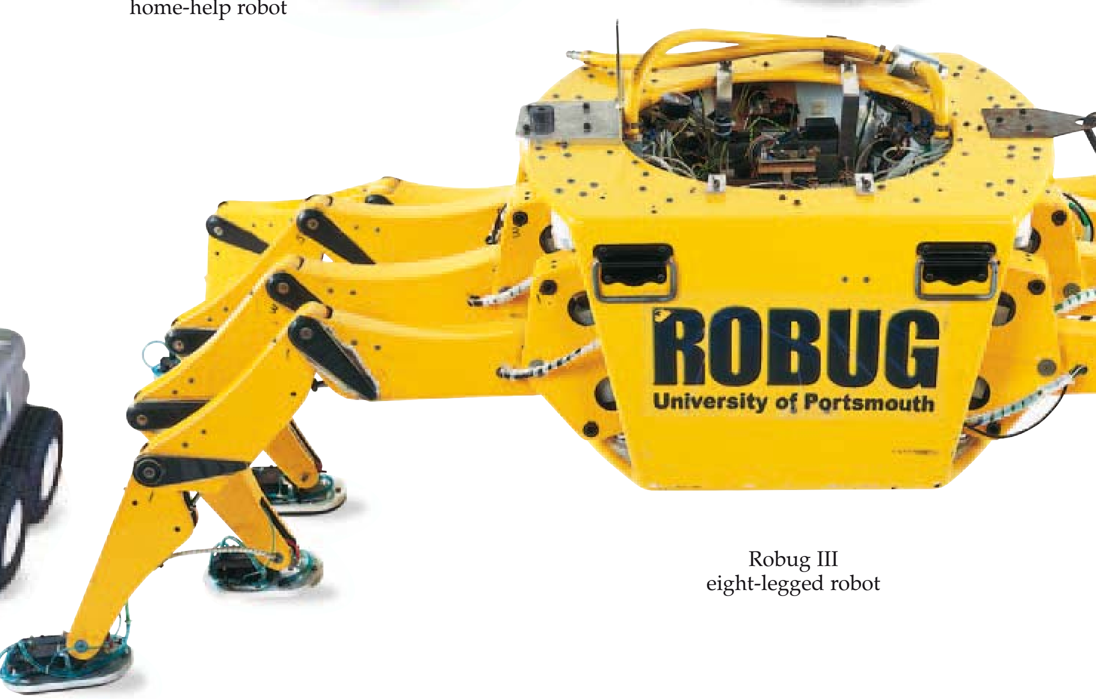

Clockwork toy robot


Hobo bomb-disposal robot


Evolution ER2 home-help robot

PeopleBot ready-made robot


Lego Mindstorms humanoid robot



Robug III eight-legged robot

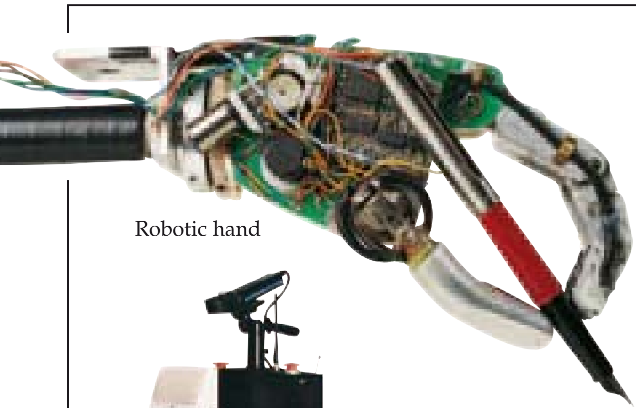

Koala ready-made robot

Eyewitness
ROBOT

Written by
ROGER BRIDGMAN

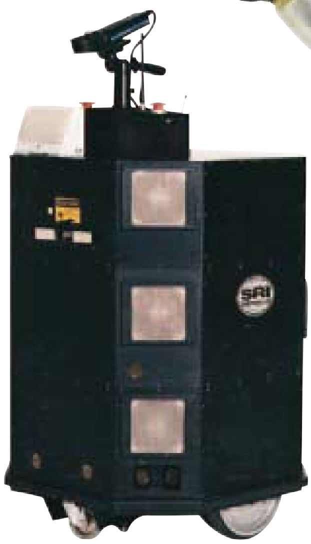
Toy robot

DK



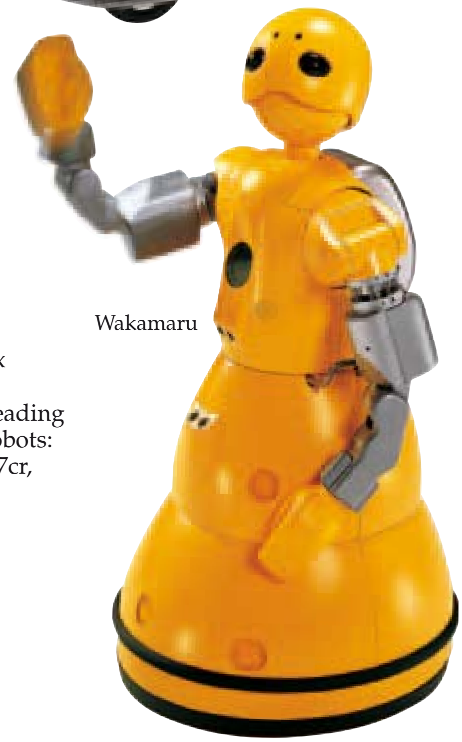
Robotic hand

Swarm robots



Flakey

Asimo



Wakamaru

Lego Artbot

Amigobots

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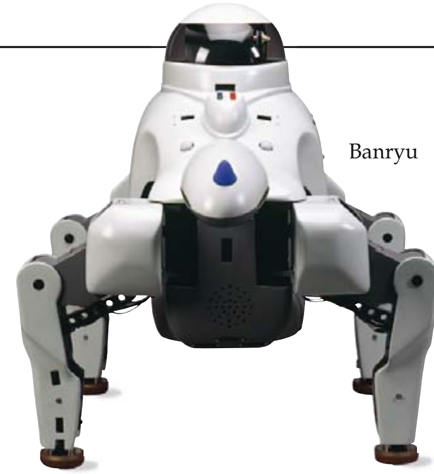
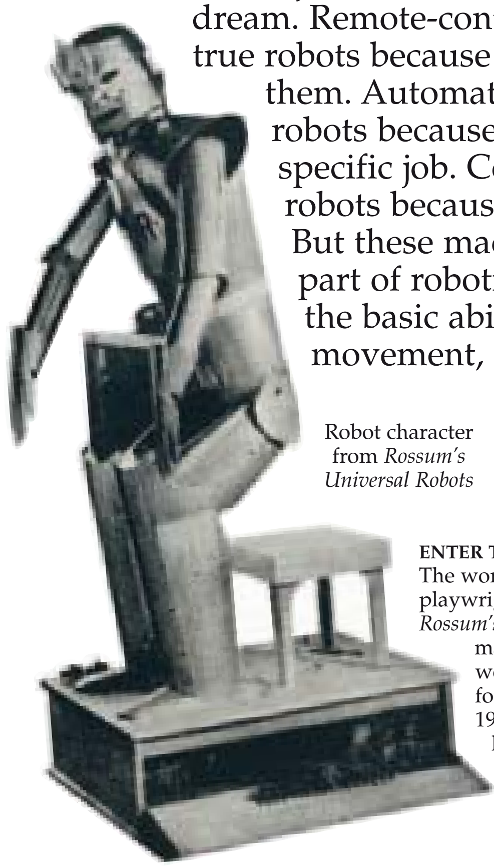
Contents



Banryu

What is a robot?

A TRUE ROBOT IS any machine that can move about and do different tasks without human help. It does not have to look like a human being. In fact, a machine that actually looks and behaves just like a real person is still a distant dream. Remote-controlled machines are not true robots because they need people to guide them. Automatic machines are not true robots because they can do only one specific job. Computers are not true robots because they cannot move. But these machines are still an important part of robotics. They all help to develop the basic abilities of true robots: movement, senses, and intelligence.

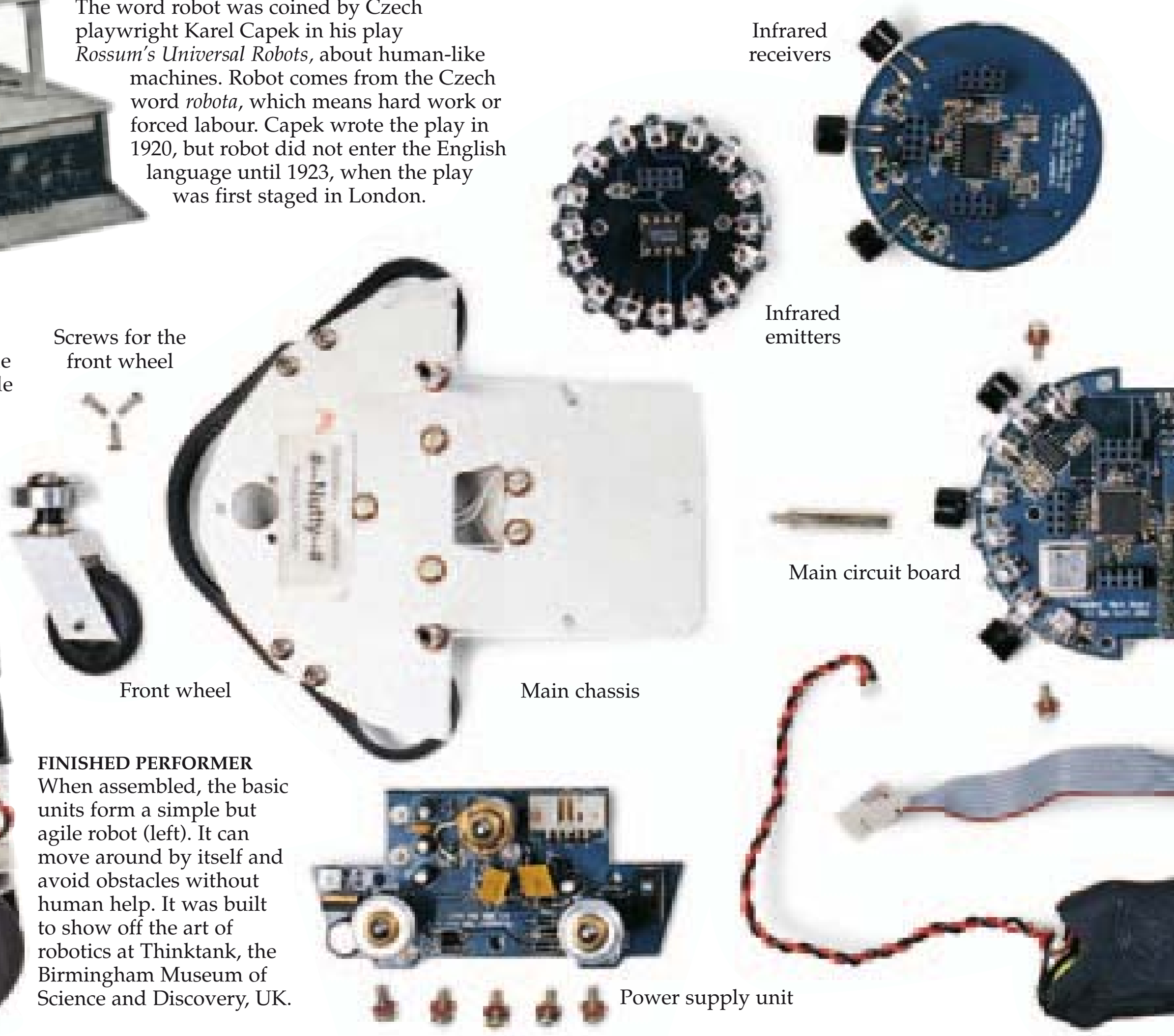


Robot character from *Rossum's Universal Robots*

MECHANICAL MOVIE STARS
This mechanical woman was one of the first robots in film. She was created in the 1926 silent film *Metropolis* by German director Fritz Lang. Film can make almost anything seem real, and fiction and fantasy have helped inspire the development of robots in the real world.

ENTER THE ROBOT
The word robot was coined by Czech playwright Karel Capek in his play *Rossum's Universal Robots*, about human-like machines. Robot comes from the Czech word *robota*, which means hard work or forced labour. Capek wrote the play in 1920, but robot did not enter the English language until 1923, when the play was first staged in London.

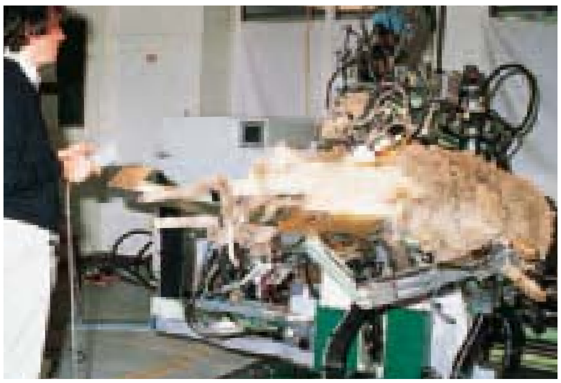
BASIC BITS
The simplest mobile robots are made up of several basic units that provide them with movement, senses, and intelligence. This robot moves on electrically driven wheels and uses infrared light for sensing. Its intelligence comes from a tiny on-board computer housed on the main circuit board.



FINISHED PERFORMER
When assembled, the basic units form a simple but agile robot (left). It can move around by itself and avoid obstacles without human help. It was built to show off the art of robotics at Thinktank, the Birmingham Museum of Science and Discovery, UK.

FACTORY WORKERS
Most of the world's million or so robots are not true robots, but fixed arms that help to make things in factories. The arms that weld car bodies led the way for industrial robotics. Cars made this way are cheaper and more reliable than those made by humans, because industrial robots can work more accurately and for longer.

SHEAR SKILL
Like most robots used in industry, the University of Western Australia's sheep-shearing robot is designed to be flexible. It can safely shear the wool off a live sheep. It needs power to work fast, as well as sensitivity to avoid hurting the sheep.



With a body packed full of computers, motor drives, and batteries P2 stood over 1.8 m (6 ft) tall and weighed in at a hefty 210 kg (460 lb).

HUMANOID ROBOTS
P2, launched in 1996, was the first autonomous (independent) humanoid robot. Many people think that all robots should look like humans, but robots are usually just the best shape for the job they are built to do. Robots of the future, however, will need to work alongside people in houses and offices, so a humanoid body may be best.

Powerful, flexible legs enabled P2 to walk, push a cart, and climb stairs.

Fictional robots

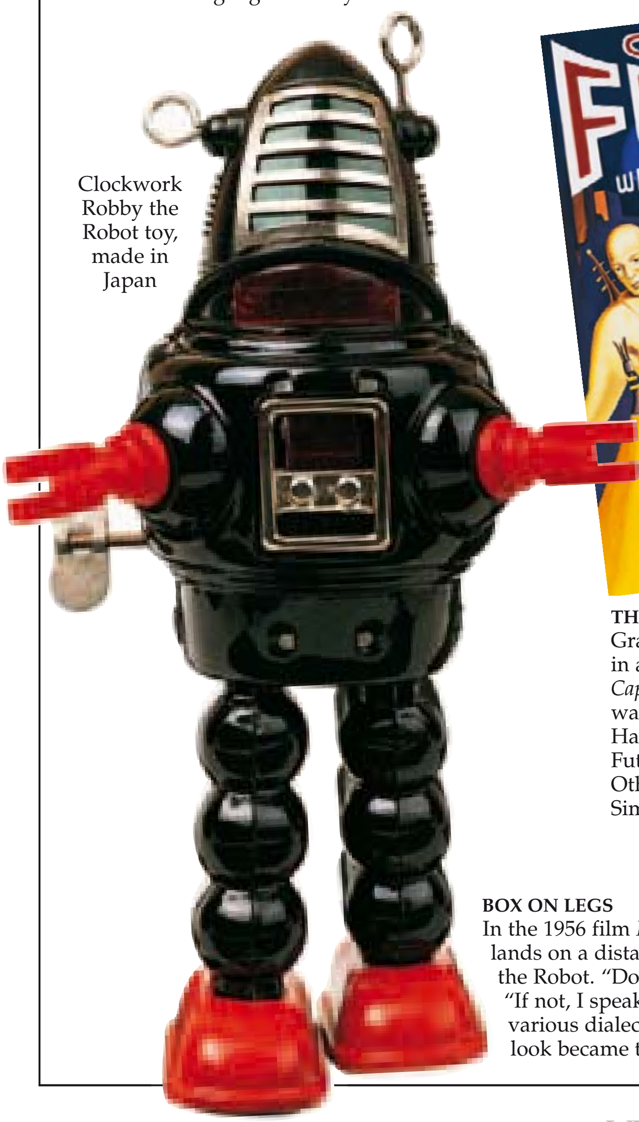
C-3PO as he appeared in *The Empire Strikes Back*, Episode V of the *Star Wars* saga, 1980

His golden outer shell was added by Anakin's mother Shmi. Before that he had to put up with being naked, with all his parts and wires showing.

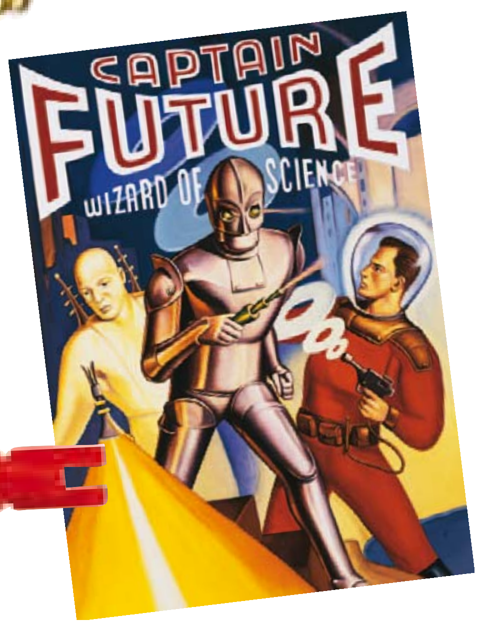
The shell helped to protect his inner workings from sand storms on the planet Tatooine.

IN THE WORLD OF robotics, there is a close relationship between imagination and technology. Many people get their first ideas about robots from books, films, and television. Authors and film-makers have long been fascinated by the idea of machines that behave like people, and have woven fantasy worlds around them. Improbable as they are, these works of fiction have inspired scientists and engineers to try to imitate them. Their attempts have so far fallen short of the android marvels of science fiction. However, robots are getting more human, and may inspire even more adventurous fictional creations.

KEEPING THE PEACE
C-3PO, the world's best known humanoid robot, first appeared in the 1977 film *Star Wars*. In the film, he was built from scrap by a nine-year-old boy called Anakin Skywalker on the planet Tatooine. C-3PO was designed as a "protocol droid" to keep the peace between politicians from different planets. He understands the culture and language of many colonies.

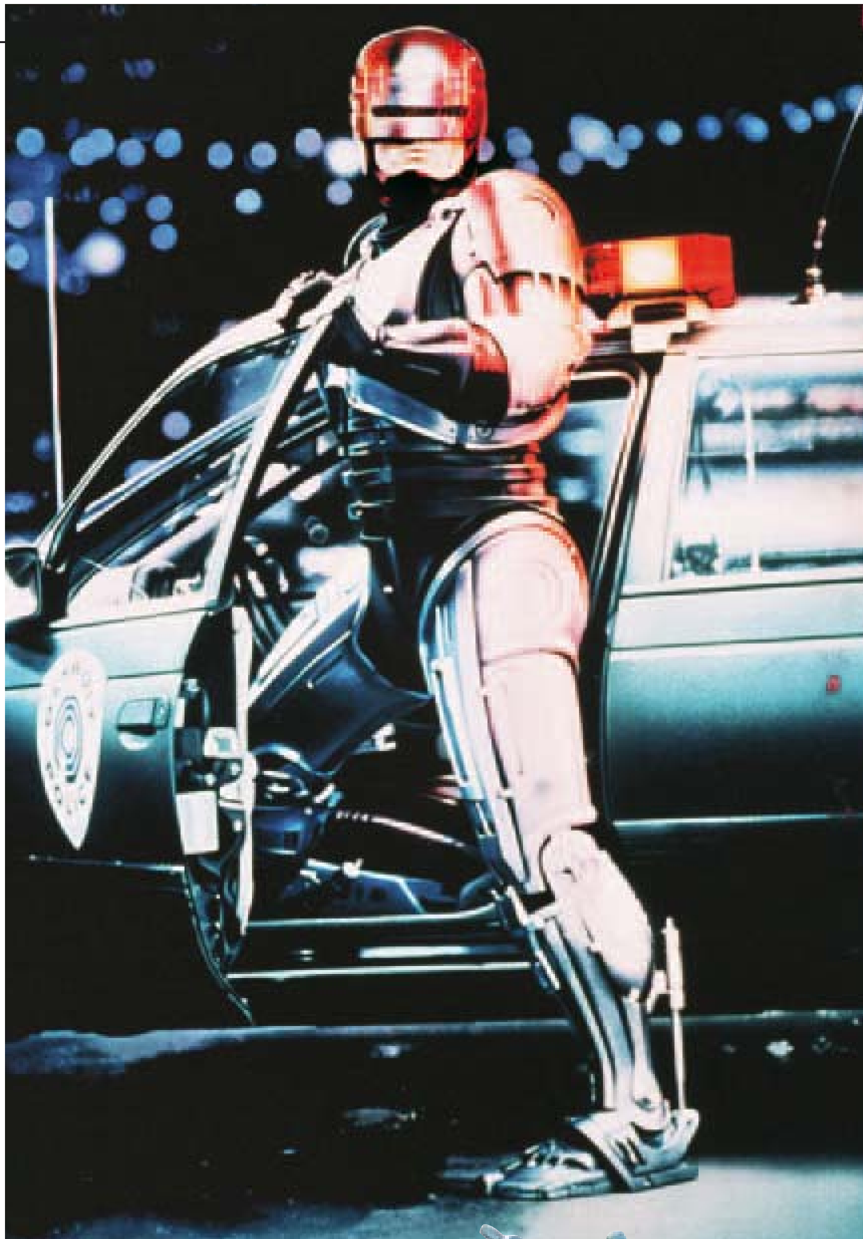


Clockwork Robby the Robot toy, made in Japan

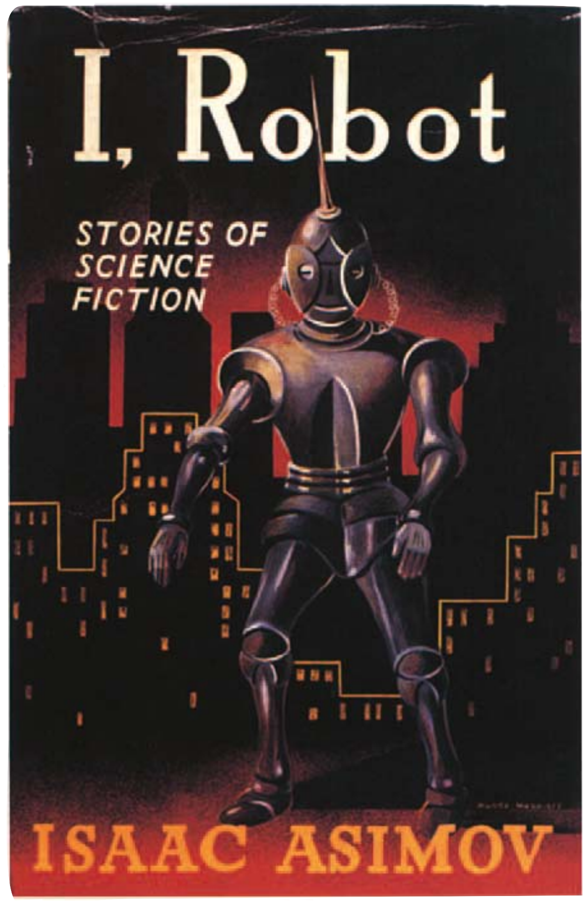


THE FUTUREMEN
Grag, the metal robot, is one of the crew in a series of book-length magazines called *Captain Future, Wizard of Science*. The series was created in 1940 by US author Edmond Hamilton, and it ran until 1951. Captain Future's crew, the Futuremen, also includes Otho, the synthetic humanoid robot, and Simon Wright, the living brain.

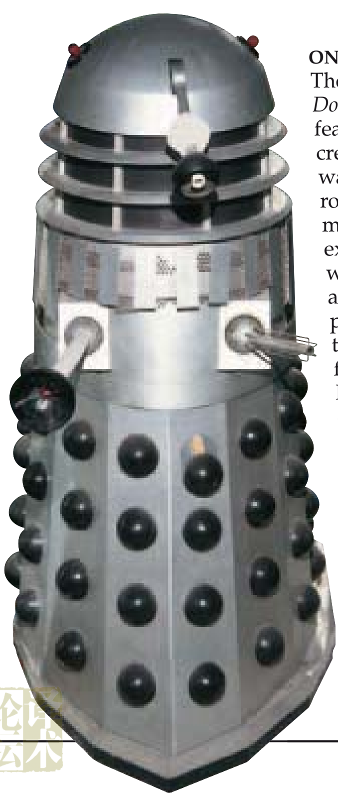
BOX ON LEGS
In the 1956 film *Forbidden Planet*, Captain Adams lands on a distant planet and is greeted by Robby the Robot. "Do you speak English?" Robby asks. "If not, I speak 187 other languages and their various dialects." Robby the Robot's box-on-legs look became the model for many early toy robots.



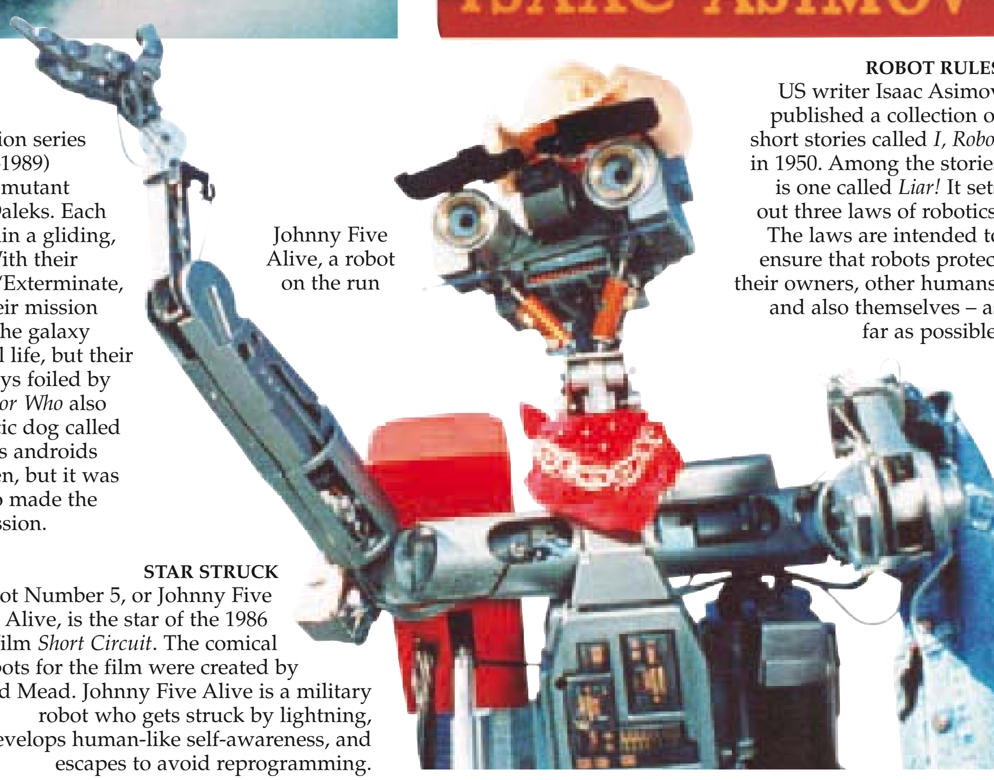
ULTIMATE COP
Robocop first appeared in 1987, in the futuristic film of the same name. Robocop is created when the brain of police officer Alex Murphy (killed by a gang) is combined with robot parts to produce the ultimate "cop". Robocop works with terrifying effectiveness 24 hours a day and can record everything that happens, providing unshakeable evidence to convict criminals.



ROBOT RULES
US writer Isaac Asimov published a collection of short stories called *I, Robot* in 1950. Among the stories is one called *Liar!* It sets out three laws of robotics. The laws are intended to ensure that robots protect their owners, other humans, and also themselves – as far as possible.



ON A MISSION
The British television series *Doctor Who* (1963–1989) featured a race of mutant creatures called Daleks. Each was encased within a gliding, robotic "tank". With their metallic cries of "Exterminate, exterminate!" their mission was to conquer the galaxy and dominate all life, but their plans were always foiled by the Doctor. *Doctor Who* also featured a robotic dog called K-9 and ruthless androids called Cybermen, but it was the Daleks who made the greatest impression.



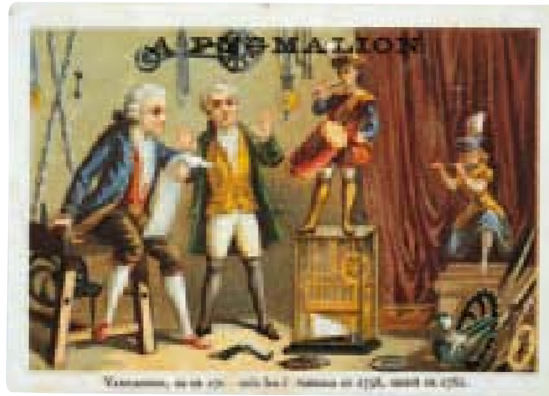
Johnny Five Alive, a robot on the run

STAR STRUCK
Robot Number 5, or Johnny Five Alive, is the star of the 1986 film *Short Circuit*. The comical robots for the film were created by Syd Mead. Johnny Five Alive is a military robot who gets struck by lightning, develops human-like self-awareness, and escapes to avoid reprogramming.

Robot ancestors

MECHANICAL creatures, wind-up toys, and dolls that move have all played a part in the development of robotics. The earliest models were not true robots because they had no intelligence and could not be instructed to do different tasks. These machines are called automata, from the same Greek word that gives us automatic. From the 16th century onwards, automata were made following mechanical principles originally used by clockmakers to produce actions such as the striking of bells. These techniques were adapted, particularly in Japan and France, to produce moving figures that would astonish anyone who saw them.

EARLY BIRD
The first known automaton was an artificial pigeon built in about 400 BC by ancient Greek scientist Archytas of Tarentum. The pigeon was limited to "flying" around on an arm driven by steam or air. Archytas probably built his pigeon as a way of finding out more about the mathematics of machines.



FAKE FLAUTIST
One of the 18th century's most famous automata was a flautist, or flute-player, created by French engineer Jacques de Vaucanson. Built in 1783, the automaton's wooden fingers and artificial lungs were moved by a clever mechanism to play 12 different tunes on a real flute. It worked so well that some people thought there must be a real player concealed inside.

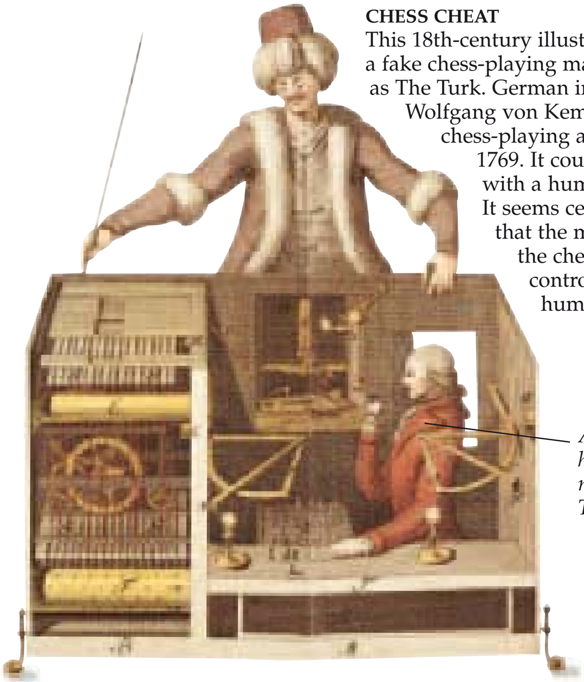
Openings at the top of the organ pipes allow sound to escape.

The handle is turned to operate the pipe and bellows mechanism of the organ.

TIPPOO'S TIGER
This mechanical wooden tiger doubles as an elaborate case for a toy organ. It was built in about 1795 for the Indian ruler Tippoo Sultan, whose nickname was The Tiger of Mysore. When the handle on the tiger's shoulder is turned, the model comes to life. The tiger growls as it savages a British soldier, and the soldier feebly waves his arm and cries out. The sounds are produced by the organ inside the tiger.

Air pumped into the bellows is expelled as a shriek and a roar.

CHESS CHEAT
This 18th-century illustration shows a fake chess-playing machine known as The Turk. German inventor Wolfgang von Kempelen built the chess-playing automaton in 1769. It could play chess with a human and win! It seems certain, however, that the movements of the chess pieces were controlled by a human player.



An operator hidden inside may have played The Turk's moves.

The Turk, with its possible secret revealed

TEA MACHINE
Between 1615 and 1865, puppets called Karakuri were developed in Japan. They included dolls that served tea. The host would place a cup on a tray held by the doll. This triggered the doll to move forwards. It would stop when a guest picked up the cup. When the cup was put back on the tray, the doll would turn around and trundle back to its starting place.

The doll is driven by clockwork with a spring made from part of a whale.

When the large cat turns the handle, the small cat kicks its legs.

When the small cat kicks, the large cat turns and watches.

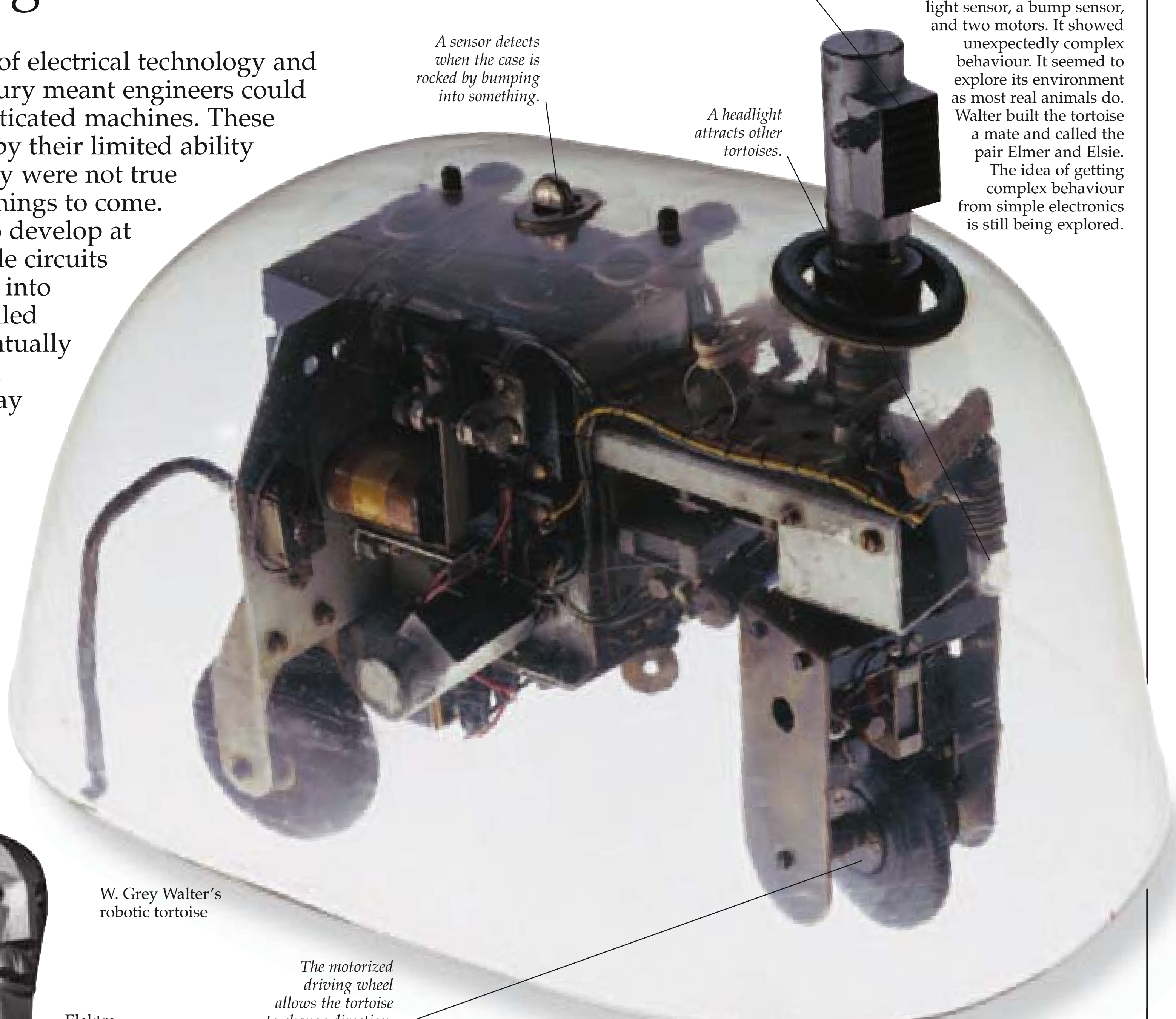
The tiger is almost life-size, and measures 71 cm (28 in) tall and 178 cm (70 in) long.

Keys for playing tunes on the organ are behind a flap in the tiger's side.

MODERN DESCENDANTS
The Barecats is a modern wooden automaton designed by Paul Spooner. Turning a handle on its base makes the cats move. Spooner loves to get lifelike movement from simple mechanisms. As in its 16th-century ancestors, gear wheels transmit power, while cranks and cams (shaped rotors) create movement.

The beginnings of real robotics

THE RAPID DEVELOPMENT of electrical technology and electronics in the 20th century meant engineers could begin to build more sophisticated machines. These machines were hampered by their limited ability to handle information. They were not true robots, but gave a hint of things to come. As electronics continued to develop at an amazing pace, the simple circuits of pioneer devices evolved into elaborate computer-controlled systems. These would eventually lead to robots with enough intelligence to find their way around in the real world.



Photosensitive cells react to light given off by other tortoises.

A sensor detects when the case is rocked by bumping into something.

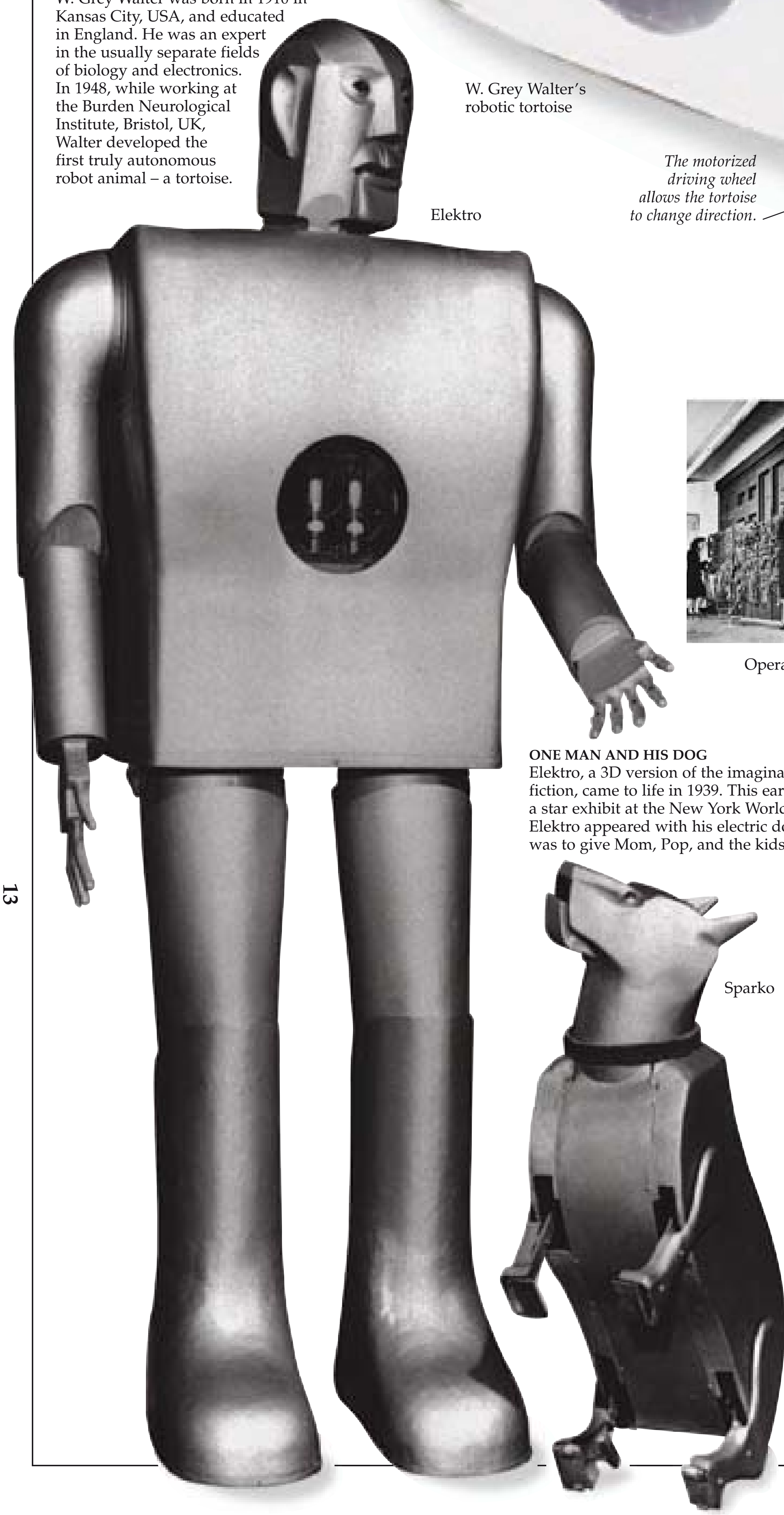
A headlight attracts other tortoises.

The motorized driving wheel allows the tortoise to change direction.

W. Grey Walter's robotic tortoise

ELMER AND ELSIE
Grey Walter developed a robot tortoise with two amplifiers, a light sensor, a bump sensor, and two motors. It showed unexpectedly complex behaviour. It seemed to explore its environment as most real animals do. Walter built the tortoise a mate and called the pair Elmer and Elsie. The idea of getting complex behaviour from simple electronics is still being explored.

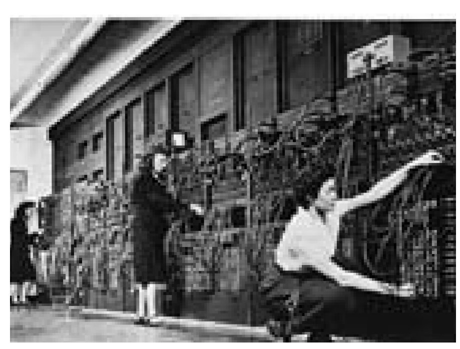
WORLD FIRST
W. Grey Walter was born in 1910 in Kansas City, USA, and educated in England. He was an expert in the usually separate fields of biology and electronics. In 1948, while working at the Burden Neurological Institute, Bristol, UK, Walter developed the first truly autonomous robot animal – a tortoise.



Elektro

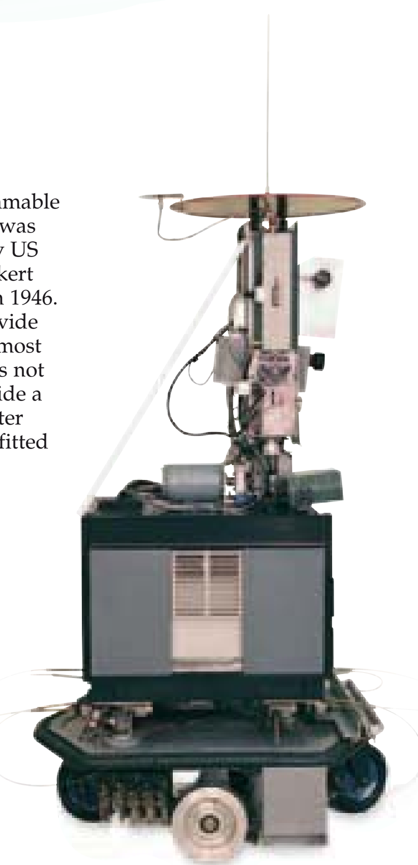
ONE MAN AND HIS DOG
Elektro, a 3D version of the imaginary robot of early fiction, came to life in 1939. This early humanoid was a star exhibit at the New York World's Fair in the USA. Elektro appeared with his electric dog Sparko, and his job was to give Mom, Pop, and the kids a vision of the future.

Sparko

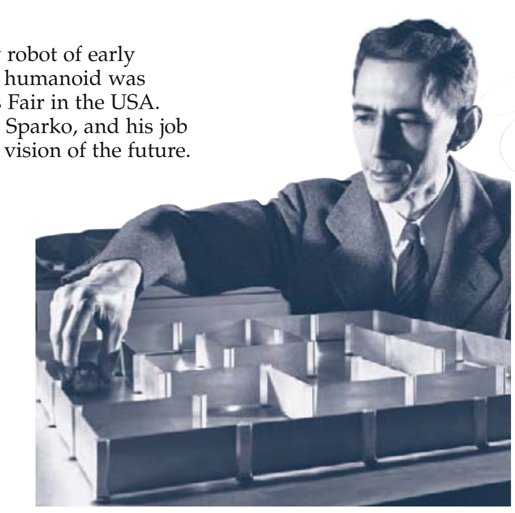


Operators programming Eniac

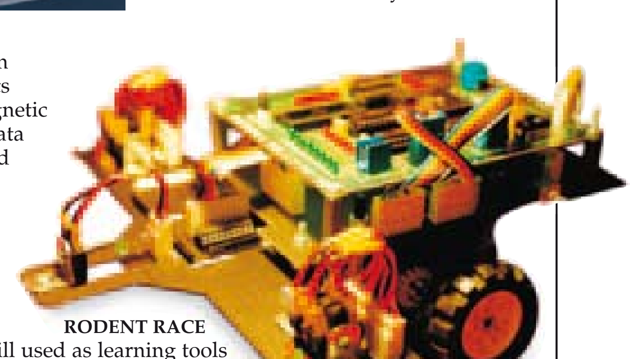
BIG BRAIN
The earliest programmable electronic computer was Eniac. It was built by US scientists Presper Eckert and John Mauchly in 1946. Computers now provide the brain power for most robots, but Eniac was not quite ready to fit inside a robot. It was a monster machine that barely fitted inside a room!



FREE WHEELING
Shakey was among the first robots to move freely without help. It was developed at the Stanford Research Institute in the USA between 1966 and 1972, and was the ancestor of today's Pioneer robots (pp. 24–25). Shakey was connected by radio to a computer. It worked – but the name tells you how well!



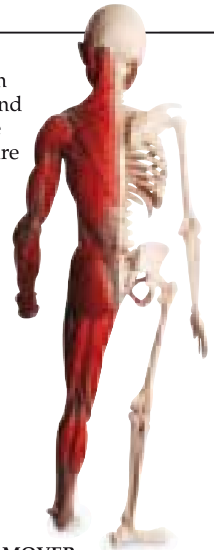
MOUSE MAN
In 1952, US engineer Claude Shannon built a robot mouse that could find its way around a metal maze using magnetic signals. The mouse was guided by data stored in circuits under the maze, and could quickly learn to navigate a new maze. It was one of the earliest experiments in artificial intelligence.



Modern maze-running robot

RODENT RACE
Maze-running mice are still used as learning tools in schools, and competitions form part of some university electronics courses. Today's mice have on-board computers and the maze is usually just painted lines that the robots track using optical sensors. The mouse that navigates the maze fastest wins.

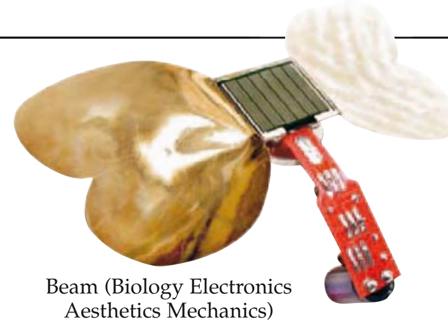
Robots on the move



Human bone and muscle structure

TRUE ROBOTS ARE able to move around to perform their designated tasks. Their motion needs to be more flexible and complex than other moving machines, such as cars, so they often require something more sophisticated than wheels. Arms and legs are one answer, but moving these effectively demands a robotic equivalent of muscles. Scientists and engineers have adapted existing power devices to create robot muscles. They have also invented new types of muscles. Some make innovative use of air pressure, while others are based on exotic metal alloys that shrink when heated.

PRIME MOVER
Human muscles are natural motors that get their energy from glucose, a kind of sugar. Even the most advanced robot is a long way off being able to move like a human.

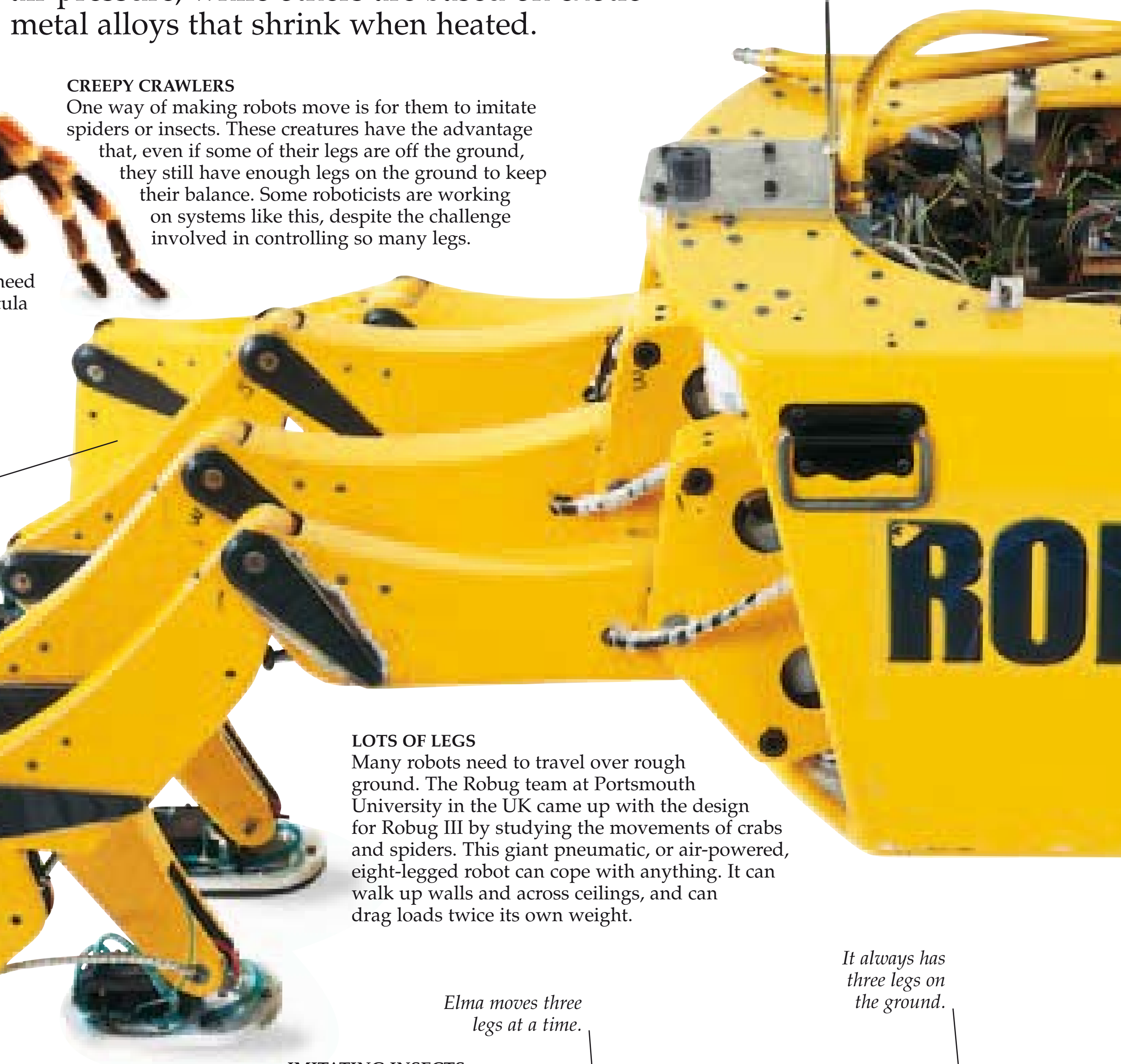


Beam (Biology Electronics Aesthetics Mechanics) robotic butterfly

ALL WIRED UP
Muscle wire creates the movement for some miniature robots, like this solar-powered butterfly. Muscle wire is a mixture of nickel and titanium, called Nitinol. When heated by an electric current, the wire gets shorter and pulls with enough force to flap the robotic butterfly's lightweight wings.

Red-kneed tarantula

CREEPY CRAWLERS
One way of making robots move is for them to imitate spiders or insects. These creatures have the advantage that, even if some of their legs are off the ground, they still have enough legs on the ground to keep their balance. Some roboticists are working on systems like this, despite the challenge involved in controlling so many legs.



Robug III's top walking speed is 10 cm (4 in) per second.

Each leg is controlled by a separate microprocessor.

When the foot is placed on a surface, a pump in the leg draws air from under the foot to create a vacuum.

LOTS OF LEGS
Many robots need to travel over rough ground. The Robug team at Portsmouth University in the UK came up with the design for Robug III by studying the movements of crabs and spiders. This giant pneumatic, or air-powered, eight-legged robot can cope with anything. It can walk up walls and across ceilings, and can drag loads twice its own weight.

IMITATING INSECTS
Hexapod, or six-legged, robots like Elma can mimic the way insects move. Each leg, powered by its own computer-controlled electric motor, has to move in the right sequence, while adapting its action to the terrain. When Elma is switched on, it stands, limbers up, then sets off with jerky determination.

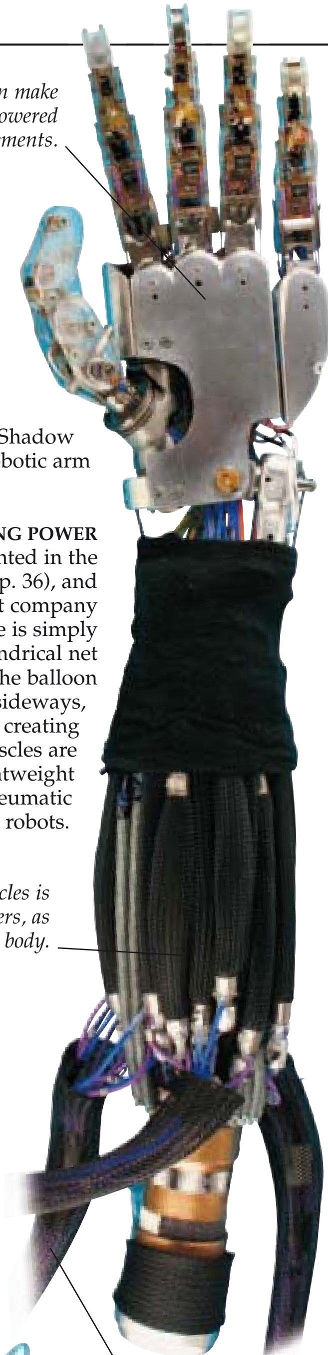
Elma moves three legs at a time.

It always has three legs on the ground.

Cybot is equipped with an array of sensors.

THREE WHEELER
Cybot, designed for *Real Robots* magazine, uses wheels to get around. The wheels limit it to travelling over smooth surfaces, but offer the advantage of simpler control. This frees up the robot's tiny brain for more important tasks like working out where to go next, making it more independent.

The front wheel can swivel, which helps with steering.



The hand can make 24 different powered movements.

Shadow robotic arm

PULLING POWER
Air muscles were invented in the 1950s for artificial limbs (p. 36), and rediscovered by UK robot company Shadow. Each air muscle is simply a balloon inside a cylindrical net cover. When inflated, the balloon stretches the cover sideways, making it shorter and creating a pulling action. Air muscles are relatively cheap and lightweight compared to other pneumatic systems used to move robots.

A whole group of muscles is needed to move the fingers, as in the human body.

The air muscles in the forearm connect to tubes in the upper arm.

These tubes link to an air compressor, which provides the power behind Robug III's movements.

Most of Robug III's body is made of light, strong carbon fibre.

Each leg has four joints, which can operate separately or as a group.

It repeats the same sequence over and over again.

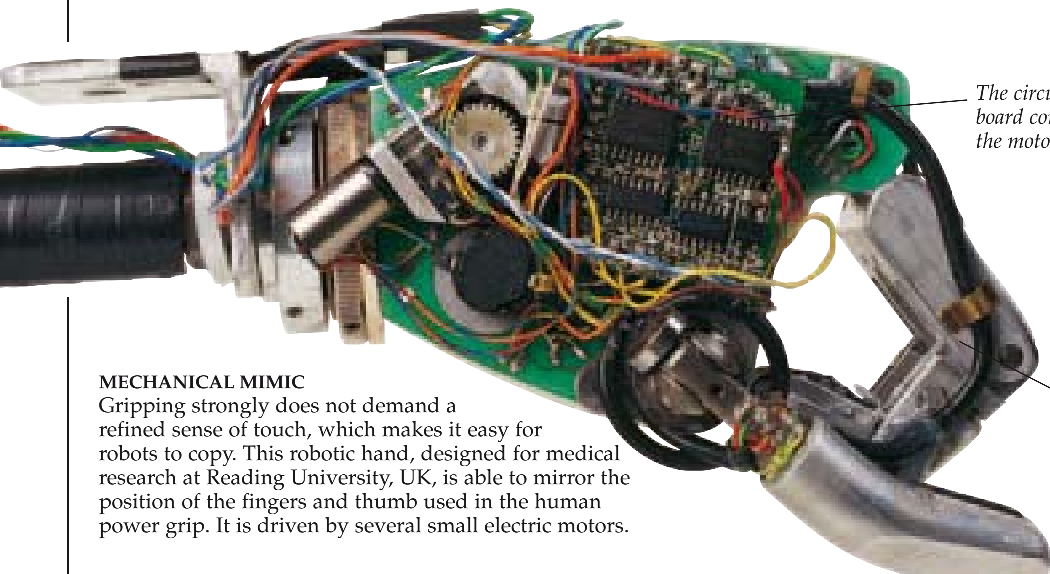
It can clamber over uneven ground.

It leans forwards to help itself balance.

Robot senses

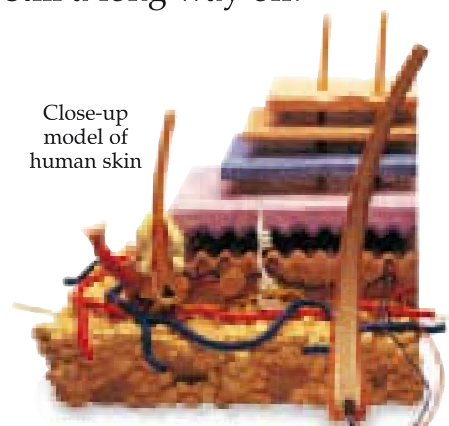
TO SURVIVE IN THE real world, robots need to be able to see, hear, feel, and tell where they are. Giving a robot the power to understand objects in the world around it is one of the most complex challenges of modern robotics. Machines already exist that can respond to touch, avoid bumping into things, react to sounds and smells, and even use senses, like sonar, that humans do not have. A robot that can sense as fully and reliably as a human, however, is still a long way off.

POWER GRIP
When people grip an object like a hammer, they curl their four fingers and thumb around it. They can exert great force, but cannot position or move the object precisely. Robot hands can mimic this power grip well.



The circuit board controls the motors.

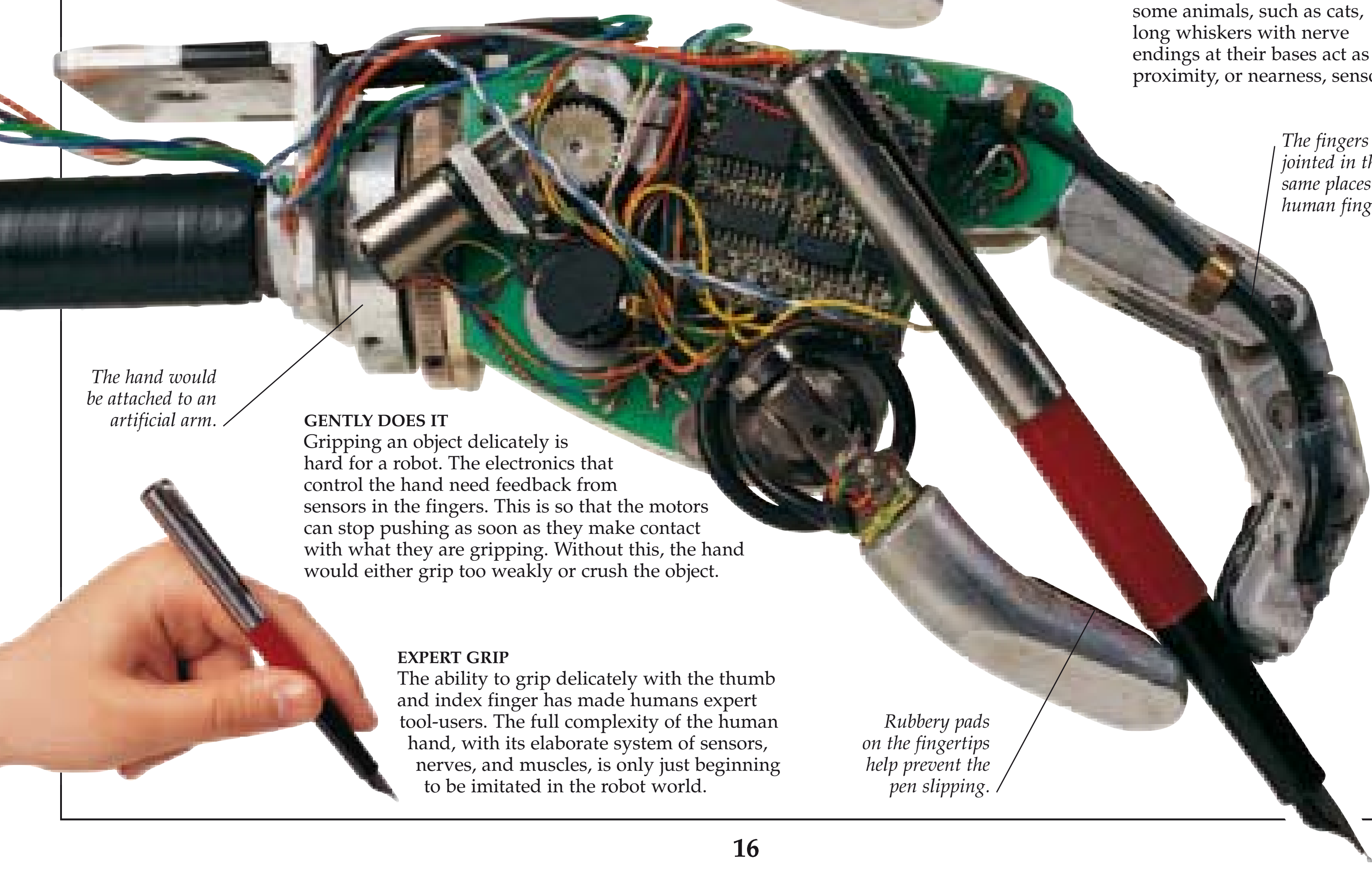
The robotic hand cannot curl up as tightly as a human hand.



Close-up model of human skin

MECHANICAL MIMIC
Gripping strongly does not demand a refined sense of touch, which makes it easy for robots to copy. This robotic hand, designed for medical research at Reading University, UK, is able to mirror the position of the fingers and thumb used in the human power grip. It is driven by several small electric motors.

SENSITIVE ALL OVER
Robots cannot compete with the all-over sensitivity of animals, whose skin contains a dense network of sensitive nerve endings. These act as touch and bump sensors, and also detect heat or cold. In some animals, such as cats, long whiskers with nerve endings at their bases act as proximity, or nearness, sensors.



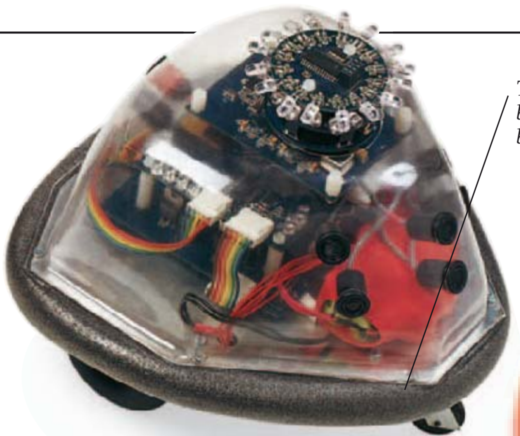
The fingers are jointed in the same places as human fingers.

The hand would be attached to an artificial arm.

Rubbery pads on the fingertips help prevent the pen slipping.

GENTLY DOES IT
Gripping an object delicately is hard for a robot. The electronics that control the hand need feedback from sensors in the fingers. This is so that the motors can stop pushing as soon as they make contact with what they are gripping. Without this, the hand would either grip too weakly or crush the object.

EXPERT GRIP
The ability to grip delicately with the thumb and index finger has made humans expert tool-users. The full complexity of the human hand, with its elaborate system of sensors, nerves, and muscles, is only just beginning to be imitated in the robot world.



The rubbery bumper contains bump sensors.

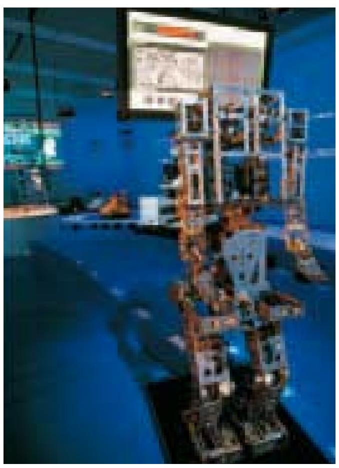
Pulses of infrared light emitted by the LEDs can be detected by the other robots in the group.

FAR OR NEAR
This police officer is using a radar gun to detect how quickly cars are moving towards him. Some robots use similar technology to sense their distance from walls and other objects. They emit sound waves that bounce off objects, indicating their distance and speed of approach.

CLOSE ENCOUNTERS
Interactive robots that travel in groups need a range of senses. One of the most basic of these, touch, can be provided by a bumper. When the robot runs into something, the bumper makes an electrical contact that sends a signal to the robot's computer. The robot then backs off a little, changes direction, and carries on. Infrared signals allow robots in a group to communicate. Light-emitting diodes (LEDs) are used to release waves of infrared light that tell robots how near they are to each other.

This LED system is fully assembled and ready to be put to use.

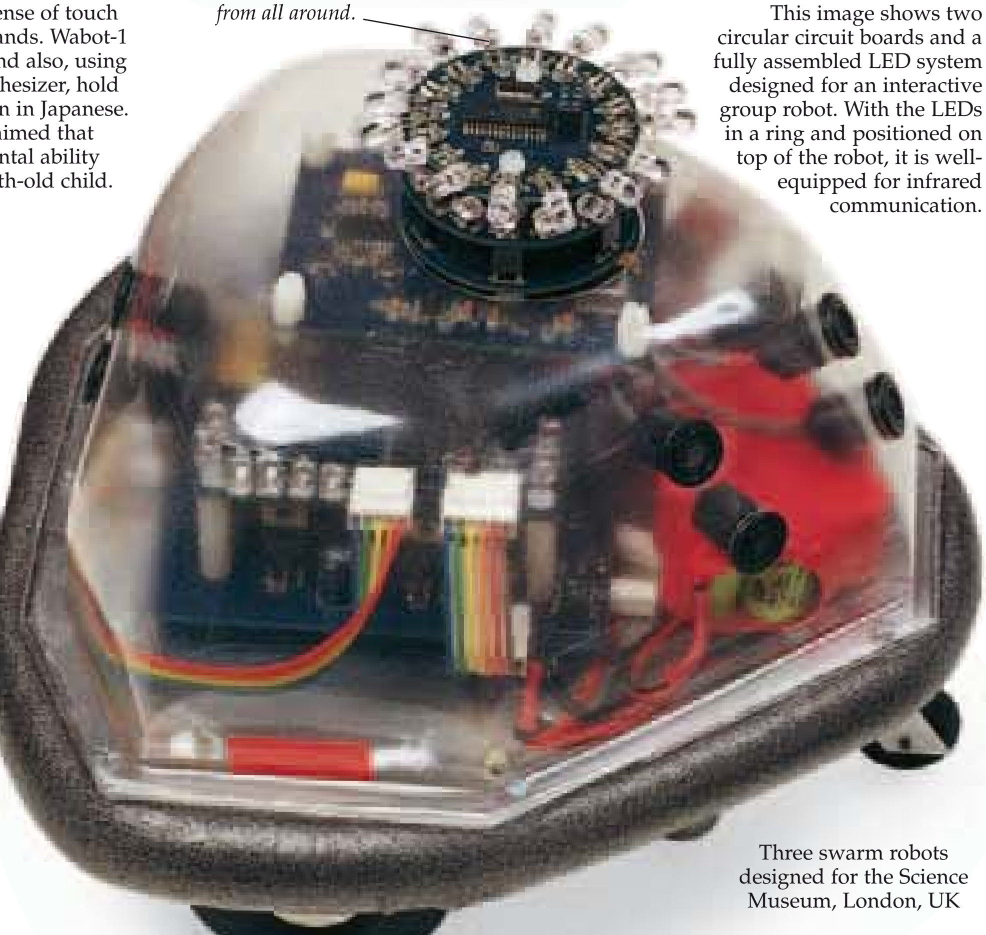
LIGHT WORK
This image shows two circular circuit boards and a fully assembled LED system designed for an interactive group robot. With the LEDs in a ring and positioned on top of the robot, it is well-equipped for infrared communication.



SENSE OF HISTORY
The first robot equipped with anything like human senses was Wabot-1, built at Waseda University, Japan, in 1973. It had artificial ears, eyes, and a sense of touch in its robot hands. Wabot-1 could walk and also, using a speech synthesizer, hold a conversation in Japanese. Its makers claimed that it had the mental ability of an 18-month-old child.

The LEDs form a circle so their light can be detected from all around.

ARTIFICIAL EYES
Real guide dogs use their sight to help their blind owner to get around. The GuideCane detected objects using pulses of sound too high to hear. It was invented by Johann Borenstein at the University of Michigan in the USA. When it sensed something in its path, it steered its owner safely around the obstruction.



Three swarm robots designed for the Science Museum, London, UK

Artificial intelligence

BRAIN POWER
The human brain has 100 billion nerve cells. These combine information from the outside world with stored memories to produce actions that help its owner survive. Other animal brains do this too, but only humans can master tasks as complex as speech and writing. Today's robot brains operate at the level of very simple animals.

PEOPLE AND ANIMALS are intelligent. They can work things out from incomplete information. A machine that could do this would have artificial intelligence. Scientists have had some success with AI. For example, computers can now help doctors tell what is wrong with patients. Experts still do not agree, however, on whether a truly intelligent machine can be built, or how to build one. Complex computer programs have so far failed to provide robots with truly effective brains. It is now hoped that lots of small, simple programs can work together to create a really intelligent robot.

INTELLIGENT FANTASY
This scene from Steven Spielberg's 2001 film *AI* shows David, a robot child, at an anti-robot rally called a Flesh Fair. David is programmed to form an unbreakable bond of love with a human mother. When abandoned, he begins a quest to become a real boy. Intelligent behaviour like this is a long way from the capabilities of real robots.

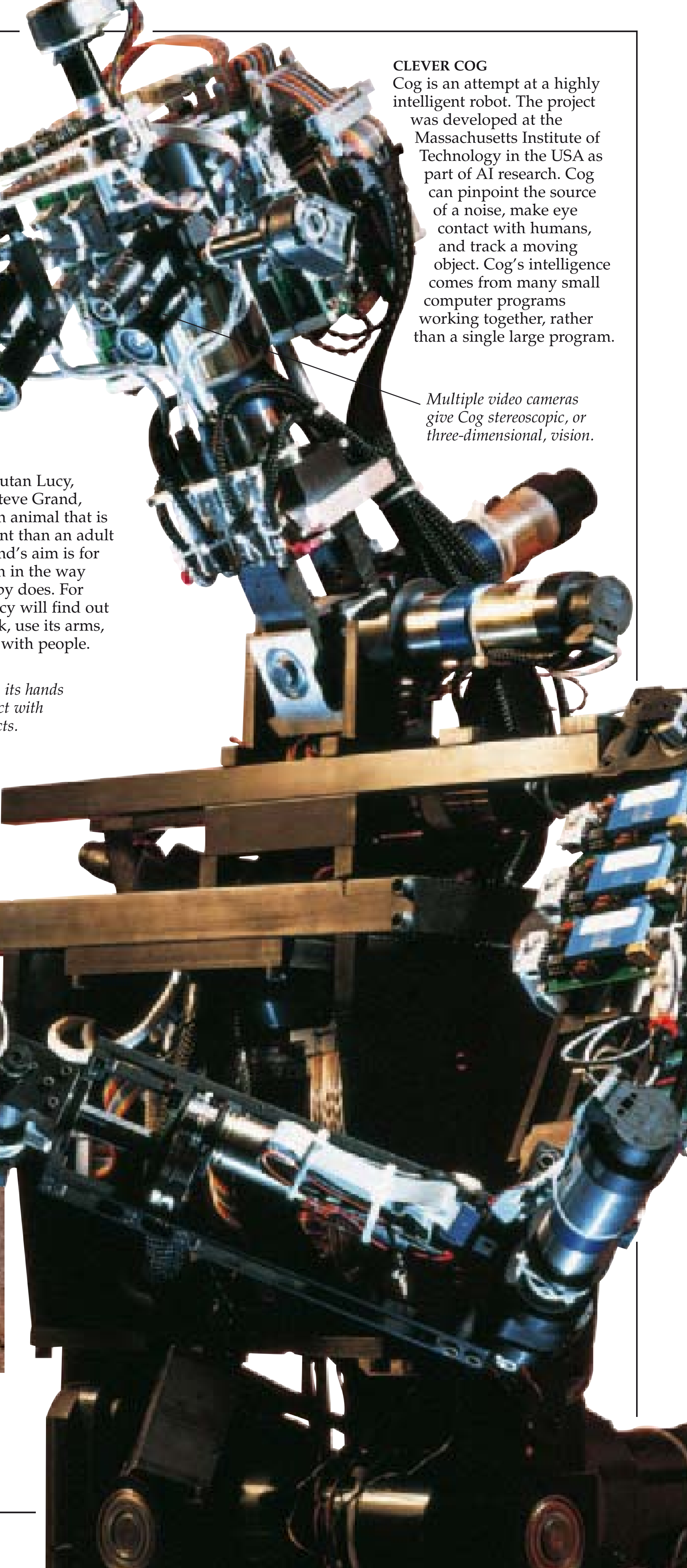
CHESS CHAMP
On 11 May 1997, a chess-playing computer called Deep Blue forced world chess champion Garry Kasparov to resign from a game. It was the first time that a reigning world champion had lost to a computer under tournament conditions. Although Deep Blue had managed to outwit a human in an intellectual contest, it would not be able to answer the simple question "Do you like chess?"

COOL CALCULATOR
Designers are now trying to make ordinary home appliances a little brainier. Computers and sensors inside everyday gadgets allow them to make smart decisions. This fridge, as well as bringing the Internet right into the kitchen, can also help its busy user by coming up with ideas for meals based on the food currently stored in it.

"It's possible that our brains are too complicated to be understood by something as simple as our brains."

AARON SLOMAN
Professor of Artificial Intelligence, Birmingham University, UK

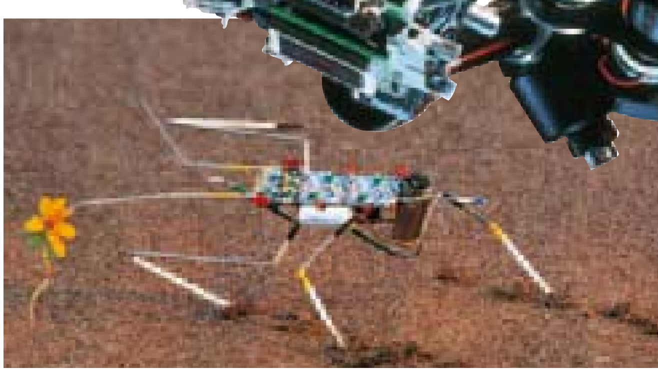
BABY BOT
Robot orangutan Lucy, created by Steve Grand, represents an animal that is less intelligent than an adult human. Grand's aim is for Lucy to learn in the way a human baby does. For example, Lucy will find out how to speak, use its arms, and interact with people.



CLEVER COG
Cog is an attempt at a highly intelligent robot. The project was developed at the Massachusetts Institute of Technology in the USA as part of AI research. Cog can pinpoint the source of a noise, make eye contact with humans, and track a moving object. Cog's intelligence comes from many small computer programs working together, rather than a single large program.

Multiple video cameras give Cog stereoscopic, or three-dimensional, vision.

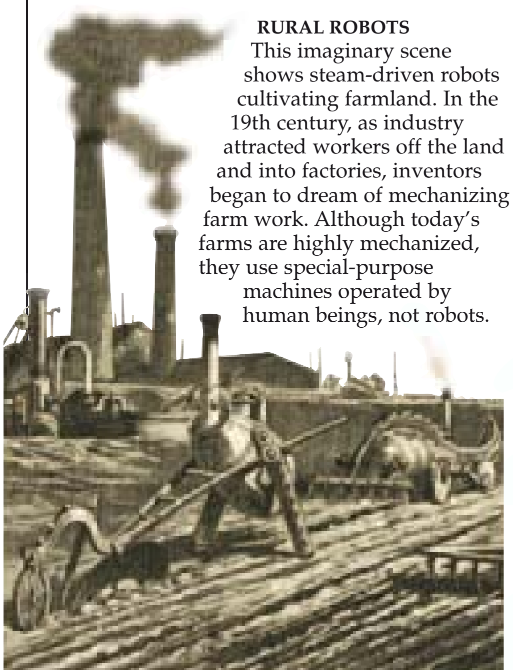
Cog uses its hands to interact with real objects.



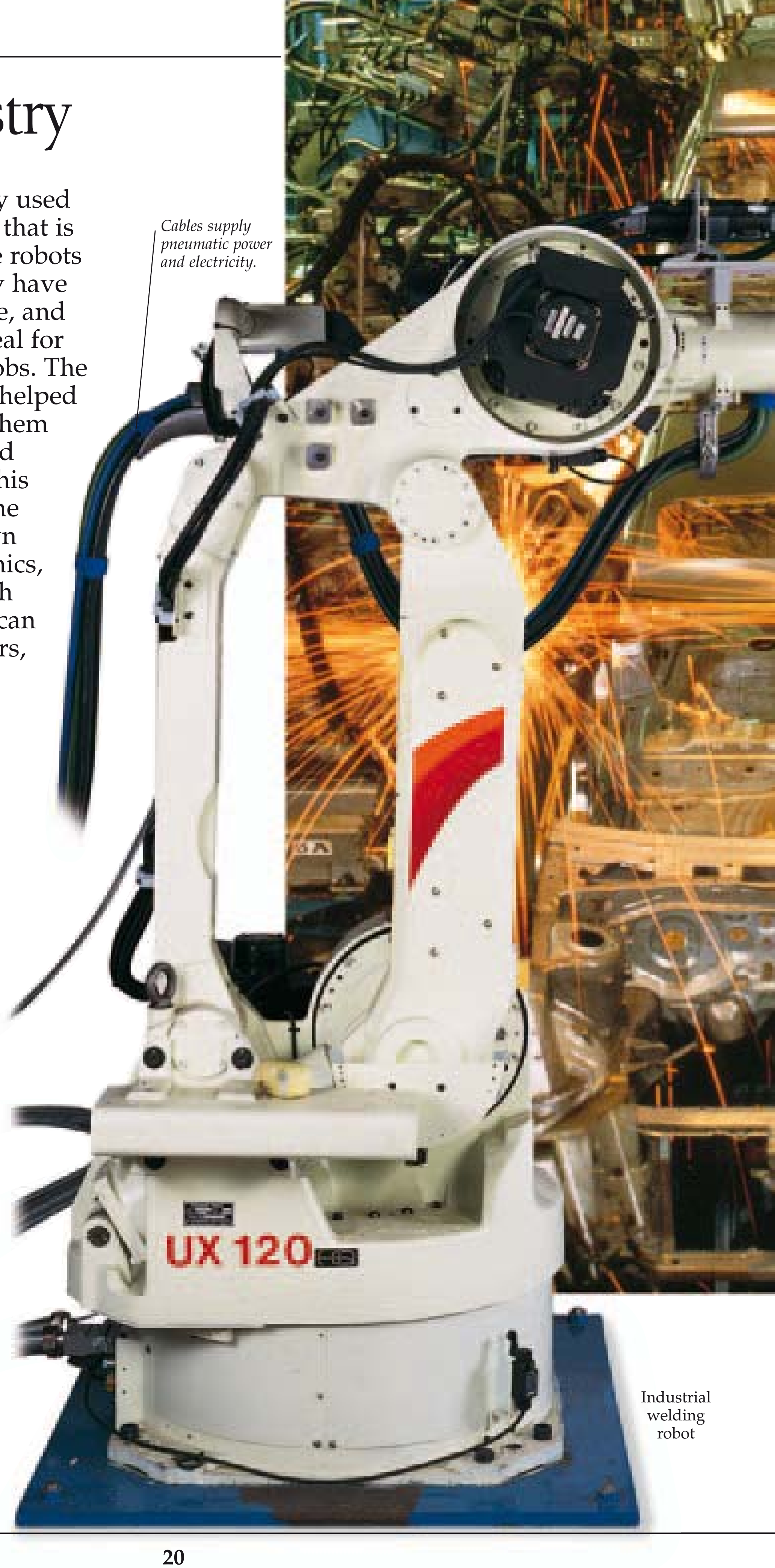
THAT'S LIFE
Artificial life researcher Mark Tilden designed this robot insect. He believes robots can evolve like natural organisms. This kind of AI coaxes complex behaviour from simple components. The idea is used in computer programs that simulate nature to produce virtual creatures that learn, breed, and die.

Robots in industry

THE WORD ROBOT was originally used to describe factory workers, and that is just what the majority of real-life robots are. Unlike human workers, they have limitless energy, little intelligence, and no feelings. This makes them ideal for tiring, repetitive, or dangerous jobs. The earliest industrial robots simply helped ordinary machines by bringing them materials, or stacking the finished product. Many are still used in this way, but many more have become production machines in their own right, assembling cars or electronics, and even doing delicate jobs with plants or food. Although robots can not yet replace all human workers, they have made the world's factories much more productive.



RURAL ROBOTS
This imaginary scene shows steam-driven robots cultivating farmland. In the 19th century, as industry attracted workers off the land and into factories, inventors began to dream of mechanizing farm work. Although today's farms are highly mechanized, they use special-purpose machines operated by human beings, not robots.



Cables supply pneumatic power and electricity.

Industrial welding robot

WELL WELDED
A robot-built car is a safer car, because robots never miss out any of the thousands of welds it takes to assemble a car body. Today's cars are built on assembly lines, where rows of robots wield heavy welding guns in a shower of sparks. Because the robots cannot see, both the cars and the welding guns have to be positioned with great accuracy to ensure that all the welds come in the right place.

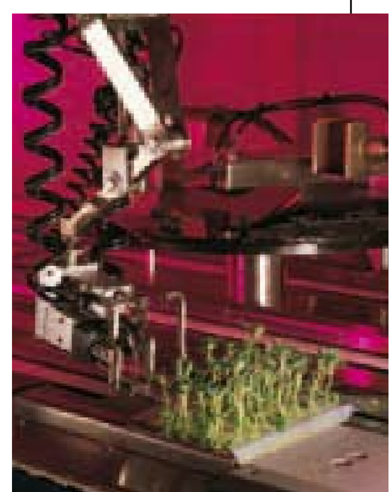
Humans can spread germs on hands, hair, and clothing.

Electrodes at the tip of the welding arm apply an electric current that fuses together pieces of metal.

Robots welding cars on an assembly line

UNTOUCHED BY HAND
Sushi is now a popular dish outside its original home in Japan, and robots are helping to meet demand. This sushi robot is in the USA. It can be reprogrammed to make many different varieties.

HANDMADE SUSHI
Making sushi is a skilled job because customers like their sushi to look like a work of art. Strips of fish are combined with cooked rice, seasoned, and formed into rolls or balls. Hygiene is also important because the fish is served raw. This is where robots can make the greatest contribution.



SEEDS OF THE FUTURE
This robot in a US agricultural lab is gently teasing out baby potato plants so that they can be put into individual pots. They will then produce seed potatoes, which will, in turn, produce crops of potatoes. Using robots in this way allows plant breeders to cultivate new varieties more quickly.

1980s Unimate model

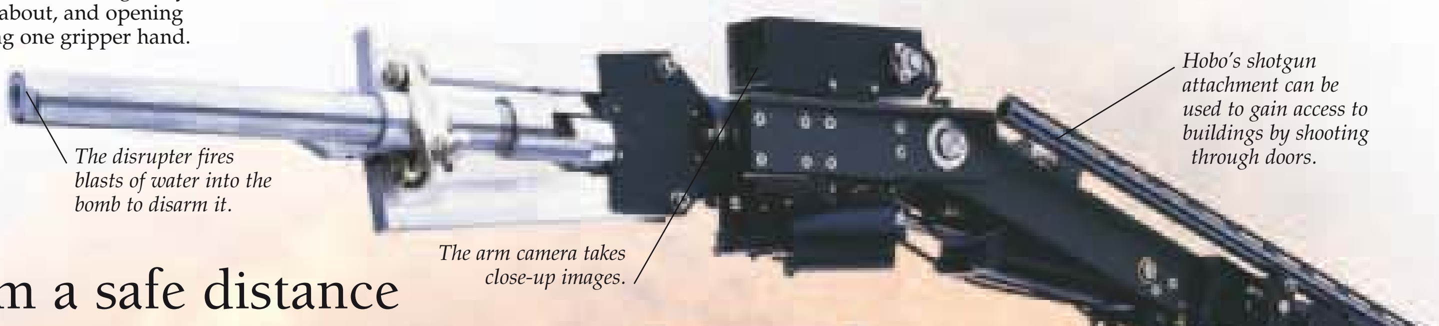
Unimate can be programmed to position parts with great accuracy.

FACTORY FIRST
The first industrial robot, Unimate, started work at General Motors in 1961. Unimate was originally designed to help make television picture tubes, but was used to stack hot metal parts. It followed step-by-step commands stored on a magnetic drum, and could lift nearly 2 tonnes. The robot was created by US engineers Joe Engelberger and George Devol.

Remote control

MANY OF TODAY'S robots are unable to make their own decisions. They would be helpless without a human sending them a constant stream of instructions by wire or radio. Strictly speaking, they are not robots at all, just machines that obey orders. Remote control is a way of getting round the problem of providing a machine with the knowledge and skill it needs to deal with the real world. It allows robots with little intelligence to do valuable jobs in science, industry, police work, medicine, and even archaeology.

DOMESTIC DUMMY
Omnibot 2000, launched in 1980 by the Tomy toy company, was an early domestic robot. It had little intelligence, so its owner had to use remote control to make the most of its limited capabilities. These included flashing its eyes, wheeling about, and opening and closing one gripper hand.



The disrupter fires blasts of water into the bomb to disarm it.

The arm camera takes close-up images.

Hobo's shotgun attachment can be used to gain access to buildings by shooting through doors.

From a safe distance

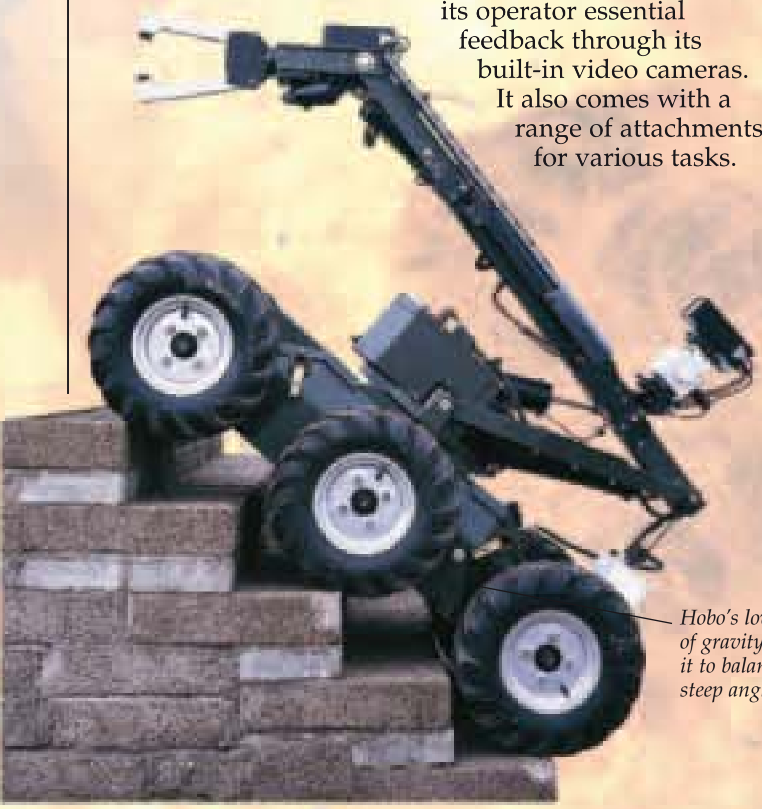
The Hobo remotely operated vehicle was developed in the 1980s to disarm terrorist bombs. It needed to be strong, reliable, and versatile to do its job. These qualities have since made it useful to the police, army, customs services, and private companies. Hobo gives its operator essential feedback through its built-in video cameras. It also comes with a range of attachments for various tasks.

COMMAND AND CONTROL
Hobo is controlled through this tough, portable console, which transmits signals to the receiver mounted on the back of the robot. Using the pictures from Hobo's cameras, a bomb-disposal expert can move the robot, its arm, and its tools until the threat is neutralized.

Claw used to grab objects

Probe used to break windows

Disrupter used to disarm bombs



Hobo's low centre of gravity enables it to balance at steep angles.

ONWARDS AND UPWARDS
Hobo can go almost anywhere a human soldier could. Specially designed wheels and axles mean that kerbs, steps, and bomb debris are no obstacle. It can turn in a small space and lift weights of 75 kg (165 lb). Hobo's advanced electronics stand up to rough handling, while its batteries are automatically managed to ensure they do not go flat at a critical moment.

The drive camera is fixed in one position.

REALLY REMOTE
Robots can be controlled from almost any distance. *Sojourner*, part of the NASA Pathfinder mission, was the first robot to be controlled from Earth after landing on Mars. Because radio waves take seven minutes to get to Mars and back again, *Sojourner*'s controller could give only general instructions. For the detail, the robot was on its own and worked independently.

A speakerphone and video camera are located in the head.

NET EFFECT
CoWorker is the first off-the-shelf robot designed to be controlled via the Internet. Equipped with a camera and phone, it will trundle around factories and offices on command, allowing an expert to assess a situation or take part in a meeting without travelling to the site.

Souryu is equipped with a camera and microphone to help it locate survivors.

FLEXIBLE FIND
Getting a camera into a pile of rubble to search for earthquake victims is a job for Souryu, which means Blue Dragon. It is a remote-controlled, snake-like robot devised at the Tokyo Institute of Technology in Japan. The sections of its body can swivel independently to almost any angle, while its caterpillar tracks can get a grip on even the rockiest surface.

The rear video camera can be used to aim the shotgun.

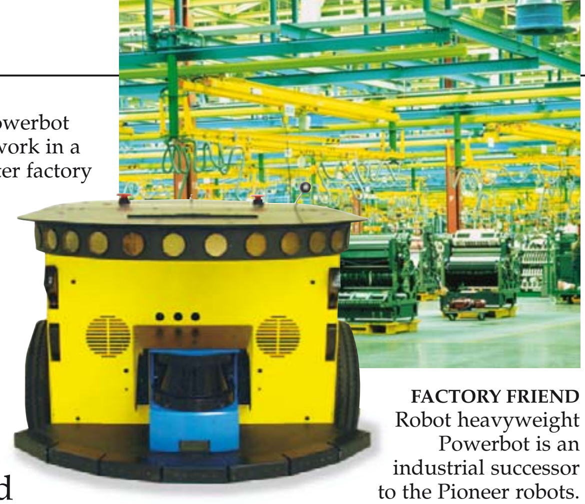
Hobo's remote control unit receives messages from its operator.

Each wheel is driven by a separate motor.

CRATER NAVIGATOR
Dante 2 looked like a huge robotic spider. It had sensors in its legs that allowed them to operate automatically, but was also remote-controlled. In the summer of 1994, amid smoke and ash, it descended the crater of the Mount Spurr volcano in Antarctica on an experimental mission. Unfortunately, its legs buckled when it hit a rock, and the badly damaged robot had to be rescued by helicopter.

Ready-made robots

WHAT IF YOU HAVE an idea that demands a robot, but do not have the time or ability to design and make exactly what you need? An off-the-shelf model may be the answer. Today, ready-made robots come in various sizes, with accessories to adapt them for many purposes. They can be used for research, as exhibition guides, and in industry, where they carry products and documents around factories. Most of these machines are descendants of the first truly mobile robot, Shakey, completed as long ago as 1972, but are much smaller, lighter, and cheaper.



Powerbot at work in a printer factory

FACTORY FRIEND
Robot heavyweight Powerbot is an industrial successor to the Pioneer robots. It can travel at 10 kph (6 mph), carry 100 kg (220 lb), and is water resistant. Powerbot can find its way around using its own intelligence, but it allows manual override. Uses include delivery, collection, inspection, and surveillance.

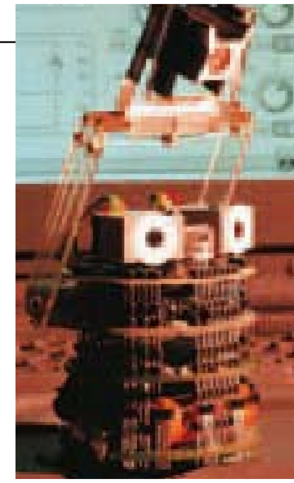
READY-MADE FAMILY
Flakey was one of a line of mobile robots starting with Shakey and ending with today's ready-mades. It was developed by Kurt Konolige at the Stanford Research Institute in the USA. A heavyweight at 140 kg (300 lb), Flakey had two independently driven wheels, 12 sonar rangefinders, a video camera, and several on-board computers.

TEAM PLAYER
Designed for home-help and education, as well as professional research, Amigobot is based on Pioneer. Teachers like this robot's sturdy reliability and its versatile programming options. It is also designed to work in teams (pp. 56–57) with other Amigobots and can be adapted to play football.

CHEAP CHAMP
Pioneer I is a descendant of Flakey, via Erratic, a lower-cost research robot. Kurt Konolige developed Pioneer 1 as a commercial version of Erratic. The result was a robot that cost ten times less, and universities could at last afford to teach robotics. Pioneer 1, fitted with football-playing accessories, won the RoboCup Soccer Championship in 1998. It was succeeded by Pioneer 2.

ONE OF THE PEOPLE
Peoplebot is another offspring of the Pioneer robots. It is specifically designed to interface with people. It has a waist-high module, which contains a microphone and speakers for voice interaction. Peoplebot can act as a tour guide, receptionist, messenger, or security guard.

SMALL BUT CAPABLE
The Swiss-made Khepera, popular with experimenters and hobbyists, is perhaps the best known ready-made robot. It measures only 55 mm (2 in) in diameter and weighs just 70 g (2 oz). Using the same software as other robots descended from Shakey, it is often a player in robot football matches.



The cameras, which look like eyes on stalks, can tilt to get a panoramic view of the robot's surroundings.

BIG BROTHER
At 30 cm (1 ft) across, with six rugged wheels, Koala is Khepera's big brother and is capable of proper work. For example, it can clean floors with a vacuum cleaner when a special arm is attached. It is similar to Khepera, so any new ideas for it can be tried out on the smaller robot first.

A colour camera takes snapshots of what the robot sees.

Accessories can be mounted on Amigobot's back.

The aerial receives messages from the radio control unit.

Amigobot is equipped with sonar sensors.

HI-TECH TEACHER
In the 1980s, a robot called Nutro, operated remotely by a human teacher, toured the USA to teach children about the importance of a healthy diet. Real robots are not yet clever enough to do all the work of teachers themselves, but a remote-controlled one can make a lesson more memorable.

Robots in the classroom

When you use a computer at school, it is usually just a box on a table. However, some school computers have now sprouted wheels or legs and can roam around. They have become robots. Robots designed for classroom use are a fun way of learning basic maths. They can also be used to introduce students to computer programming and help them discover how machines are controlled. Some classroom robots are used by young children, who enjoy this playful, interactive approach to learning. At a much higher level, in colleges and universities, a classroom robot is essential for teaching the art and science of robotics to potential robot engineers of the future.

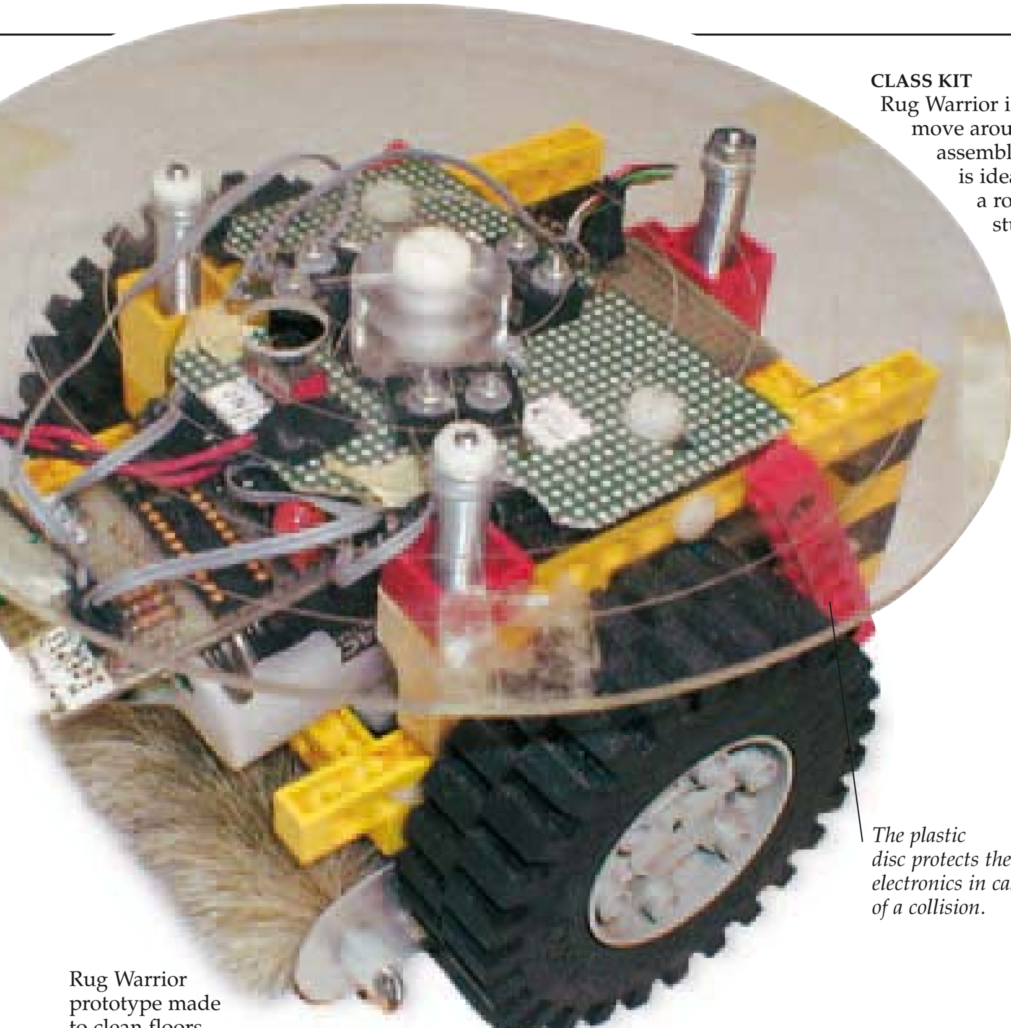
MATHS TEACHER
South African mathematician Seymour Papert started interest in educational robots in the late 1960s. He had the idea of teaching children maths by letting them play with a computer-controlled turtle that moved on a sheet of paper to draw shapes and patterns. He invented a simple but powerful programming language called Logo for the turtle.

Children program Roamer to follow a path

TURTLE POWER
Turtle robots are now commonly used to introduce children to computer programming. This remote-controlled turtle, made by Valiant Technology, converts infrared signals from a computer into moves, turns, and pen action.

Roamer robot decorated with eyes

ROAM AROUND
Roamer is a round robot with concealed, motorized wheels. It can be programmed simply by pressing buttons on its cover, so it is popular in primary schools. Children can use Roamer to improve basic skills such as counting and telling left from right. The robot trundles around the classroom as instructed or moves a pen across paper to draw patterns. It can also play tunes. Teachers often encourage children to dress up their class robot as a pet or a monster.

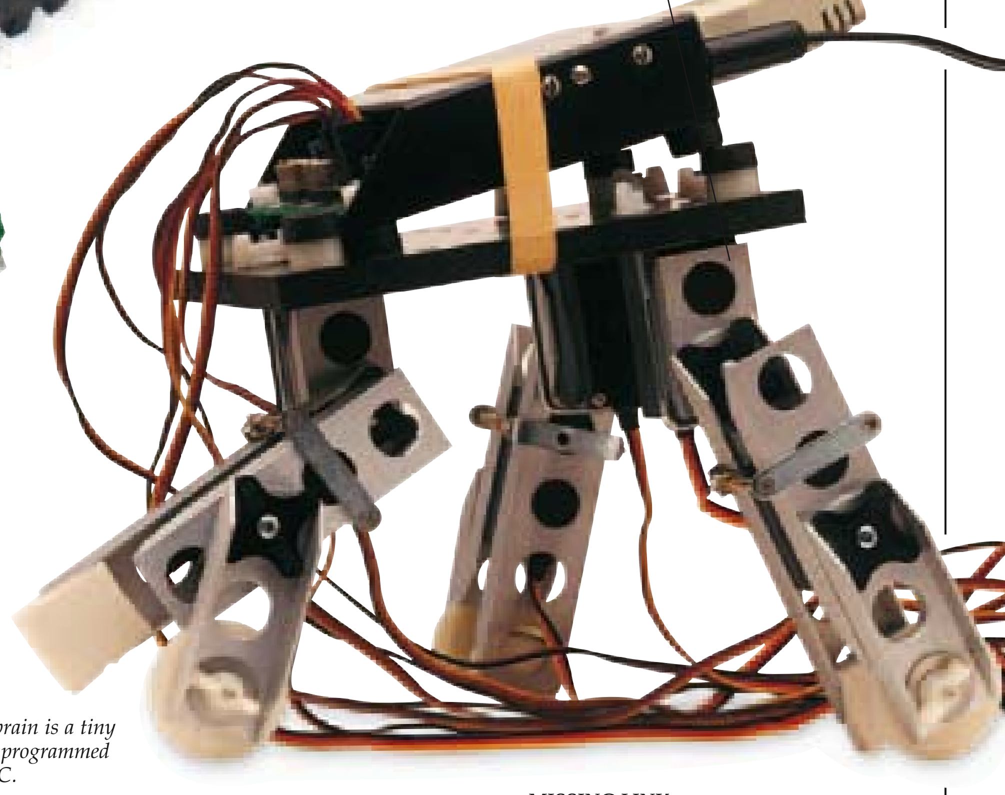


The plastic disc protects the electronics in case of a collision.

Rug Warrior prototype made to clean floors

CLASS KIT
Rug Warrior is a small, intelligent mobile robot that can move around by itself. It comes as a kit that users have to assemble, and can easily be programmed from a PC, so is ideal for learning robotics. Rug Warrior is based on a robot developed for teaching robotics to university students. It is now one of the best-selling robot kits.

SUMMER SCHOOL
In the USA, the Carnegie Mellon University Mobile Robot Programming Lab runs summer courses for students interested in robotics. The students build and program mobile robots, which they are allowed to take home and keep when the course is over.



The links are the bones of the robot and the motors are its muscles.

Freddy's brain is a tiny computer programmed using a PC.

MIND GAMES
Freddy is a humanoid robot created using a kit called Lego Mindstorms. The kit allows children to design, build, program, and use their own robots. It was developed by Seymour Papert and Danish toy company Lego.

MISSING LINK
Robix construction kits are used to build robots that can walk, throw balls, and even make cups of tea. The kits are popular in the USA for teaching robotics and engineering at all levels, from high school to university. The kits consist of metal links, which are joined with computer-controlled motors.

Playing with robots

THE IDEA OF A toy that appears to have a mind of its own would appeal to most children. Although early models were no more than plastic shapes with flashing lights, the latest toys can see, hear, and respond to commands from their owner, as well as exhibiting a range of emotions. Some even fall asleep at bedtime. Whatever the level of their abilities, designing robot toys is more than child's play for roboticists. It has provided them with a challenge to create better robots that can then be adapted for more serious purposes.

WALKIE TALKIE
This 1950s toy robot was highly sophisticated for its time. It moved along, guided by a remote-control tether. It also showed the shape of things to come by being able to talk. But it was still a long way from being able to respond to human speech.

IT'S A WIND UP
The first toy robots were often made from cheap printed metal, powered by clockwork, and wound up with a key. Toy-makers had been producing moving figures using this method since the 19th century, but toys shaped like robots only became popular in the 1930s.

A green light flashes when the robot is switched on.

Early plastic, battery-powered toy robot

The legs are driven by an electric motor.

BATTERY BOT
By the 1960s, when cheap plastics, efficient electric motors, and good batteries had been developed, more sophisticated toy robots began to appear. The use of plastics allowed more elaborate body shapes, while battery power made it possible to add extras like flashing lights and beeping sounds.

The speaker is located behind the switch on Furby's tummy.

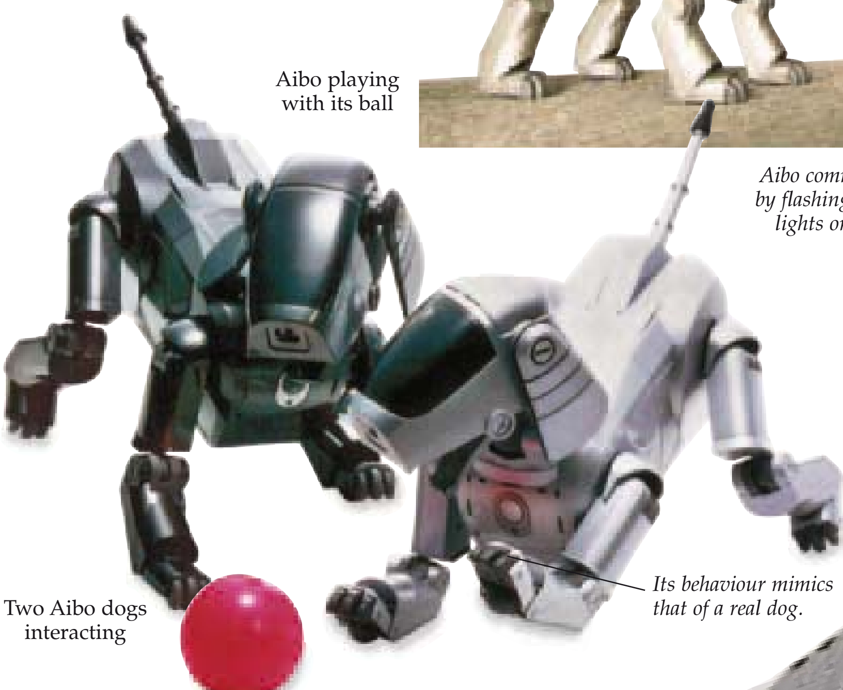
Furby without its fur coat

A selection of the many Furby varieties

FURRY FRIEND
Furby is a furry robotic creature with moving ears, eyes, and mouth. It can talk, sing, dance, and respond to its owner. It demands constant attention, but automatically sleeps when night falls. Furby was launched by toy designer Dave Hampton and Tiger Electronics in 1998 and was hugely popular.

The dog can obey basic commands.

Aibo playing with its ball



Its behaviour mimics that of a real dog.

Two Aibo dogs interacting

Aibo communicates by flashing coloured lights on its head.

1999 ERS-110 Aibo model

PERFECT PETS
Sony's robotic dog, Aibo, is programmed with basic instincts to sleep, explore, exercise, and play. It can also express joy, sadness, anger, surprise, and fear using a combination of lights, sounds, and gestures. Aibo first went on sale in 1999. Since then, Sony has developed the toy to make it less expensive and more reliable. The latest models have an amazing range of abilities. They can even respond to the sound of their name and recognize their owner's face.

> *"Toys like Aibo ... will come to populate our world more and more."*
>
> **RODNEY BROOKS**
> *Robot – the Future of Flesh and Machines*

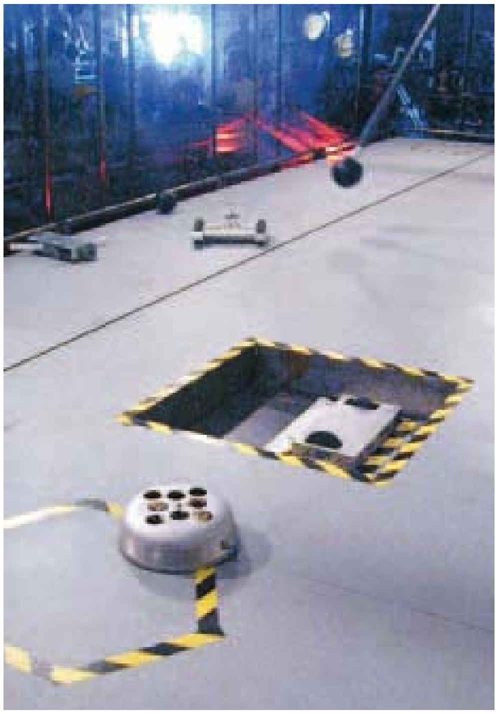
Battle of the bots

THE MACHINES ENTER the arena. Engines roar and metal flies. The battlebots are in action and the crowd goes wild. The challenge is to design and build a remote-controlled machine (not a true robot) that can travel quickly and reliably over a wide area and can outdo the others in strength and agility. It can be dangerous if you don't know what you are doing, but is great fun both to compete in and to watch. Many serious robot engineers regard combat robotics as a way of improving their skills. It is a rewarding and fun way of developing the components that are also part of more everyday, practical robots.

FIGHTING FOR FUN
Battling as entertainment has been popular since Roman times, when gladiators fought in arenas. Their fighting techniques are now copied by robots. Like gladiators, robot warriors need both strength and skill. The robots may have power-driven weapons and titanium armour, but humans still provide the skill – by remote control.

Repairs may be needed in between competition rounds.

WARRIORS GREAT AND SMALL
Combat robot contestants are divided into classes according to their weight to ensure fair fights. This competitor is working on a robot for a lightweight class. The classes range from monsters weighing 177 kg (390 lb) to sozbots, or sixteen-ounce robots, which weigh less than 0.5 kg (1 lb). There are also restrictions on the size of the robots and the weapons they carry. Explosives are not allowed!



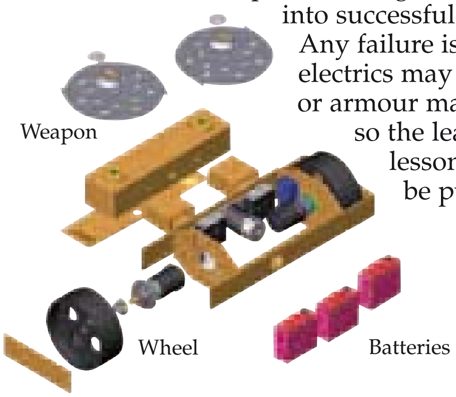
IN IT FROM THE START
One of the first robot combat events was BotBash, which started in the USA as two robots fighting in a chalk circle – much simpler than this recent BotBash arena. Today, events are organized by groups all over the world. Most follow rules laid down by the US Robot Fighting League.

The armoured shell is made from light but tough fibreglass matting.

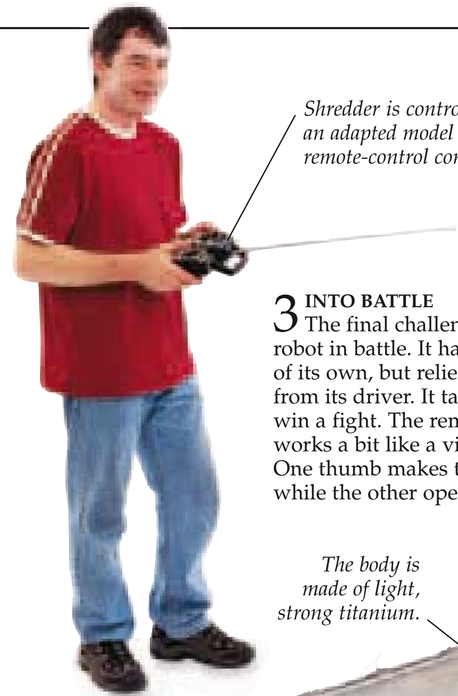
Matilda's tusk weapons are powered by hydraulics.

Building a battle robot

The challenge of finding solutions to technical problems is as interesting to many combat robot builders as the actual battles. British robot team Shredder is typical. It uses careful design and precision engineering to turn basic ideas into successful robotic fighting machines. Any failure is immediate and obvious – electrics may fail, motors may burn out, or armour may not withstand attack, so the learning curve is steep. But lessons learned the hard way can be put to use in other projects.



1 VIRTUAL ROBOT
The Shredder team first considers the weight of the components, what materials to use, how much power is required, and where to put the large batteries that will supply this. The team uses a computer to plan the design of their robot.

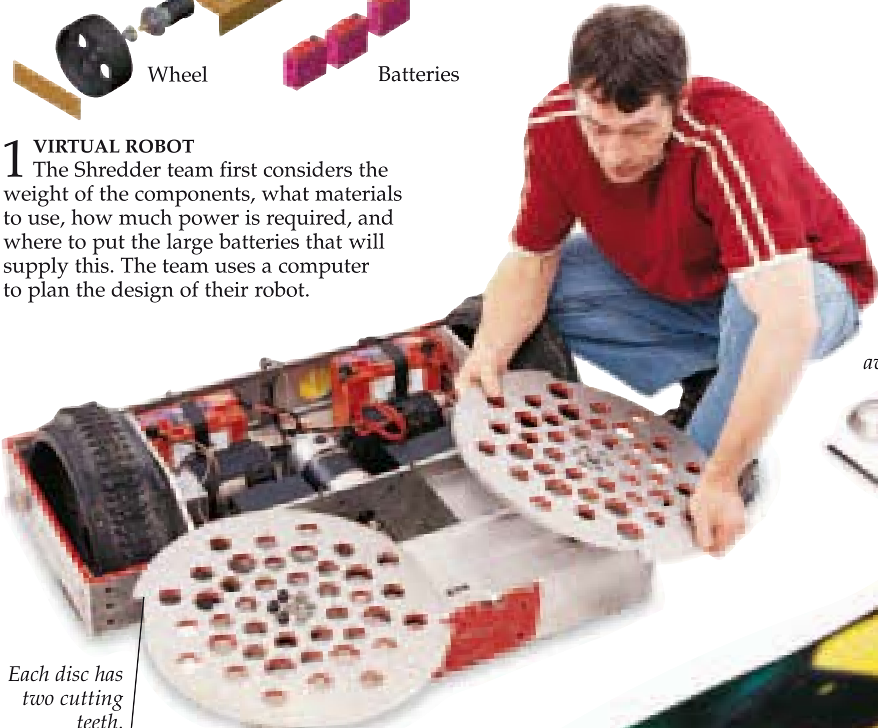


Shredder is controlled by an adapted model aircraft remote-control console.

3 INTO BATTLE
The final challenge is to test the robot in battle. It has no intelligence of its own, but relies on radio signals from its driver. It takes a lot of skill to win a fight. The remote-control unit works a bit like a video game console. One thumb makes the robot move, while the other operates the weapons.

The body is made of light, strong titanium.

The wheels are solid, not air-filled, to avoid punctures.



Each disc has two cutting teeth.

2 BUILDING THE BOT
A team member bolts on the robot's cutting discs, which rotate in opposite directions. The teeth on the edge of the discs are designed to cut through the tough armour of other battlebots. This is just part of the long and painstaking building process.

Two powerful lifting arms act as weapons.

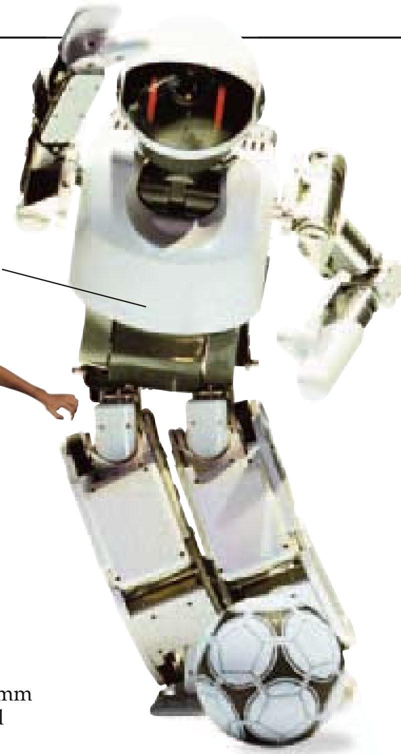
Dreadnaut has a low ground clearance to prevent other robots from flipping it over.

TV SPECTACULARS
Robot Wars is a television show in which robots built by competitors, like Dreadnaut, do battle with each other and with the show's resident robots, including dinosaur-like Matilda. Other fearsome resident robots are Shunt, which carries an axe that can cut opponents in half, and Dead Metal, which has pneumatic pincers and a circular saw. Battling robots make great TV!

19th-century illustration showing a steam-powered robot baseball pitcher

Sporting robots

THERE IS much to learn – and lots of fun to be had – building robots to play human sports. Robots already compete in simplified games, but matching the speed and skill of a human is proving to be a much tougher task. It is a worthwhile goal, though, because building a successful player will teach roboticists how to design better robots for everyday use. Today, a robot can walk across a pitch and kick a ball into an open goal. When it can run towards a goal defended by humans, and still score, the robot age will be here.

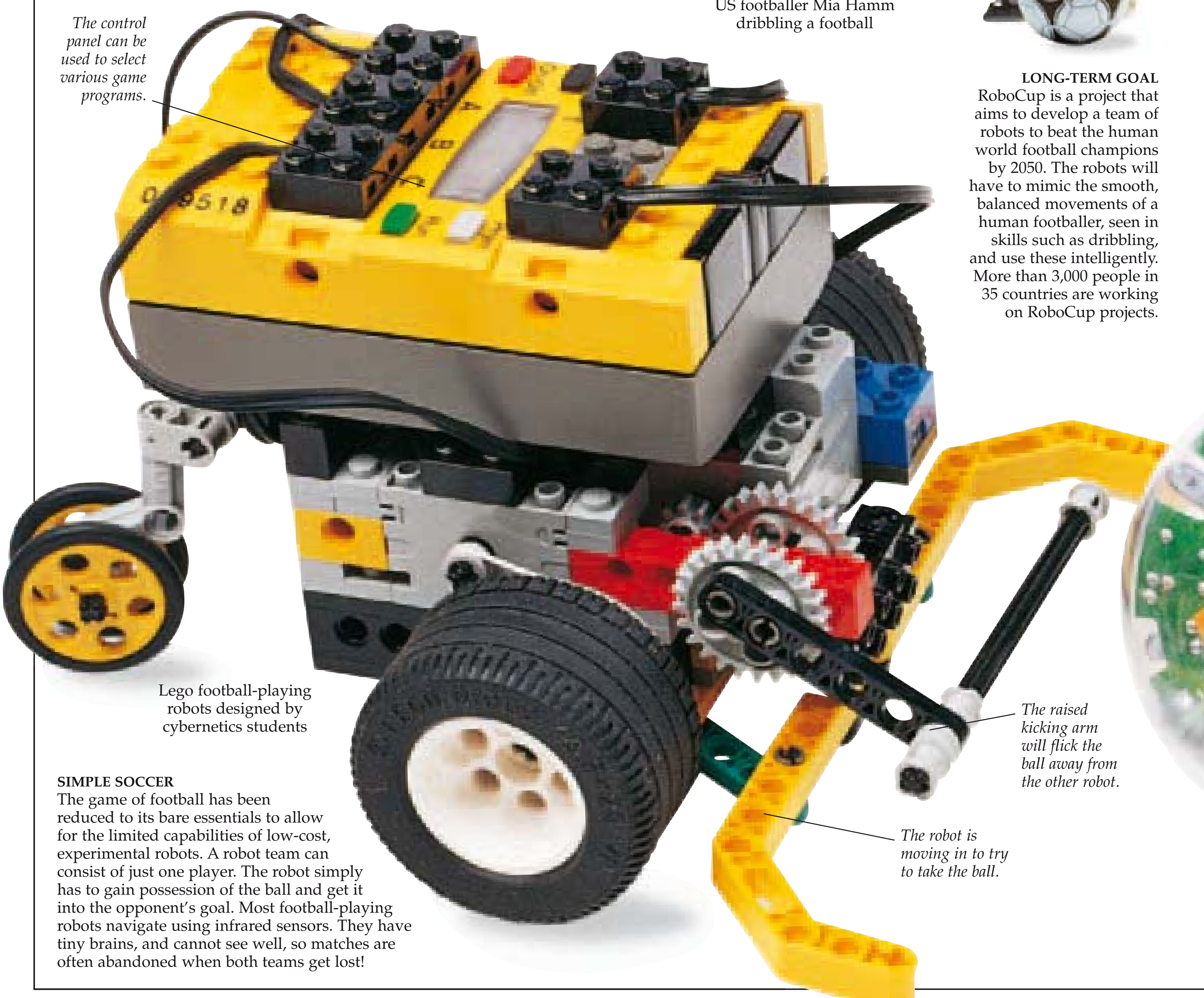


Humanoid robot SDR-3X dribbling a football

The robot's body position mimics that of the human footballer.

US footballer Mia Hamm dribbling a football

LONG-TERM GOAL
RoboCup is a project that aims to develop a team of robots to beat the human world football champions by 2050. The robots will have to mimic the smooth, balanced movements of a human footballer, seen in skills such as dribbling, and use these intelligently. More than 3,000 people in 35 countries are working on RoboCup projects.



The control panel can be used to select various game programs.

Lego football-playing robots designed by cybernetics students

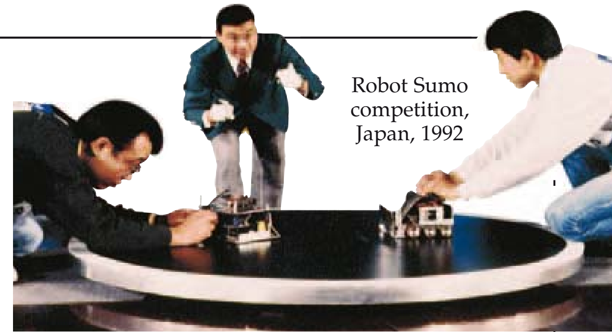
The raised kicking arm will flick the ball away from the other robot.

The robot is moving in to try to take the ball.

SIMPLE SOCCER
The game of football has been reduced to its bare essentials to allow for the limited capabilities of low-cost, experimental robots. A robot team can consist of just one player. The robot simply has to gain possession of the ball and get it into the opponent's goal. Most football-playing robots navigate using infrared sensors. They have tiny brains, and cannot see well, so matches are often abandoned when both teams get lost!

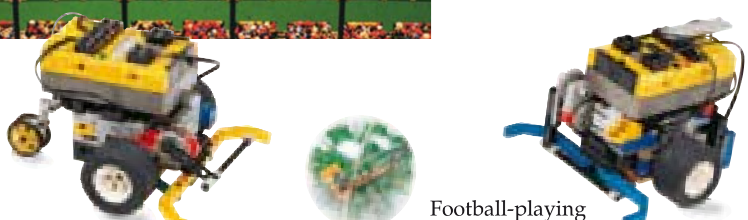
Robot Football World Cup, 1998

WORLD CLASS
More than 60 teams competed in the 1998 Robot Football World Cup in Paris, France. The robots played 20-minute matches without human help, controlled by on-board or remote computers and sensors. Since 2002, the competition has included humanoid robots. They cannot yet play games, but some can dribble and pass balls, and even score goals.



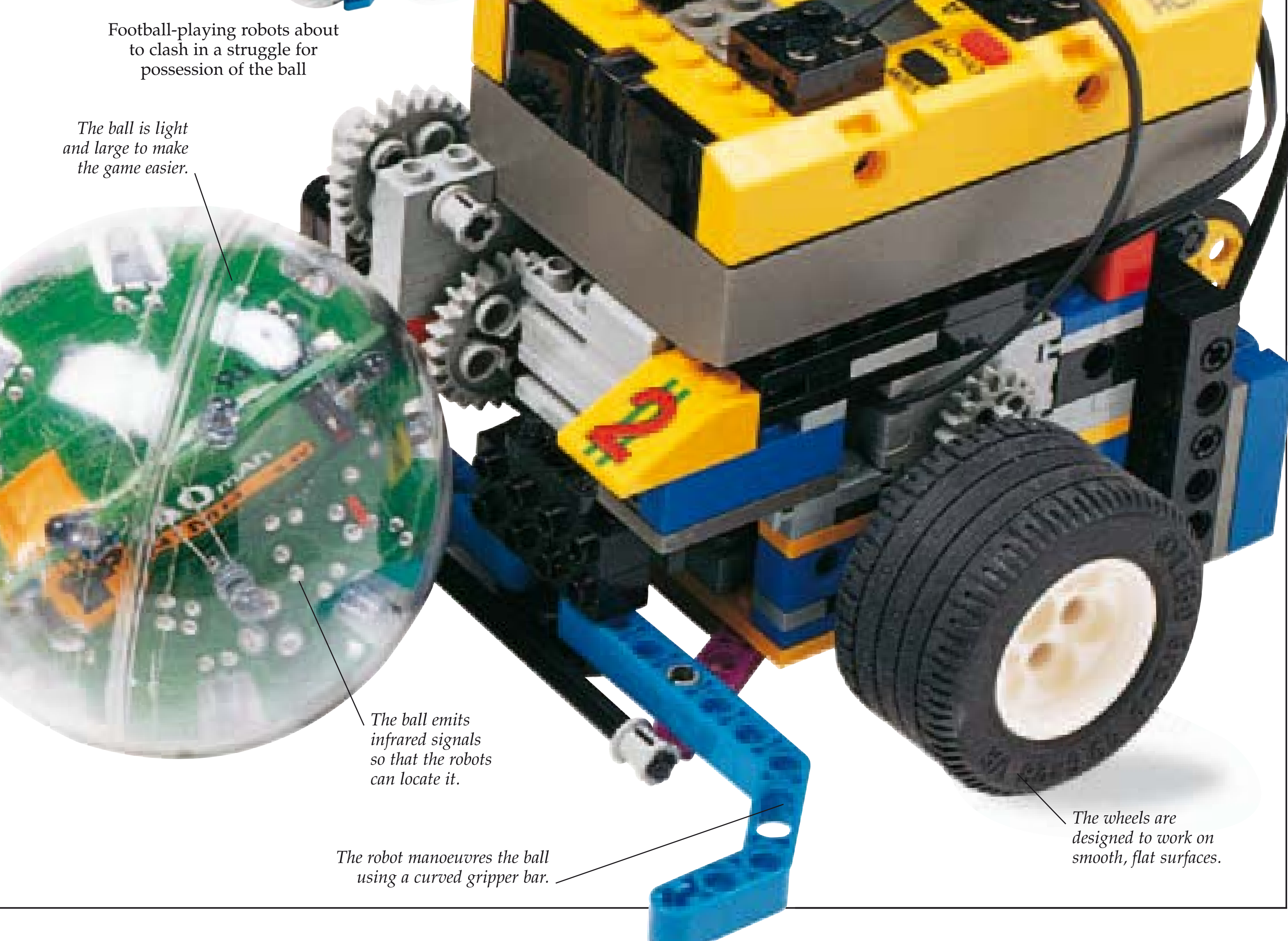
Robot Sumo competition, Japan, 1992

GETTING PUSHY
In Robot Sumo two robots wrestle in a ring 154 cm (5 ft) across. Unlike battlebots, which are armed, they rely on strength and skill alone. The bout ends when one robot is pushed out of the ring or breaks down. Sumo robots can be autonomous, with an on-board computer, or controlled from the ringside.



Football-playing robots passing the ball

Football-playing robots about to clash in a struggle for possession of the ball



The robots are powered by batteries housed near the control panel.

The ball is light and large to make the game easier.

The ball emits infrared signals so that the robots can locate it.

The robot manoeuvres the ball using a curved gripper bar.

The wheels are designed to work on smooth, flat surfaces.

Robots in the lab

SCIENTIFIC RESEARCH depends heavily on laboratory work where the same painstaking but tedious procedure has to be repeated over and over again. This is exactly what robots are good at. They do not get bored and their actions never vary, so they can do repetitive chores without making mistakes. Robots are ideal for work like developing new drugs, which requires a huge number of tests to be repeated without any random variations. They are also immune to bugs, radioactivity, and chemicals, so can do things that are too risky for humans.

AT ARM'S LENGTH
The first laboratory robots were arms like these. They were connected mechanically to their human operator, whose movements they copied directly. They were used for the remote handling of hazardous materials in the nuclear industry. Newer arms are electrically powered and connected to their operator via electronic control systems.

ROBOT TECHNICIAN
The simplest type of laboratory robot is a fixed arm. If everything is within reach, it can measure out liquids, stack specimens, and so on. A robot like this, controlled by a computer, can pick up and place things where needed as well as supply chemical measuring devices with samples for analysis.

The fixed arm has a smooth tipping action.

KEEPING IT CLEAN
The manufacture of drugs, genetically modified organisms, and gene treatments is usually carried out in sealed-off areas called clean rooms. Even in a protective suit a human could contaminate such a room, but a robot arm can do much of the work without introducing any such hazard.

The operator programs the robotic arm from outside the clean room.

The protective suit is an extra guard against contamination.

TESTING, TESTING
When a doctor sends blood to the lab for tests, the sample is often handled by a robot. Thousands of specimen tubes flood into clinical laboratories every day, and a robot can keep track of them all. In one hour the robot may pick up 2,000 tubes, read their labels, and put them in the right rack for the tests they need.

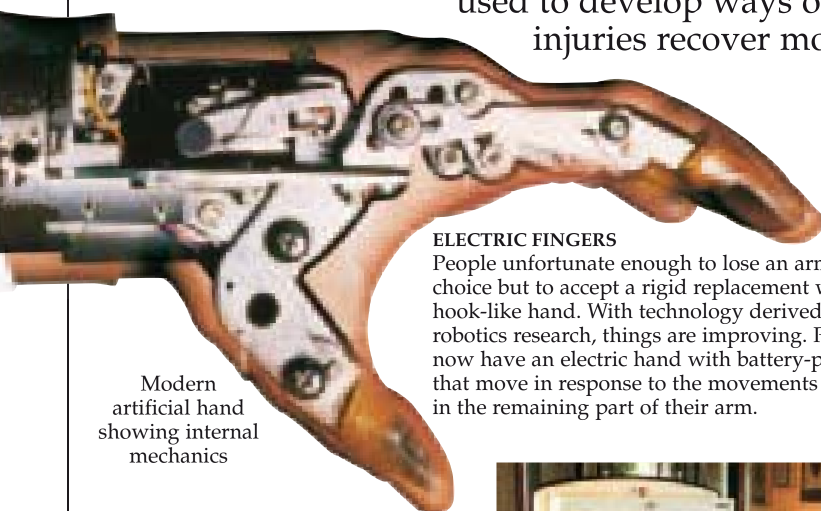
GROWING CELLS
SelecT is an automatic cell-culturing machine used in biomedical research. This involves growing cells in laboratory glassware for developing medicines, biological compounds, and gene therapy. SelecT was designed with the help of major drug companies. It improves on the speed, accuracy, and consistency of manual methods.

Cell cultures growing in petri dishes

Robots in medicine

TWENTY YEARS AGO it would have been unthinkable to let a robot loose in an operating theatre. But with today's more powerful computers and improved mechanical techniques, it is possible for a closely supervised robot to wield the knife in a number of critical procedures. Human doctors remain in control, of course, but in another 20 years the face of medicine may look very different. Robotics also promises to revolutionize artificial limbs. Knowledge gained during research into walking robots is now being used to develop ways of helping people with spinal injuries recover movement in their legs.

BEDSIDE MANNER
Nursing is hard work for 24 hours a day so robot nurses would have much to offer, even if they lacked the human touch. This French magazine illustration dates from 1912, but the reality of robotic nursing is still a long way off.



ELECTRIC FINGERS
People unfortunate enough to lose an arm once had little choice but to accept a rigid replacement with an ineffective, hook-like hand. With technology derived partly from robotics research, things are improving. Patients may now have an electric hand with battery-powered fingers that move in response to the movements of muscles in the remaining part of their arm.

Modern artificial hand showing internal mechanics

A patient's meal is delivered from Helpmate's hatch.

HOSPITAL HELPER
Helpmate is a robot designed for use in hospitals. It is a mechanical porter that carries meals, specimens, drugs, records, and X-rays back and forth between different parts of the hospital. Helpmate can find its way around corridors and even use lifts. Built-in safety devices stop it from running into the patients.

X-rays of the patient's chest provide additional guidance.

The surgeon views a 3D image of the operation site and controls the robot arms.

SMART HEART SURGERY
In 2002, US surgeon Michael Argenziano used a robot called DaVinci to repair heart defects that would normally require the patient's chest to be opened up. Using DaVinci, Argenziano made the repairs through four holes, each just 1 cm (0.4 in) wide. The procedure was successful for 14 out of 15 patients. They were fit to go home after three days instead of the usual seven.

A close-up view of the operation guides the surgeon.

SPREADING SKILLS
The first long-distance operation, when a surgeon in one country operated on a patient in another, was performed in 2001. The patient was in France and the surgeons were in New York. A live video link allowed them to manipulate robot arms 4,800 km (3,000 miles) away. The robot even understood speech commands such as "up" or "down". This technology makes surgeons' skills more widely available.

PRECISION BRAINWORK
NeuroMate is the first robotic system developed specifically for a type of brain surgery in which instruments are positioned precisely before being used. It reduces theatre time by allowing surgeons to plan procedures in advance. NeuroMate also shows the surgeons what is going on during the operation, so that they can stay in control.

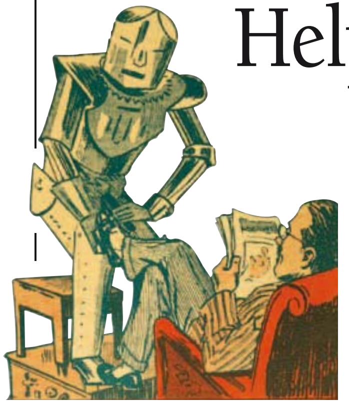
Powerful lighting is needed, as in all surgery.

Live images of the operation site are shown on the screen.

A number of robot arms work together on the patient.

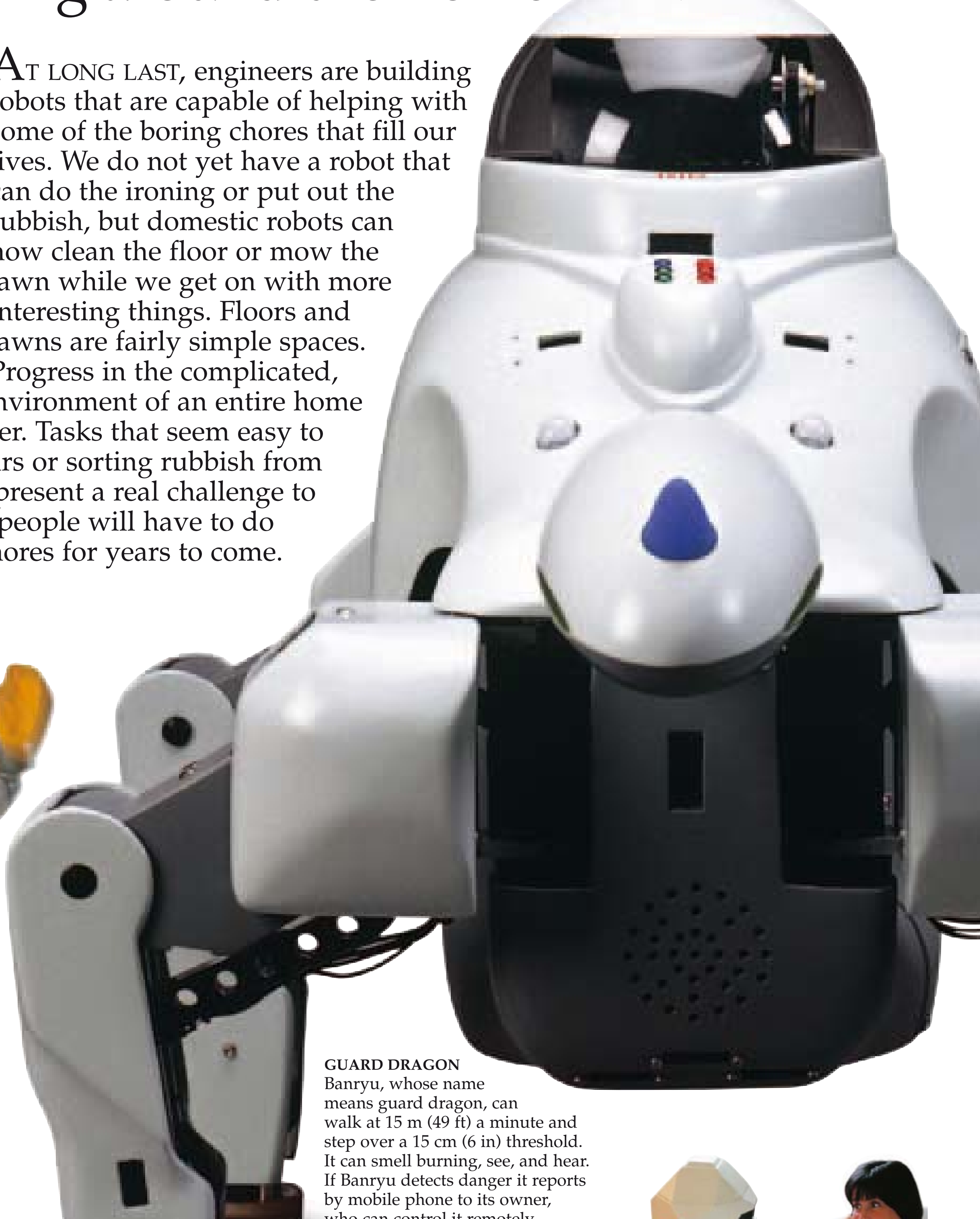
The patient is anaesthetized and must be kept very still.

Helping around the home



1929 illustration from *Le Petit Inventeur* showing the servant of the future cleaning its master's shoes

AT LONG LAST, engineers are building robots that are capable of helping with some of the boring chores that fill our lives. We do not yet have a robot that can do the ironing or put out the rubbish, but domestic robots can now clean the floor or mow the lawn while we get on with more interesting things. Floors and lawns are fairly simple spaces. Progress in the complicated, three-dimensional environment of an entire home has been much slower. Tasks that seem easy to us, like climbing stairs or sorting rubbish from prized possessions, present a real challenge to robots. It looks as if people will have to do most of their own chores for years to come.



Banryu looks like a futuristic dinosaur.

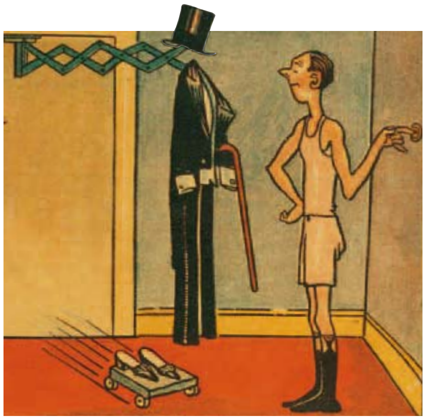
GUARD DRAGON
Banryu, whose name means guard dragon, can walk at 15 m (49 ft) a minute and step over a 15 cm (6 in) threshold. It can smell burning, see, and hear. If Banryu detects danger it reports by mobile phone to its owner, who can control it remotely.

Wakamaru sees the world through two cameras.

TALKATIVE TECHNOLOGY
Wakamaru is the first robot designed with the care of elderly people in mind. It transmits pictures of its owner to watching relatives using a built-in mobile phone and web cam. It also knows 10,000 words, so can talk well. If its owner remains quiet for any length of time, Wakamaru asks, "Are you all right?" and, if necessary, calls emergency services.

AHEAD OF ITS TIME
US company Androbot launched Topo, a toy-like plastic robot, in 1983. Nolan Bushnell, Topo's designer, saw it as a helpful friend rather than a servant. The 91 cm (3 ft) robot was controlled by a PC via a radio link. Topo is now a sought-after antique.

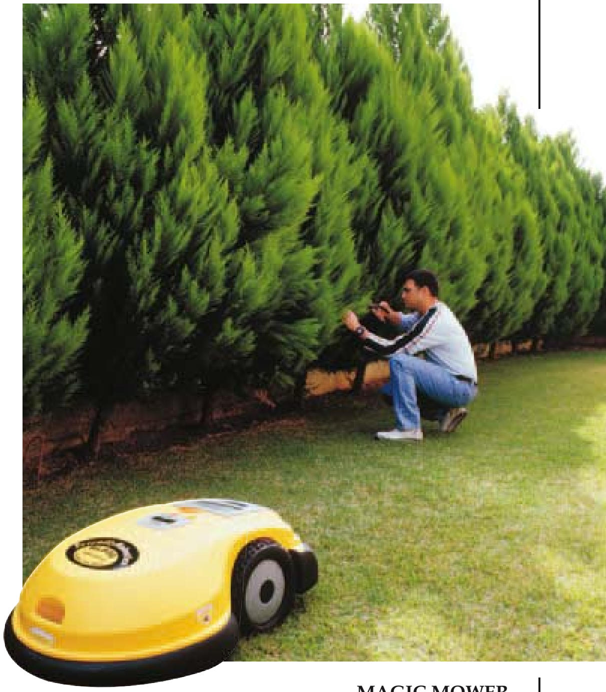
CLEVER CLEANER
Launched in 2001, the Electrolux Trilobite was one of the first domestic robots to go on sale. It is simply an intelligent version of a traditional vacuum cleaner. The Trilobite navigates using ultrasound, and magnetic strips across doorways stop it wandering off. It cleans without help for an hour, then returns to its battery charger.



WISHFUL THINKING
This imaginary robot from 1927 is doing the work of a valet, whose job is to look after clothes. After World War I, wealthy people found it hard to get domestic servants, which promoted interest in labour-saving gadgets.

The five keys can be used to control the robot.

ON GUARD!
Japanese guard robot Maron-1, made by Fujitsu, is 36 cm (14 in) tall and runs on wheels. It has a built-in mobile phone so that it can take instructions from its owner, and sensors to detect movement. If someone breaks in when Maron-1 is on guard, it sounds an alarm and phones its owner, who can see what is going on through Maron's two rotating camera eyes.



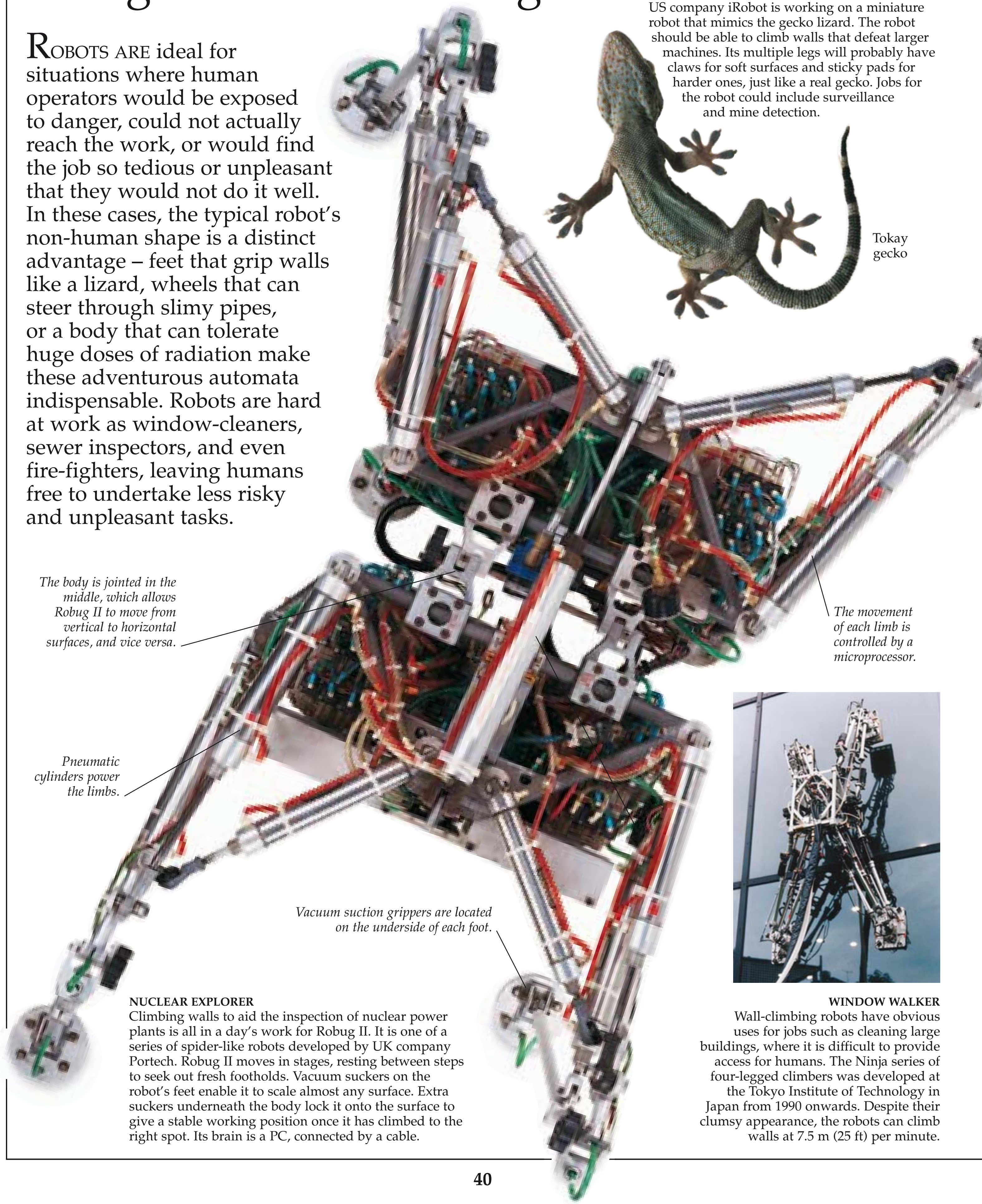
MAGIC MOWER
Robomow is one of a number of robot lawnmowers that have appeared over the last few years. Powered by a rechargeable battery, it mows the lawn without human help. A wire buried around the lawn's edge keeps the robot on the grass, while bump and lift sensors stop it from giving the cat a haircut!

Going where it's hard to go

ROBOTS ARE ideal for situations where human operators would be exposed to danger, could not actually reach the work, or would find the job so tedious or unpleasant that they would not do it well. In these cases, the typical robot's non-human shape is a distinct advantage – feet that grip walls like a lizard, wheels that can steer through slimy pipes, or a body that can tolerate huge doses of radiation make these adventurous automata indispensable. Robots are hard at work as window-cleaners, sewer inspectors, and even fire-fighters, leaving humans free to undertake less risky and unpleasant tasks.

MINI MIMIC
US company iRobot is working on a miniature robot that mimics the gecko lizard. The robot should be able to climb walls that defeat larger machines. Its multiple legs will probably have claws for soft surfaces and sticky pads for harder ones, just like a real gecko. Jobs for the robot could include surveillance and mine detection.

Tokay gecko



The body is jointed in the middle, which allows Robug II to move from vertical to horizontal surfaces, and vice versa.

The movement of each limb is controlled by a microprocessor.

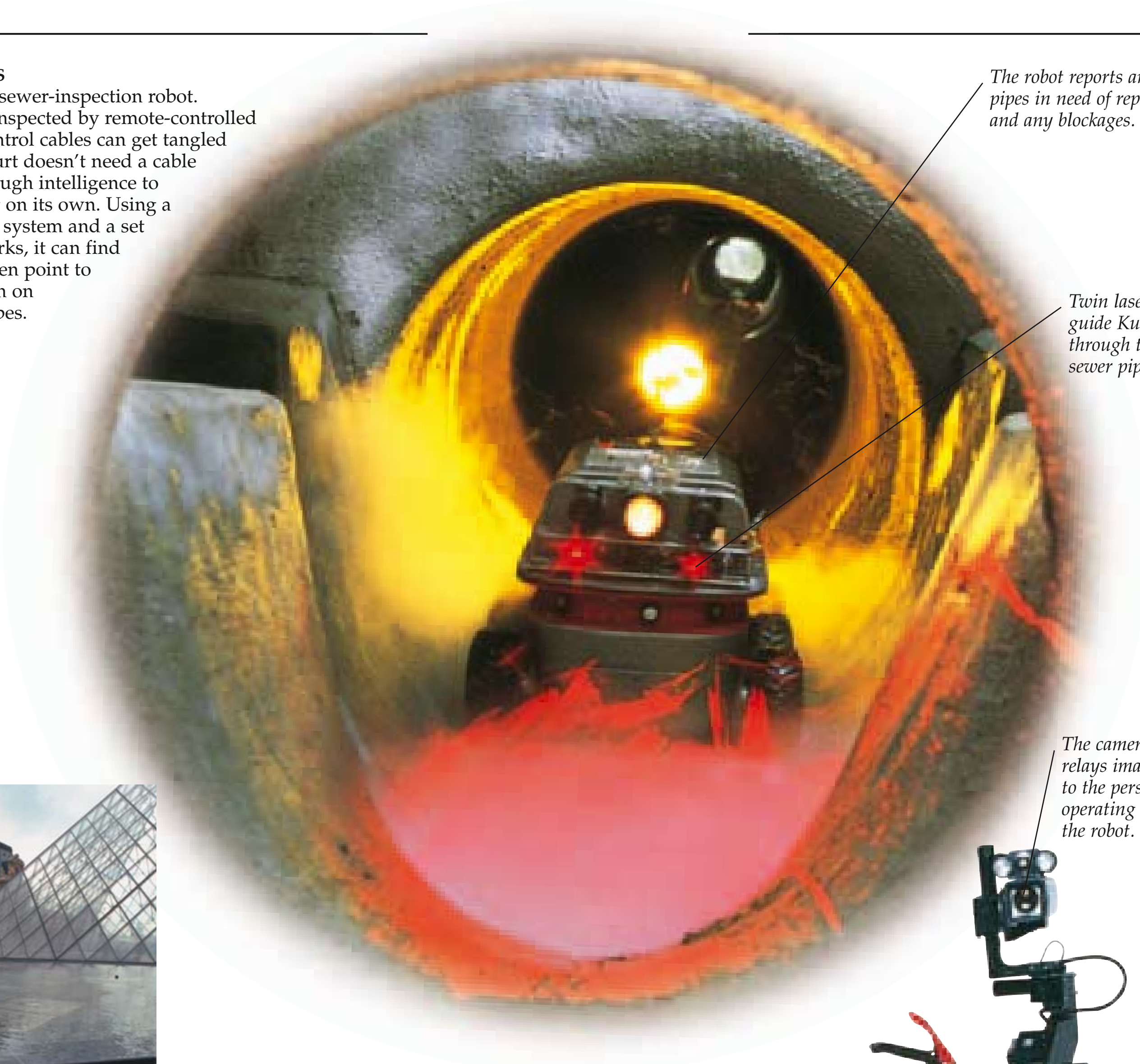
Pneumatic cylinders power the limbs.

Vacuum suction grippers are located on the underside of each foot.

NUCLEAR EXPLORER
Climbing walls to aid the inspection of nuclear power plants is all in a day's work for Robug II. It is one of a series of spider-like robots developed by UK company Portech. Robug II moves in stages, resting between steps to seek out fresh footholds. Vacuum suckers on the robot's feet enable it to scale almost any surface. Extra suckers underneath the body lock it onto the surface to give a stable working position once it has climbed to the right spot. Its brain is a PC, connected by a cable.

WINDOW WALKER
Wall-climbing robots have obvious uses for jobs such as cleaning large buildings, where it is difficult to provide access for humans. The Ninja series of four-legged climbers was developed at the Tokyo Institute of Technology in Japan from 1990 onwards. Despite their clumsy appearance, the robots can climb walls at 7.5 m (25 ft) per minute.

DOWN THE TUBES
Kurt is a German sewer-inspection robot. Sewers are often inspected by remote-controlled robots, but the control cables can get tangled on tight bends. Kurt doesn't need a cable because it has enough intelligence to follow every twist on its own. Using a digital map of the system and a set of known landmarks, it can find its way to any given point to gather information on the state of the pipes.



The robot reports any pipes in need of repair and any blockages.

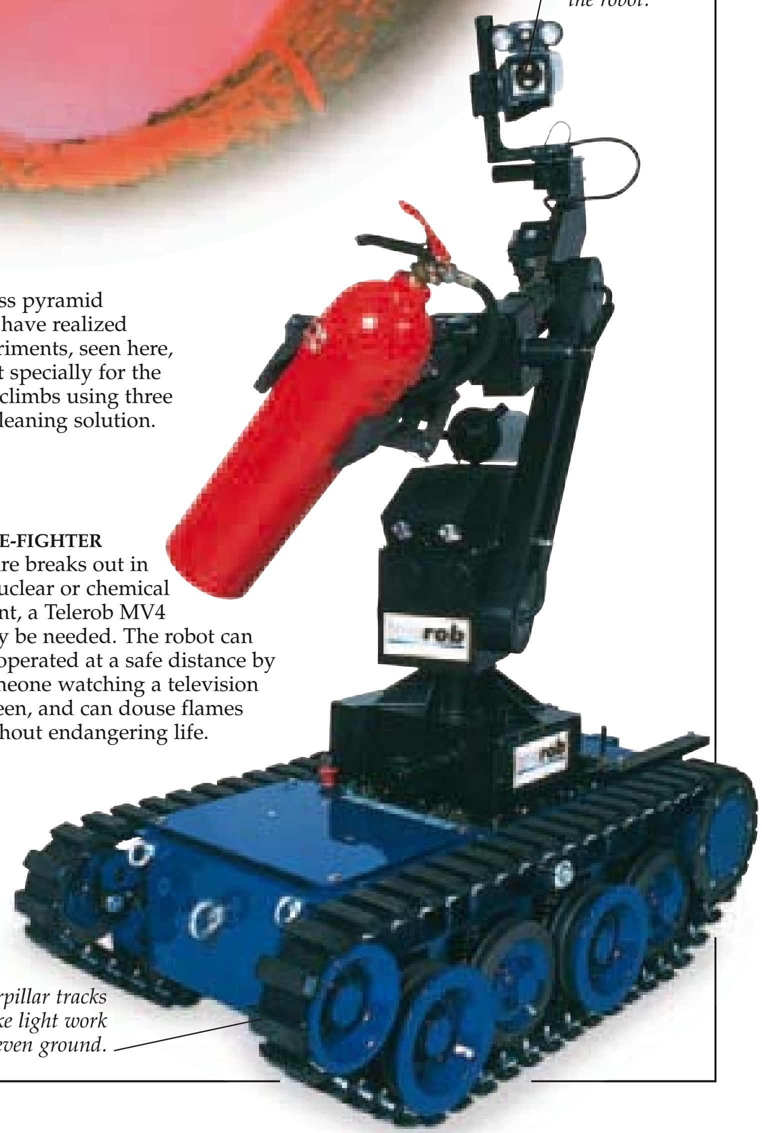
Twin lasers guide Kurt through the sewer pipes.

ART WORK
Most visitors to Paris, France, know the glass pyramid outside the Louvre art gallery. But few will have realized how it is kept clean. Following earlier experiments, seen here, the pyramid is now cleaned by a robot built specially for the job by inventor Henry Seemann. The robot climbs using three large sucker feet and delivers pressurized cleaning solution.

Robin can seal radioactive waste in containers, making it safer for humans to handle and dispose of.

RESISTING RADIATION
Robin the robot was designed for use in the nuclear industry. Robots are used in parts of this industry because they are unaffected by levels of radioactivity that would kill human workers. Robin's four legs can step over obstacles, enabling it to move nuclear material around in a workplace that may be cluttered with cables and pipes.

FIRE-FIGHTER
If fire breaks out in a nuclear or chemical plant, a Telerob MV4 may be needed. The robot can be operated at a safe distance by someone watching a television screen, and can douse flames without endangering life.

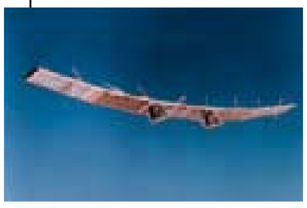


The camera relays images to the person operating the robot.

Caterpillar tracks make light work of uneven ground.

Flying and driving

IMAGINE A ROBOT car that could whizz you through the traffic to anywhere you wanted. Unfortunately, despite years of research, basic driving skills that most humans can learn remain beyond the reach of robots. The race to build a car that can drive itself is still on. High above the roads, however, where there are fewer things to bump into, great progress has been made. Pilotless planes of all sizes now fly the skies to make measurements, take pictures, or relay radio signals.



AUTO PILOT
Pathfinder is a pilotless aeroplane that is driven by solar-powered electric motors. It was developed by US company AeroVironment in 1971. Pathfinder-plus, a later version, has flown to 25,000 m (82,000 ft).

BIGGER AND BETTER
Pathfinder's successor Helios is larger and can fly higher. In 2001, it broke the world altitude record. It navigates using GPS. Later models will be able to fly by night as well as day, offering serious competition to communications satellites.

GIANT MODEL
Pilotless planes are now in regular use for surveillance. One of the most successful, Aerosonde, comes from Australia. It made its first independent flight in 1997, and the following year crossed the Atlantic Ocean. With its 3-m (10-ft) wingspan and 24 cc engine, Aerosonde is rather like a giant model aircraft. After launching from a car roof rack, it navigates using the Global Positioning System (GPS).

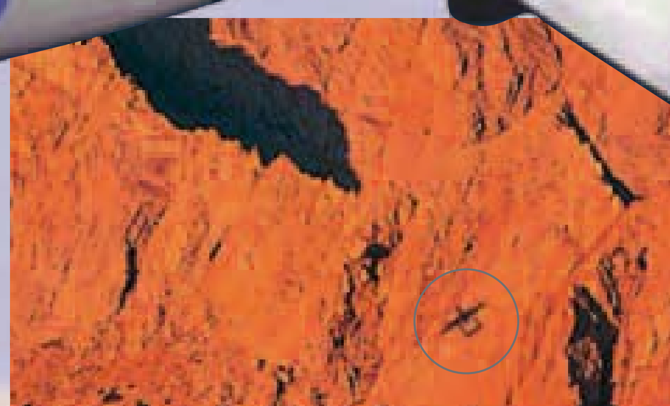
A graphite tailboom supports the tail.

The fibreglass tail stabilizes the plane.

The streamlined cowling houses the electronics.

A pressure tube measures the plane's speed.

Long, narrow wings help to reduce drag.



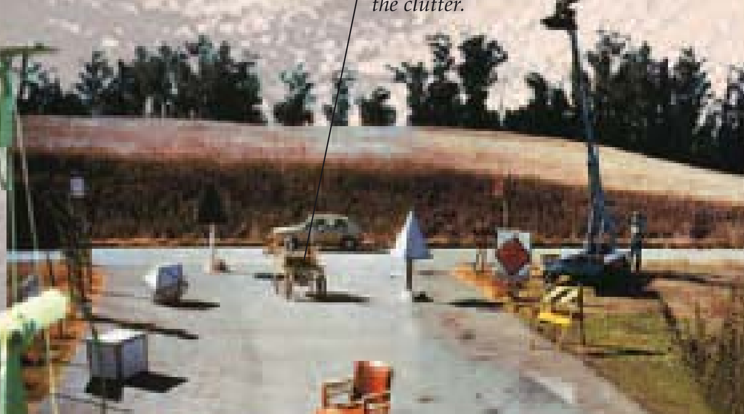
A DAY'S WORK
Aerosonde has many uses. Here its shadow crosses desert terrain as it collects meteorological, or weather-forecasting, data. It can also monitor traffic congestion or spy on illegal activities. It flies regularly in Alaska to measure the temperature of the sea ice. In 2003, Aerosonde was deployed during peacekeeping operations in the Solomon Islands in the South Pacific Ocean.

SERIOUS SNAPS
Global Hawk is a US military robot plane that can provide continuous images of a battlefield. Its development began in 1995. By 2002, it was being used in Afghanistan. It produced more than 15,000 high-resolution images.

LEARNER DRIVER
This human learner stands a far better chance of passing a driving test than Alvinn, a robot driver created in 1985 at Carnegie Mellon University. To train its brain, Alvinn made a video of a road, which it studied carefully. It then drove along the road – badly. Alvinn was a brave, but unsuccessful, attempt at creating a robot that could drive.

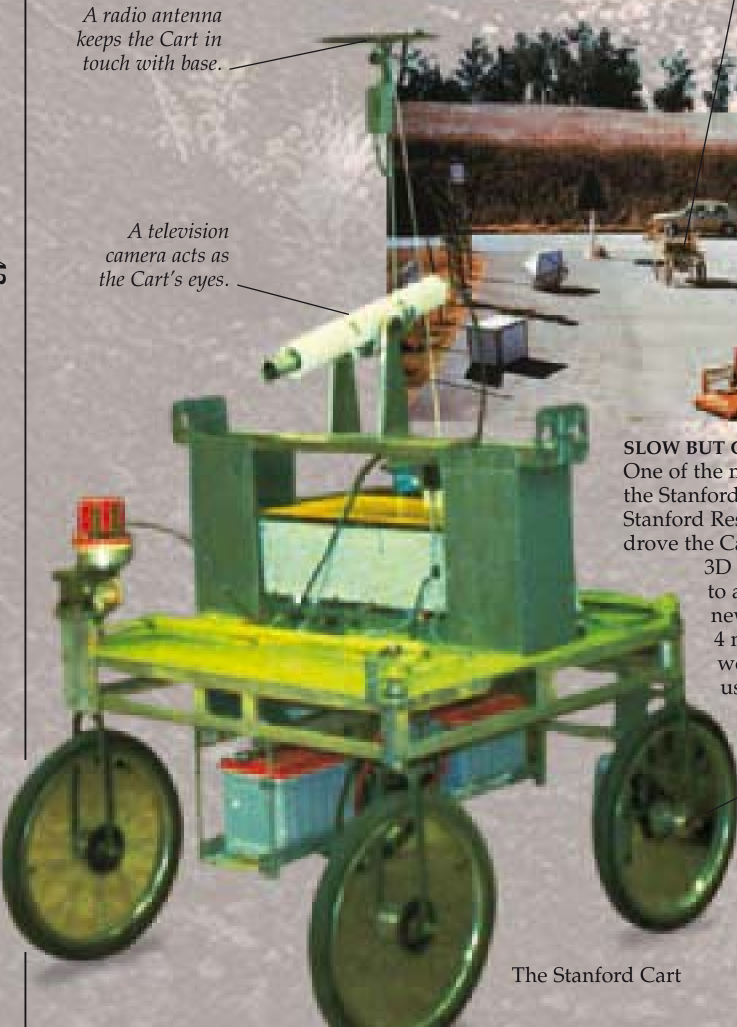
"Mobile robotics may or may not be the fastest way to arrive at general human competence in machines, but I believe it is one of the surest roads."

HANS MORAVEC
Stanford Research Institute, USA



The Cart moves cautiously through the clutter.

Obstacle course set up for the Stanford Cart



A radio antenna keeps the Cart in touch with base.

A television camera acts as the Cart's eyes.

Large wheels help the Cart to cope with rough ground.

The Stanford Cart

SLOW BUT GOING
One of the more famous robot vehicles was the Stanford Cart, devised by Hans Moravec of the Stanford Research Institute in the 1970s. A computer drove the Cart through cluttered spaces. It used 3D vision to locate objects and plan a path to avoid them, which it updated as it saw new obstacles. It worked, but only at 4 m (13 ft) an hour. Moravec is still working on improved systems that make use of lessons learned from the Cart.

GRAND DARPA CHALLENGE

THE PRICE OF SUCCESS
In March 2004, the US Defense Advanced Research Projects Agency (DARPA) held a contest for autonomous land vehicles. The route was from Los Angeles to Las Vegas, and the prize $1 million. The purpose of the challenge was to accelerate the development of robot vehicles for military use.

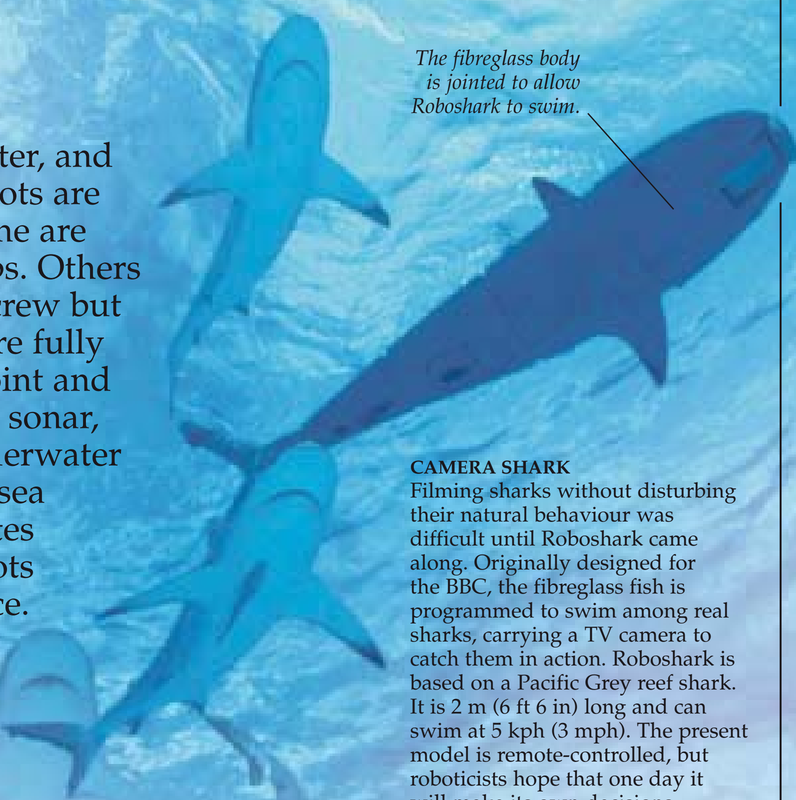
Artist's impression of a DARPA Challenge vehicle

LAND BATTLE
It is more difficult to make a robot travel over land than through air or water because there are more obstacles. A successful land vehicle not only needs to find its way to its destination, but also has to cope with bumpy surfaces, dangerous features such as rivers, and other vehicles that might get in its way.

Underwater robots

TWO-THIRDS OF OUR planet is covered by water, and most of this watery world is unexplored. Robots are now an essential tool for ocean explorers. Some are remote-controlled vehicles towed behind ships. Others are miniature submarines carrying a human crew but equipped with robot arms. However, many are fully autonomous. They can navigate to a given point and automatically carry out a survey using video, sonar, or other devices. Even the best of today's underwater robots, though, are crude compared with the sea creatures they meet. The latest research imitates the abilities of these creatures, giving the robots improved intelligence, speed, and endurance.

BEACH BABY
Ariel is a robot crab that may soon be used to clear mines from seashore minefields. Walking just like a crab, Ariel can scramble over obstacles and crevices that would defeat a wheeled robot. Even if it gets flipped over by a wave, Aerial simply carries on walking – upside down!

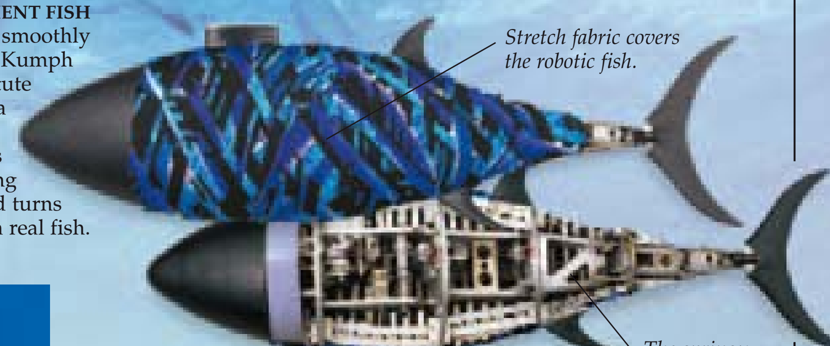


The fibreglass body is jointed to allow Roboshark to swim.

CAMERA SHARK
Filming sharks without disturbing their natural behaviour was difficult until Roboshark came along. Originally designed for the BBC, the fibreglass fish is programmed to swim among real sharks, carrying a TV camera to catch them in action. Roboshark is based on a Pacific Grey reef shark. It is 2 m (6 ft 6 in) long and can swim at 5 kph (3 mph). The present model is remote-controlled, but roboticists hope that one day it will make its own decisions.

Electric thrusters move the robot around.

EFFICIENT FISH
How do fish glide so smoothly through the water? John Kumph of the Massachusetts Institute of Technology has created a robot fish that may help to answer the question. Its body, a fibreglass spring covered with Lycra, flips and turns in the water as easily as a real fish.



Stretch fabric covers the robotic fish.

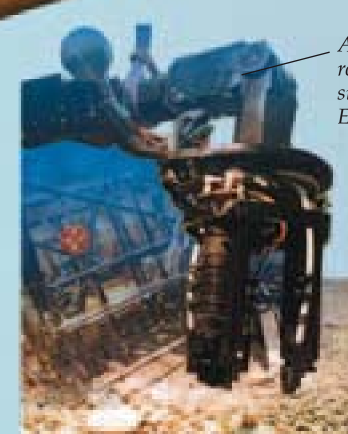
The springy body is full of complex moving parts.

SHIPWRECK AHOY
One of the main uses of undersea robots is to explore the sea floor. True autonomous underwater vehicles (AUVs) navigate independently over long distances, returning with recorded data. Others are controlled from ships on the surface. Here, a shipwreck is under investigation by Hyball. A cable supplies power and control for the robot and carries pictures of the wreck to the surface. Powerful lights are needed, because it is completely dark at depths beyond about 100 m (330 ft).

EXPERIENCED EXPLORER
Autosub, an AUV developed in the UK, is an independent robot submarine that has completed more than 200 scientific missions. These include checking up on herrings in the North Sea and locating valuable metals on the floor of a Scottish lake. Autosub has even been to Antarctica, where it dived beneath the ice of the Weddell Sea.

Cables convey signals to computers.

All the equipment is mounted on an internal frame.



A conventional robot arm supports the Elephant's Trunk.

UNDERWATER ACTION
Ordinary robot arms have problems under the sea. Positioning them accurately is time-consuming, and their movements stir up sediment, obscuring vision. A new type of arm, developed at Heriot-Watt University in Scotland, has flexible rubber sections moved by air instead of metal parts. The principle of this Parallel Bellows Actuator (nicknamed the Elephant's Trunk) could also be used to propel a submarine fitted with flexing fins.

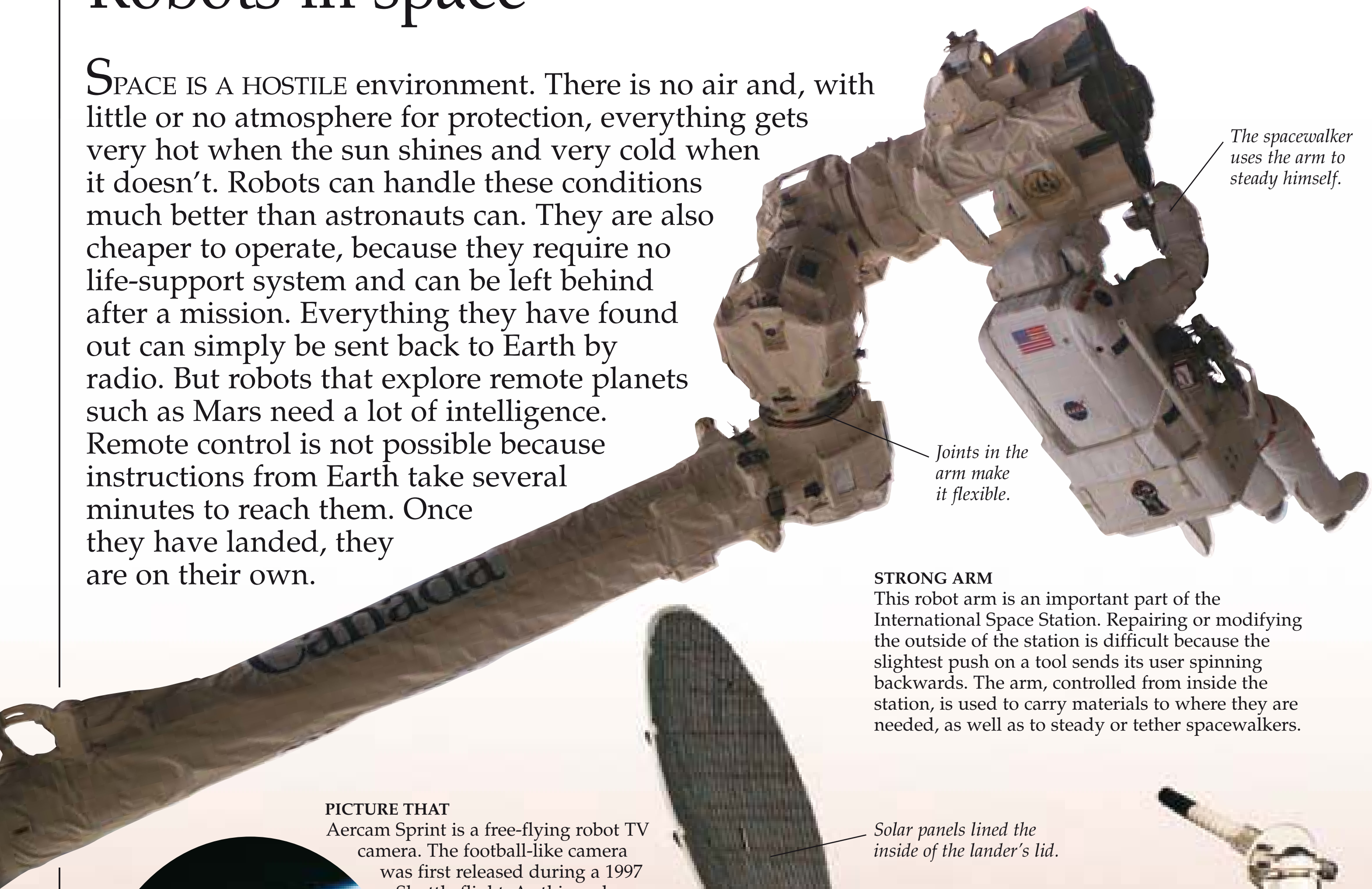
SUPER SUBMARINES
Every year, a number of US universities compete to find the fastest, most intelligent robot sub. Operating entirely under their own control, the robots look for bar-coded boxes in a deep pool. They have to decipher the code on each box, measure its depth, and report this back to base. In 2002, Cornell University's AUV, seen here, came second. It found one more box than the winner, but took longer.

Part of the ship's equipment is retrieved by the arm.

TREASURE HUNTER
The French submarine *Nautile* is not a robot. It has a three-person crew – pilot, co-pilot, and observer – who work in a compartment only 2.1 m (7 ft) in diameter. *Nautile* does, however, have a robot arm and can even launch its own little remote-controlled sub. As one of the few submarines that can operate at a depth of 6,000 m (3 miles), it was used to recover treasures from the wreck of the *Titanic*, which sank in the North Atlantic in 1912.

Robots in space

SPACE IS A HOSTILE environment. There is no air and, with little or no atmosphere for protection, everything gets very hot when the sun shines and very cold when it doesn't. Robots can handle these conditions much better than astronauts can. They are also cheaper to operate, because they require no life-support system and can be left behind after a mission. Everything they have found out can simply be sent back to Earth by radio. But robots that explore remote planets such as Mars need a lot of intelligence. Remote control is not possible because instructions from Earth take several minutes to reach them. Once they have landed, they are on their own.



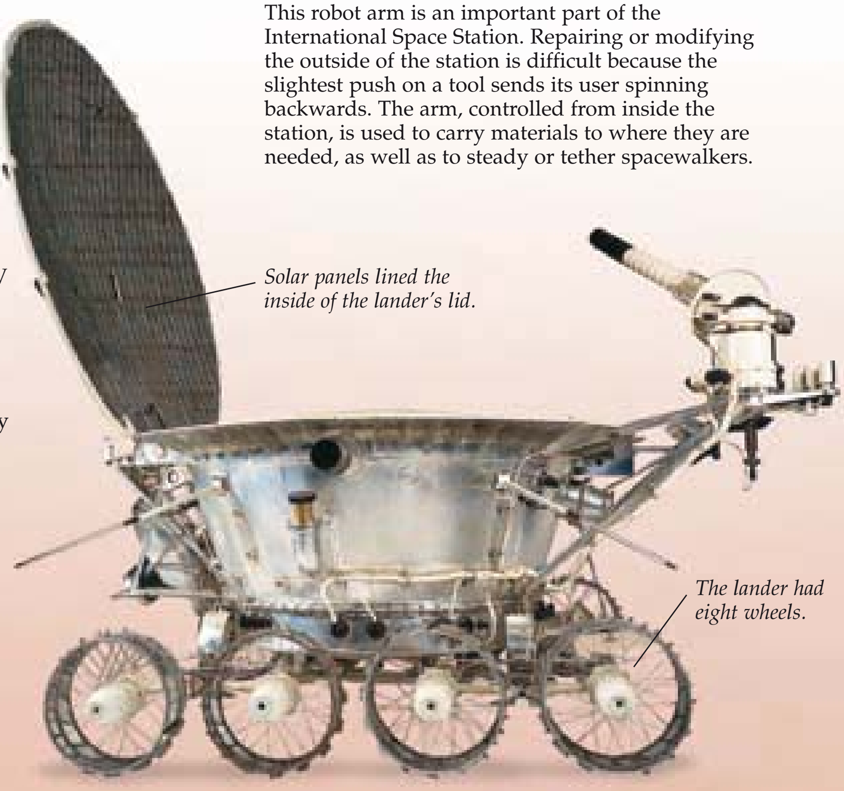
The spacewalker uses the arm to steady himself.

Joints in the arm make it flexible.

STRONG ARM
This robot arm is an important part of the International Space Station. Repairing or modifying the outside of the station is difficult because the slightest push on a tool sends its user spinning backwards. The arm, controlled from inside the station, is used to carry materials to where they are needed, as well as to steady or tether spacewalkers.

PICTURE THAT
Aercam Sprint is a free-flying robot TV camera. The football-like camera was first released during a 1997 Shuttle flight. As this early model could easily have failed, it only flew around inside the Shuttle, remotely controlled by pilot Steve Lindsey. Future versions of the flying camera may not need remote control.

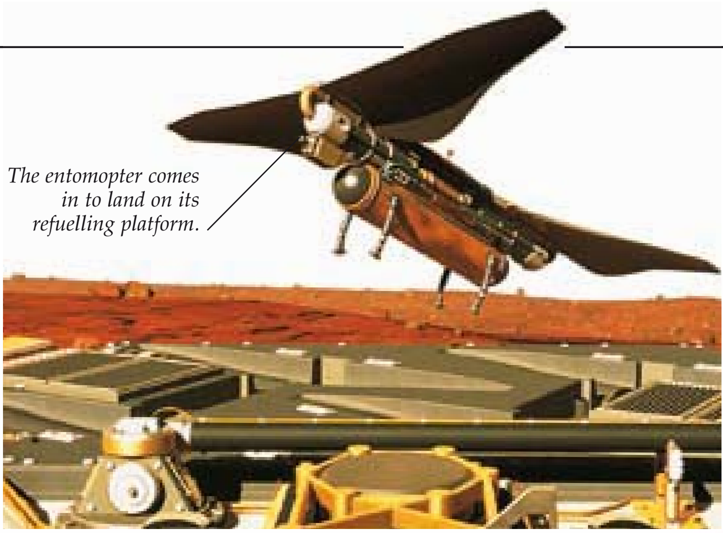
The camera is protected from collisions with other equipment by the cushioned surface.



Solar panels lined the inside of the lander's lid.

The lander had eight wheels.

MOON WANDERER
In 1970, the Russian explorer *Lunokhod* became the first robot to land on the Moon. Lunokhod weighed more than 750 kg (1,650 lb) on Earth. The solar-powered vehicle, manoeuvred by a team on Earth, took 20,000 photographs and sent back data from 500 lunar soil samples.



The entomopter comes in to land on its refuelling platform.

IN A FLAP

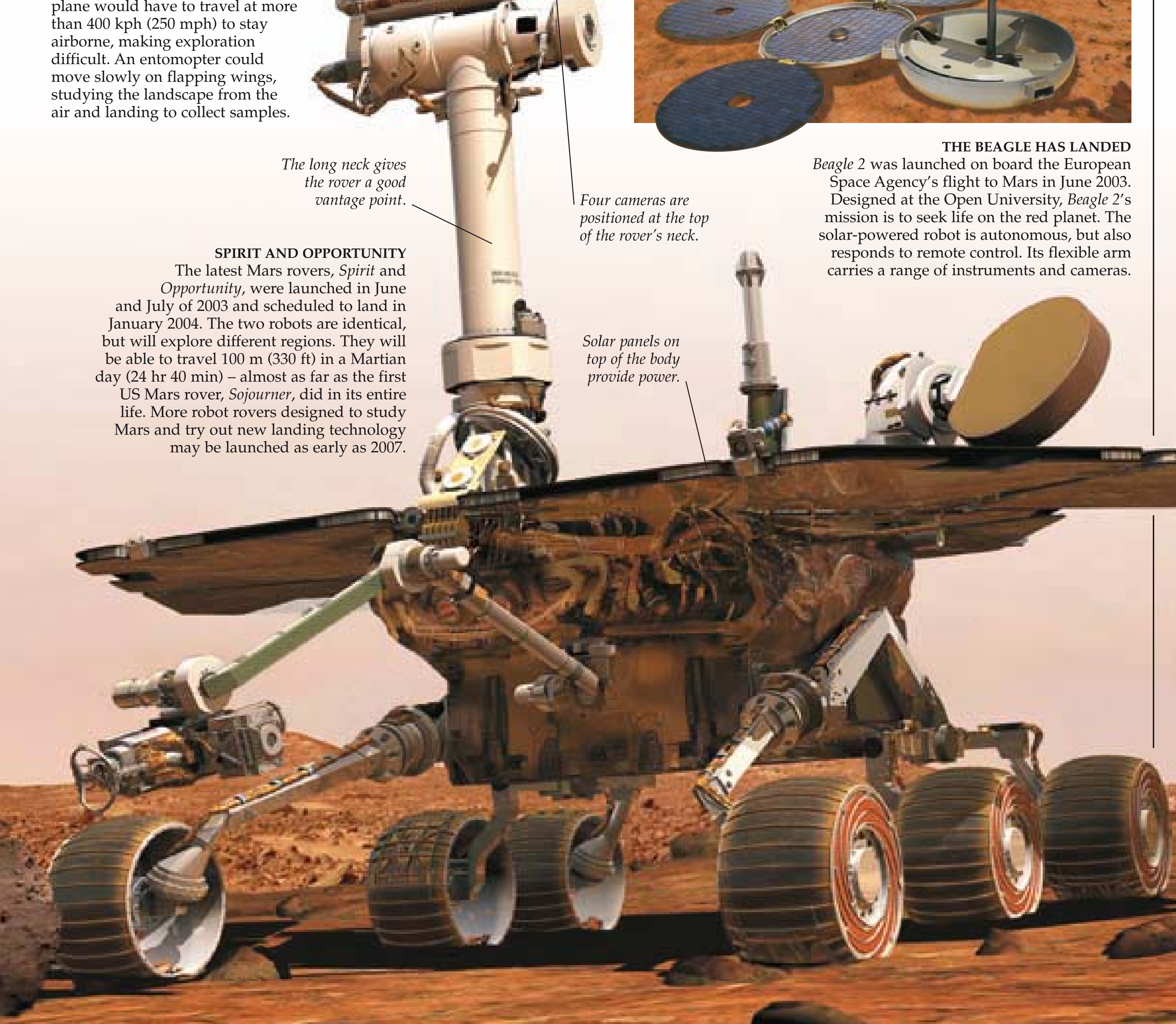
Scientists are currently working on an entomopter, or robot insect, that they think could one day fly on Mars. Because of the thin atmosphere on Mars, a fixed-wing plane would have to travel at more than 400 kph (250 mph) to stay airborne, making exploration difficult. An entomopter could move slowly on flapping wings, studying the landscape from the air and landing to collect samples.

SPACE SPIDER

NASA researchers have created Spider-bot, a six-legged micro-robot that may one day explore remote planets. Unlike wheeled rovers, a robot with legs can cope with rocky and furrowed terrain. The prototype fits in the palm of the hand. Future versions could be even smaller.

THE BEAGLE HAS LANDED

Beagle 2 was launched on board the European Space Agency's flight to Mars in June 2003. Designed at the Open University, *Beagle 2*'s mission is to seek life on the red planet. The solar-powered robot is autonomous, but also responds to remote control. Its flexible arm carries a range of instruments and cameras.



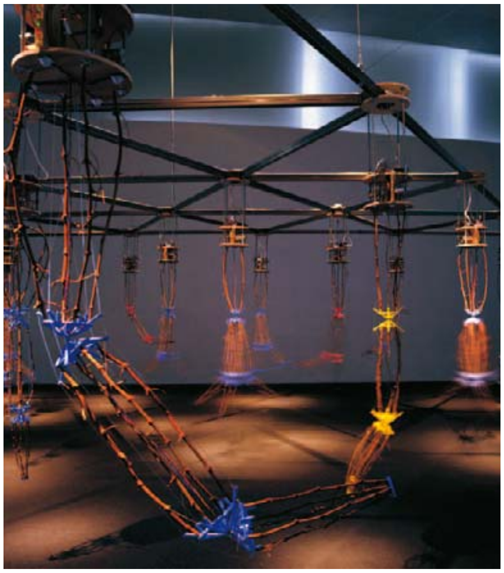
The long neck gives the rover a good vantage point.

Four cameras are positioned at the top of the rover's neck.

Solar panels on top of the body provide power.

SPIRIT AND OPPORTUNITY

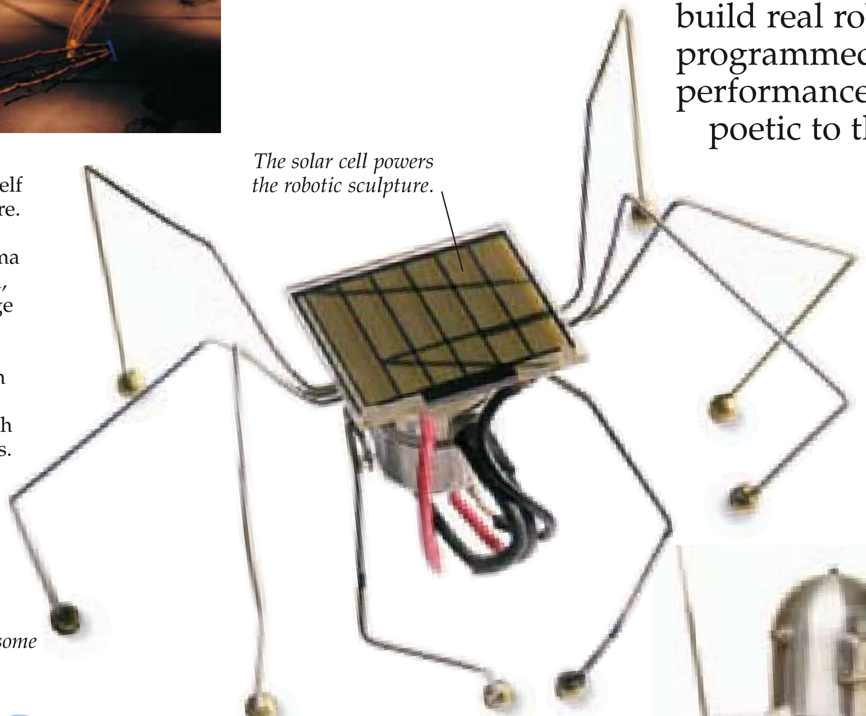
The latest Mars rovers, *Spirit* and *Opportunity*, were launched in June and July of 2003 and scheduled to land in January 2004. The two robots are identical, but will explore different regions. They will be able to travel 100 m (330 ft) in a Martian day (24 hr 40 min) – almost as far as the first US Mars rover, *Sojourner*, did in its entire life. More robot rovers designed to study Mars and try out new landing technology may be launched as early as 2007.



Robots and art

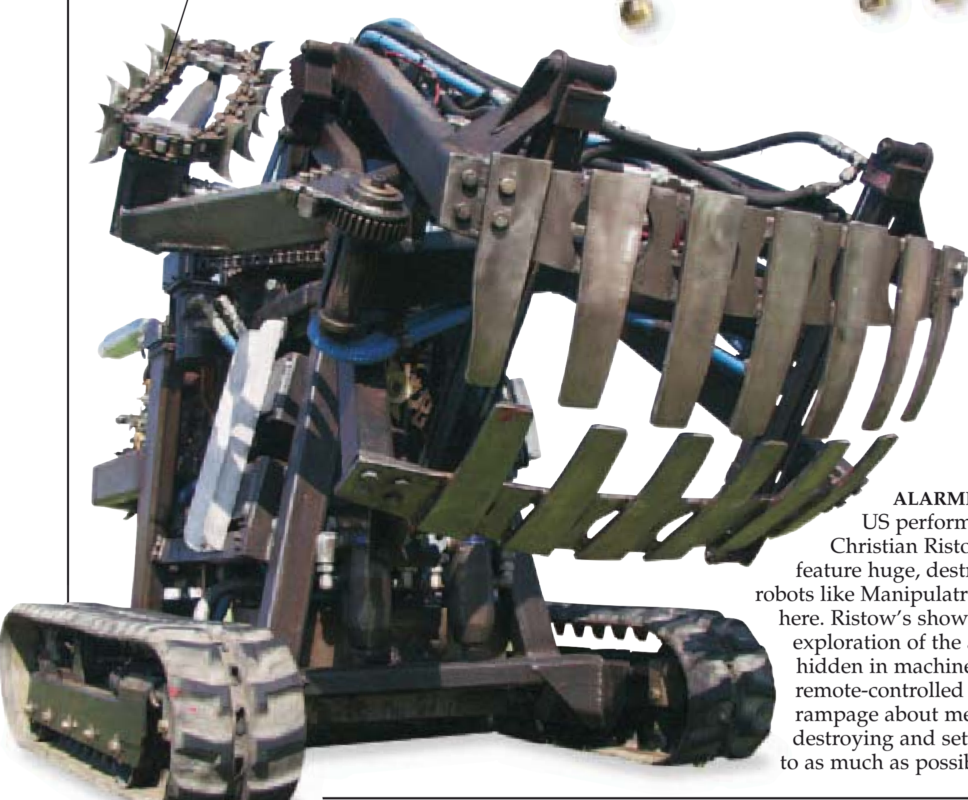
PAINTING A PICTURE seems like a uniquely human activity, but it is not. Some robots can do it. They may either use a television camera as an eye to look at someone and draw their portrait, or recall images stored in a computer memory to create a picture from their robot imaginations. Perhaps because of this, some human artists have given up painting pictures and taken to building robots. Some weld together junk parts to build amusing robot-like sculptures. Others build real robots that are programmed to put on artistic performances ranging from the poetic to the downright scary.

GETTING FEEDBACK
Autopoiesis, which means "self making", is a robotic sculpture. It was installed by US artist Kenneth Rinaldo at the Kiasma Museum in Helsinki, Finland, in 2000. Its 15 modules change their behaviour as they get feedback via infrared sensors from visitors to the exhibition and from each other. They exchange information through a language of telephone tones.



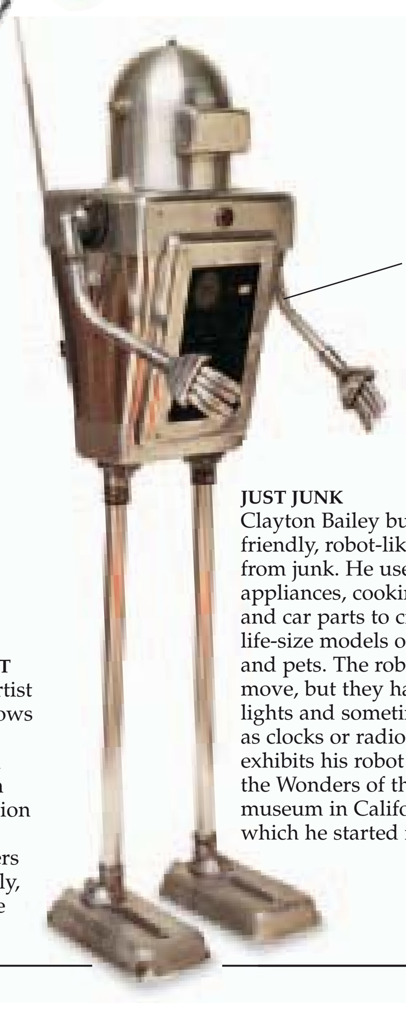
The solar cell powers the robotic sculpture.

JITTER BUG
Creepy is a work of art that almost convinces you it is a robot. It was created by US artist Dug North from a solar cell, some electronics, and the vibrator from a mobile phone. Just when you least expect it, Creepy starts buzzing and jittering about on its spindly, spider-like legs.



Manipulatrix is armed with a fearsome array of weapons.

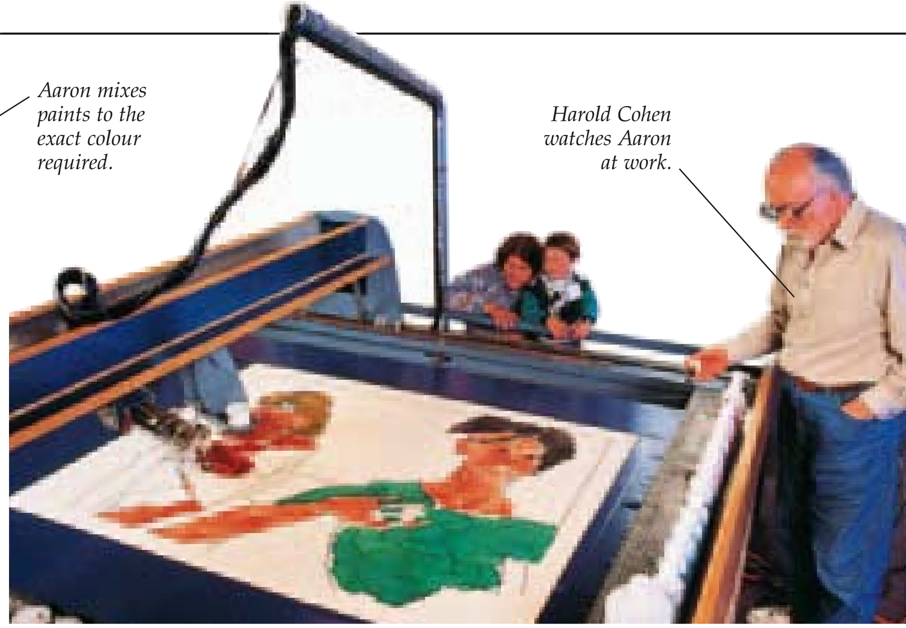
ALARMING ART
US performance artist Christian Ristow's shows feature huge, destructive robots like Manipulatrix, seen here. Ristow's shows are an exploration of the aggression hidden in machines. His remote-controlled monsters rampage about menacingly, destroying and setting fire to as much as possible.



The joints are all fixed.

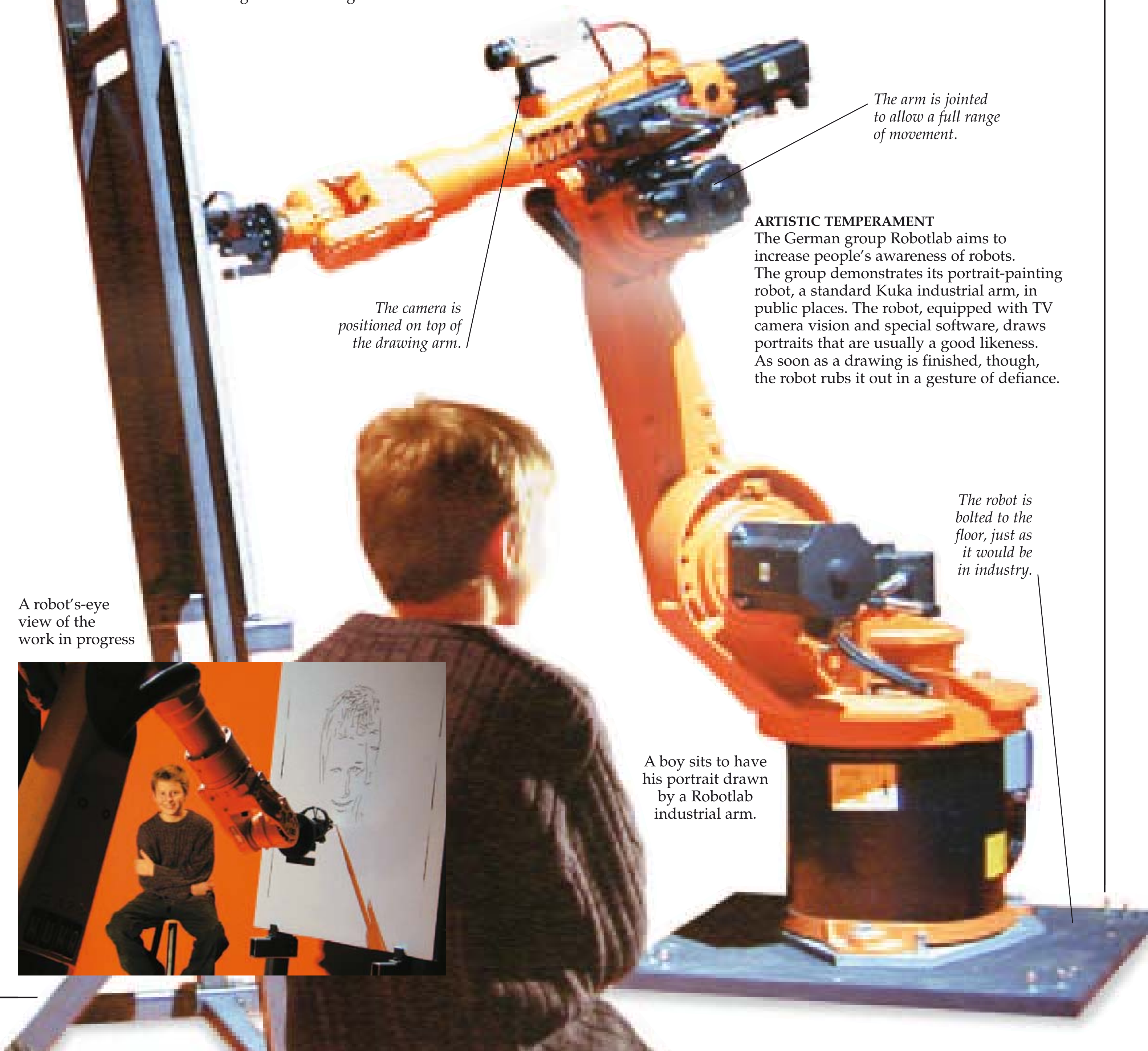
JUST JUNK
Clayton Bailey builds friendly, robot-like creatures from junk. He uses old home appliances, cooking pots, and car parts to create life-size models of people and pets. The robots do not move, but they have blinking lights and sometimes work as clocks or radios. Bailey exhibits his robot art at the Wonders of the World museum in California, USA, which he started in 1976.

Aaron mixes paints to the exact colour required.



Harold Cohen watches Aaron at work.

ROBOT REALIST
Aaron is not a true robot, but a computer connected to a large drawing machine. British artist Harold Cohen has been working on Aaron since 1973. It makes several original sketches, Cohen selects one, then Aaron paints the final picture. Its paintings have been hung in several art galleries.



The arm is jointed to allow a full range of movement.

The camera is positioned on top of the drawing arm.

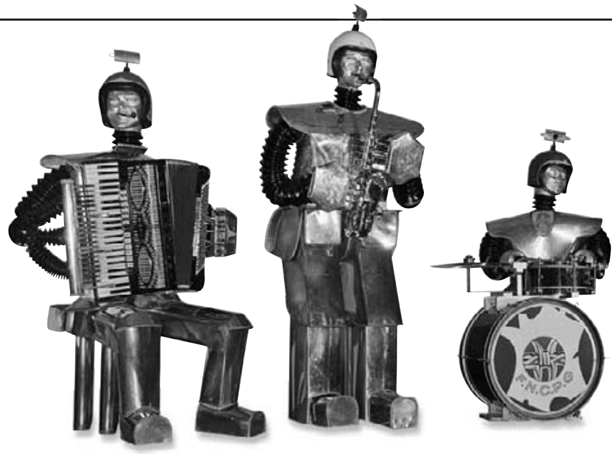
ARTISTIC TEMPERAMENT
The German group Robotlab aims to increase people's awareness of robots. The group demonstrates its portrait-painting robot, a standard Kuka industrial arm, in public places. The robot, equipped with TV camera vision and special software, draws portraits that are usually a good likeness. As soon as a drawing is finished, though, the robot rubs it out in a gesture of defiance.

The robot is bolted to the floor, just as it would be in industry.

A boy sits to have his portrait drawn by a Robotlab industrial arm.

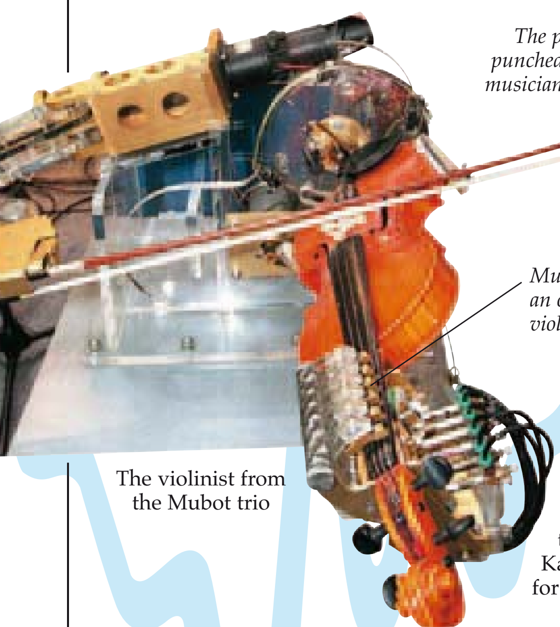
A robot's-eye view of the work in progress

Musical robots



RECORD PLAYERS
Robot bands were popular in Paris, France, in the 1950s. They were not real robots, but simply moved in time to music from a gramophone record. This trio was created by French inventor Didier Jouas-Poutrel in 1958. It could play any tune the dancers requested – as long as the record was available.

PLAYING A MUSICAL instrument demands a combination of movement and senses that presents a real challenge to robot engineers. Music has to be played with feeling, not just mechanically. Despite this, sophisticated robot pianos and other automatic instruments were available as long ago as the early 20th century. Some of the first tests of modern robots involved music, precisely because playing an instrument requires such careful coordination. Musical robots have not yet replaced human musicians, but they have put a few drummers out of a job. Drum machines controlled by computers now underpin the backing tracks of much of pop music.



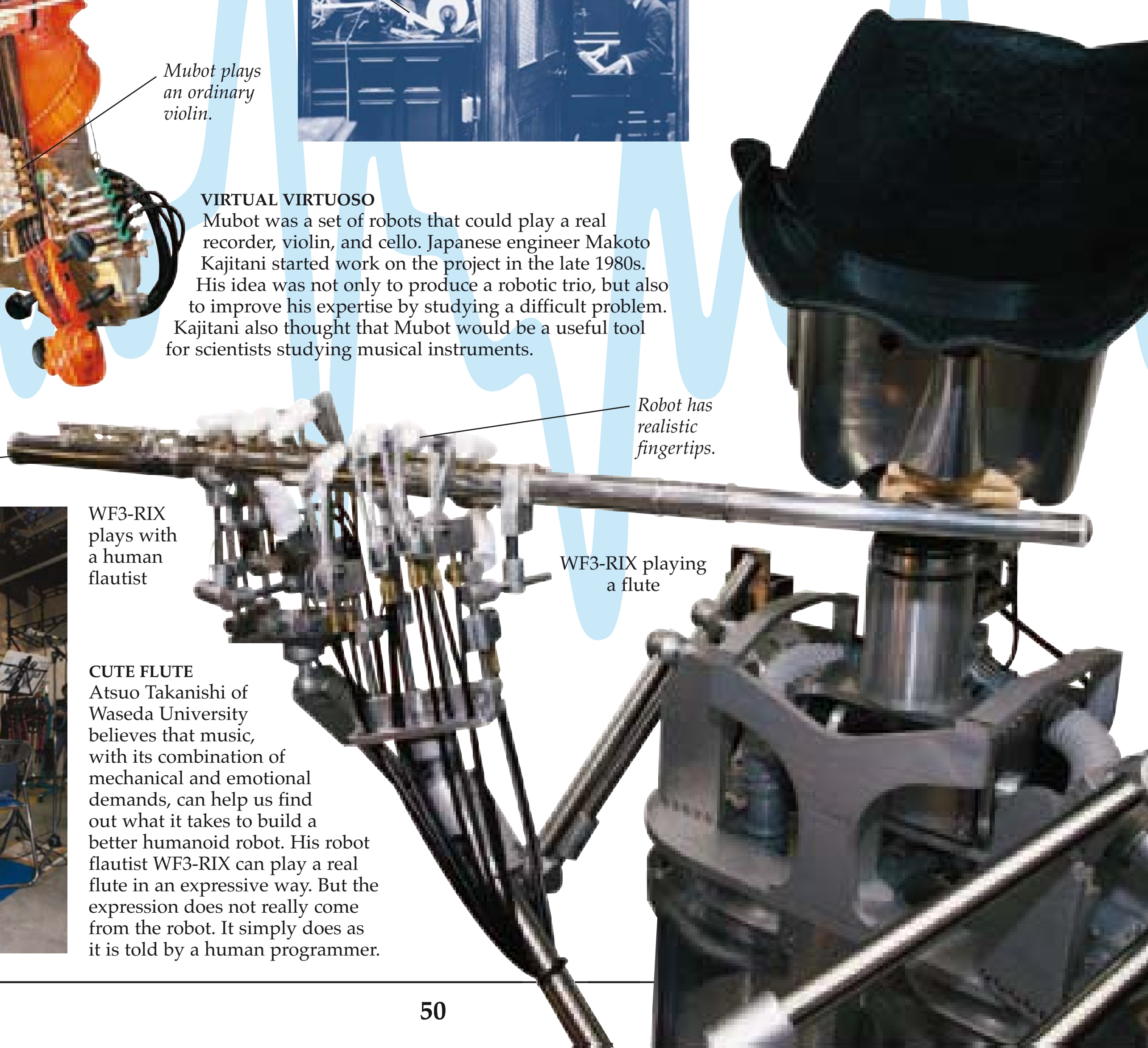
Mubot plays an ordinary violin.

The violinist from the Mubot trio

The paper is punched as the musician plays.

ROLL MODEL
In the 1920s, robot pianos brought "live" music into some homes. Musicians played on a recording piano that captured their actions as holes in a paper roll. This was played back on a reproducing piano that repeated every detail of the performance.

VIRTUAL VIRTUOSO
Mubot was a set of robots that could play a real recorder, violin, and cello. Japanese engineer Makoto Kajitani started work on the project in the late 1980s. His idea was not only to produce a robotic trio, but also to improve his expertise by studying a difficult problem. Kajitani also thought that Mubot would be a useful tool for scientists studying musical instruments.



The flute needs no modification.

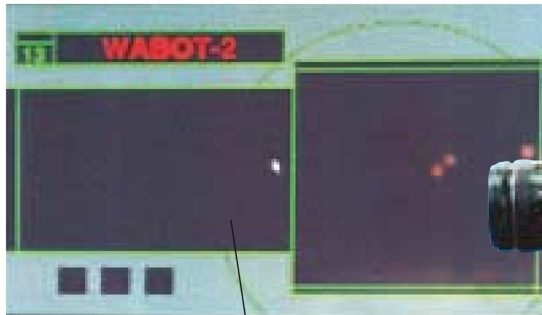
Robot has realistic fingertips.

WF3-RIX playing a flute

WF3-RIX plays with a human flautist

CUTE FLUTE
Atsuo Takanishi of Waseda University believes that music, with its combination of mechanical and emotional demands, can help us find out what it takes to build a better humanoid robot. His robot flautist WF3-RIX can play a real flute in an expressive way. But the expression does not really come from the robot. It simply does as it is told by a human programmer.

James McLurkin with his Swarm Orchestra



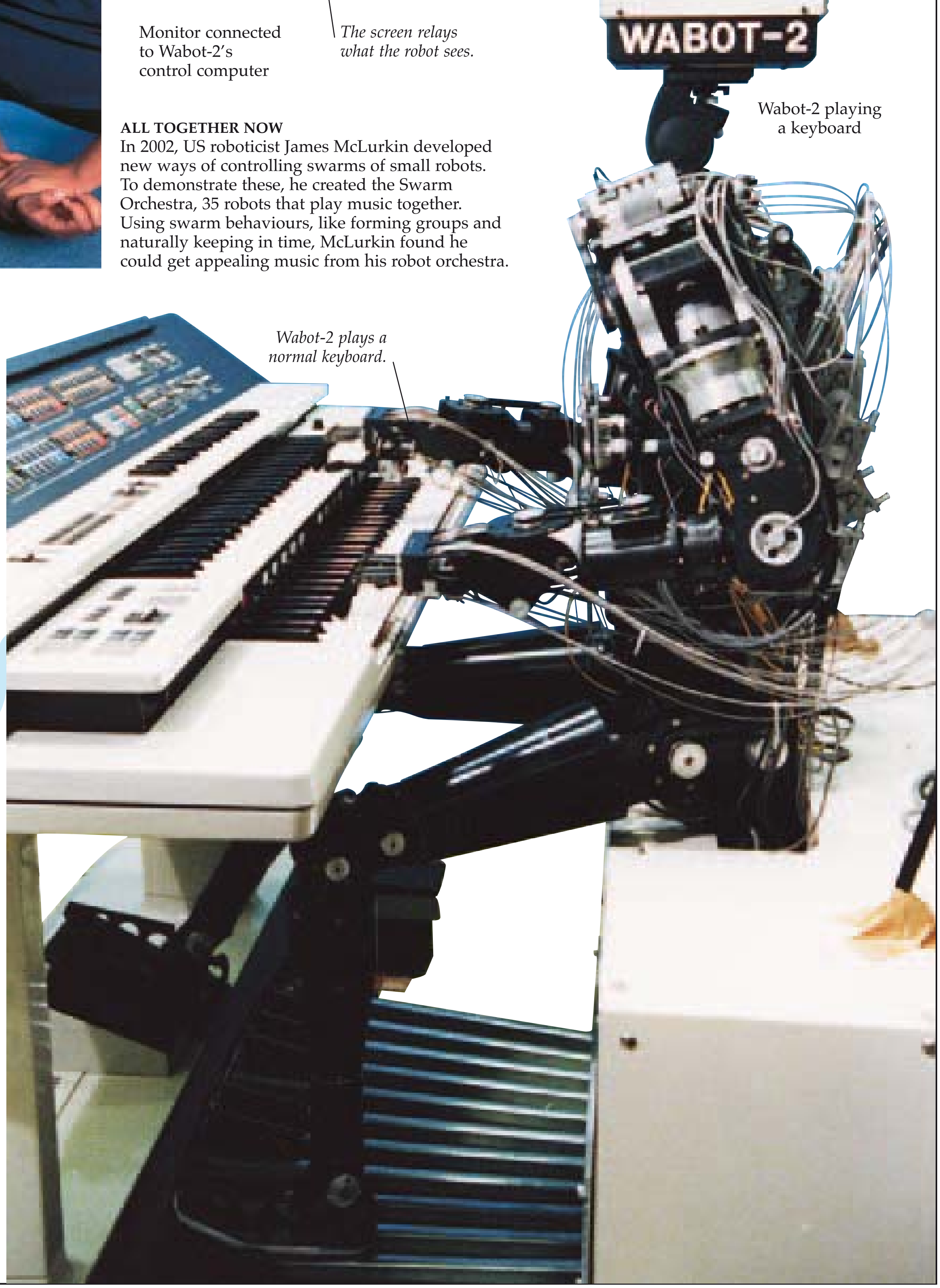
Monitor connected to Wabot-2's control computer

The screen relays what the robot sees.

ALL TOGETHER NOW

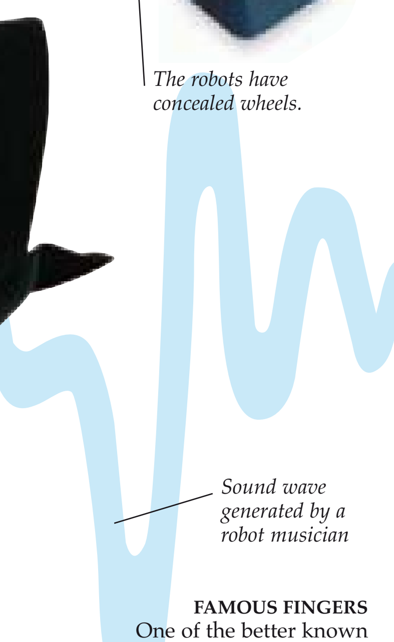
In 2002, US roboticist James McLurkin developed new ways of controlling swarms of small robots. To demonstrate these, he created the Swarm Orchestra, 35 robots that play music together. Using swarm behaviours, like forming groups and naturally keeping in time, McLurkin found he could get appealing music from his robot orchestra.

The robots have concealed wheels.



Wabot-2 playing a keyboard

Wabot-2 plays a normal keyboard.



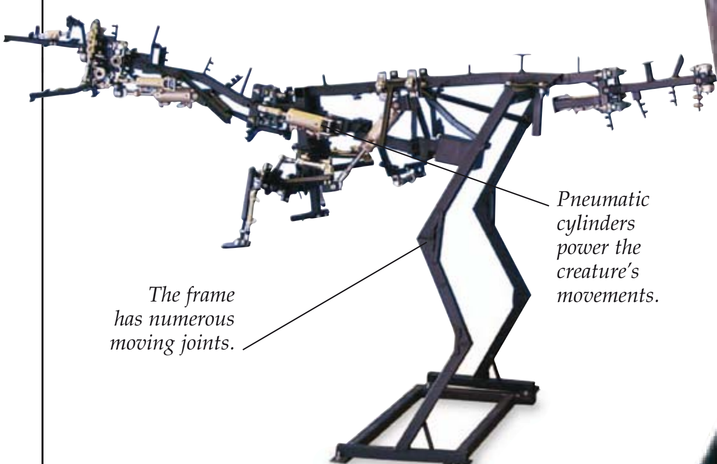
Sound wave generated by a robot musician

FAMOUS FINGERS

One of the better known musical robots is Wabot-2. It was developed at Waseda University from an earlier humanoid robot. Playing a keyboard from sheet music was an ambitious goal, but by 1984 Wabot-2 was sitting at an electronic organ, reading music with its camera eye, and playing simple tunes. It could also accompany singers, by listening to their voices and keeping in time.

Animatronics

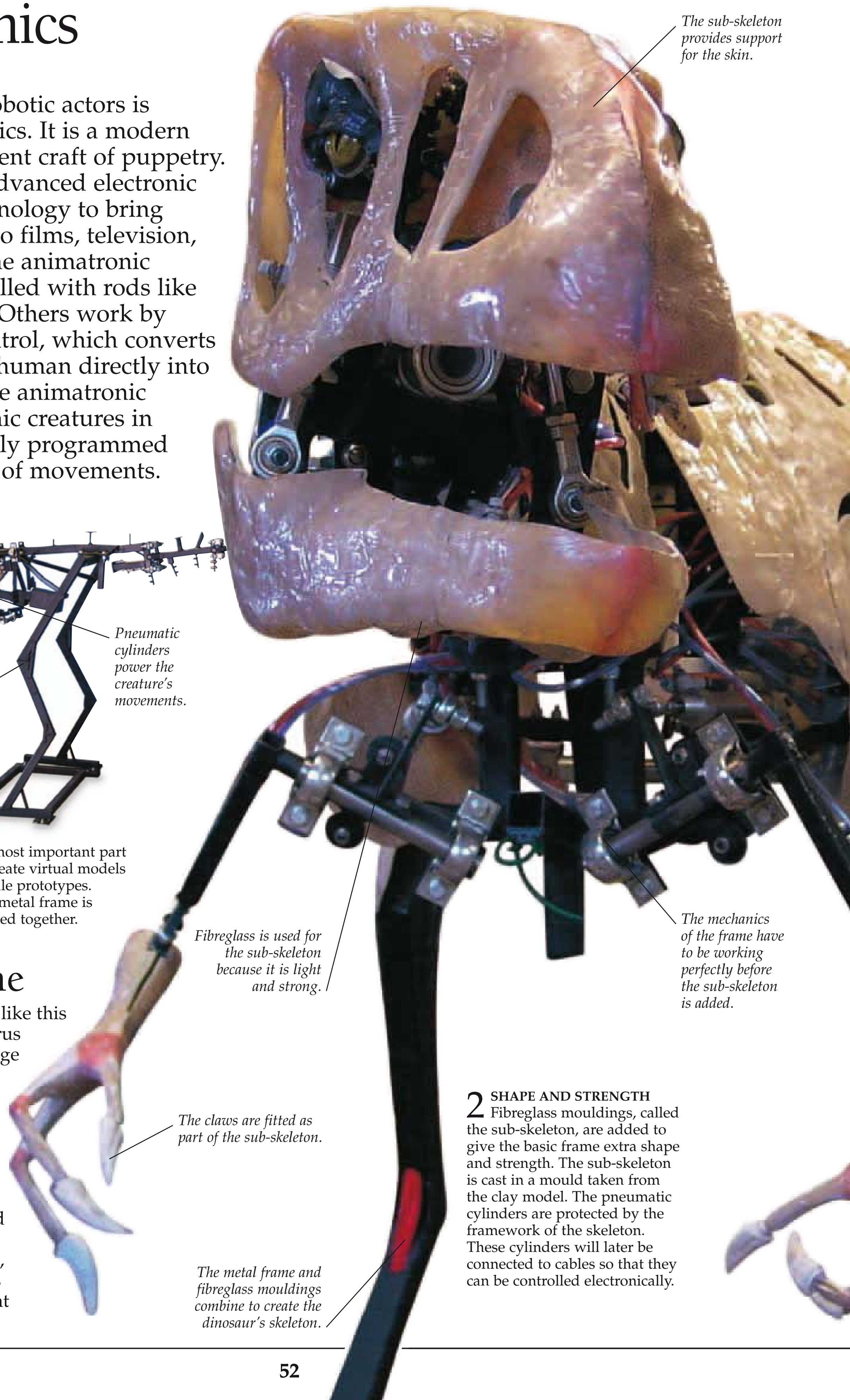
THE CREATION OF robotic actors is known as animatronics. It is a modern extension of the ancient craft of puppetry. Animatronics uses advanced electronic and mechanical technology to bring astonishing realism to films, television, and exhibitions. Some animatronic characters are controlled with rods like traditional puppets. Others work by elaborate remote control, which converts the movements of a human directly into the movements of the animatronic character. Animatronic creatures in exhibitions are usually programmed to repeat a sequence of movements.



1 MOVING PARTS
The animatronic frame is the most important part of the character. Engineers first create virtual models on computers and build small-scale prototypes. When the design is finalized, the metal frame is made in pieces then carefully bolted together.

How it is done

Bringing an extinct animal like this 2-m (6.5-ft) tall Megalosaurus back to life is a real challenge for artists, engineers, and computer programmers. The creature is based on a clay model made by sculptors. Mechanical engineers create the skeleton that will allow it to move. Painters are called in to add colour to its skin. When all this work is done, animatronics programmers will finally bring movement to the mighty Megalosaur.



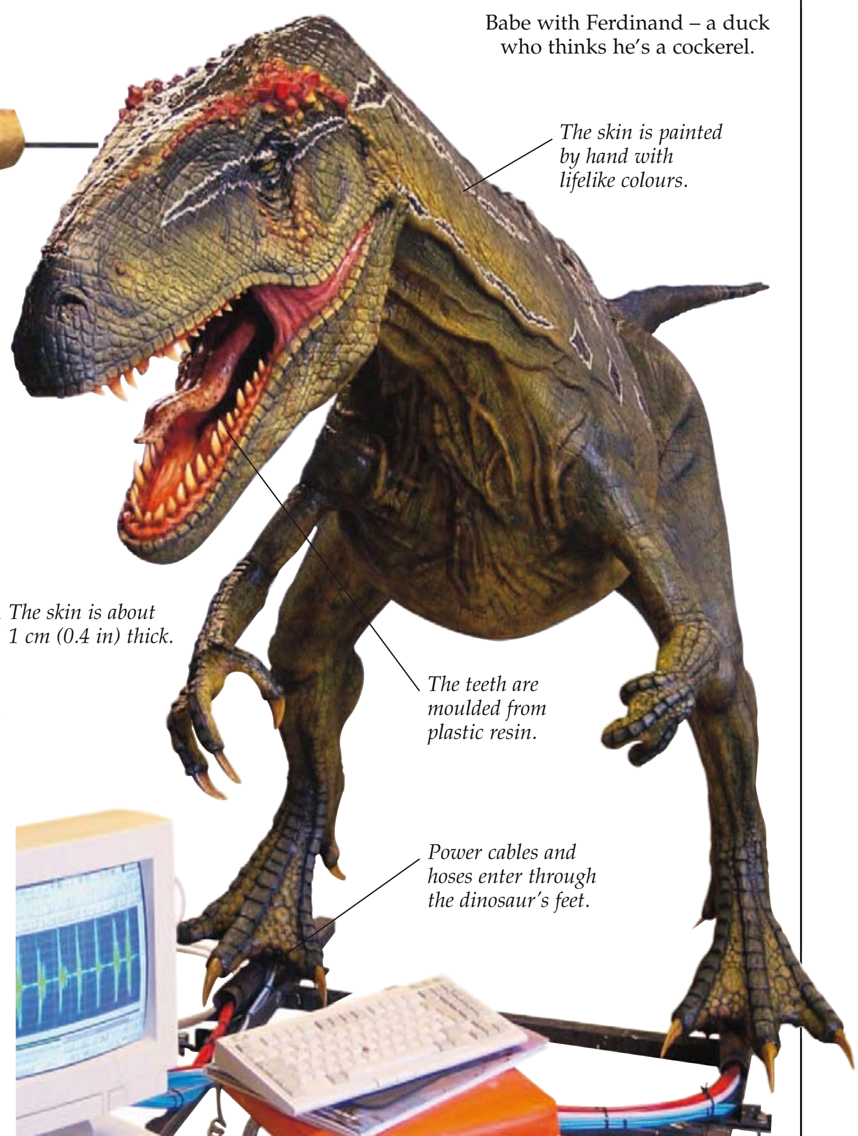
2 SHAPE AND STRENGTH
Fibreglass mouldings, called the sub-skeleton, are added to give the basic frame extra shape and strength. The sub-skeleton is cast in a mould taken from the clay model. The pneumatic cylinders are protected by the framework of the skeleton. These cylinders will later be connected to cables so that they can be controlled electronically.

ALL UNDER CONTROL
Some animatronic characters are brought to life with systems like the Neal Scanlan Studio Performance Animation Controller (PAC). It allows one person to control several actions by converting hand and finger movements into electronic signals that bring the creature to life.

PROBLEMATIC PIGLET
Author Dick King-Smith's book *Babe the Sheep-Pig* – about a talking piglet that could round up sheep – presented a real challenge when it was made into a film in 1995. It took specialists two years to develop an animatronic piglet with a full range of facial expressions.

Babe with Ferdinand – a duck who thinks he's a cockerel.

The skin is about 1 cm (0.4 in) thick.



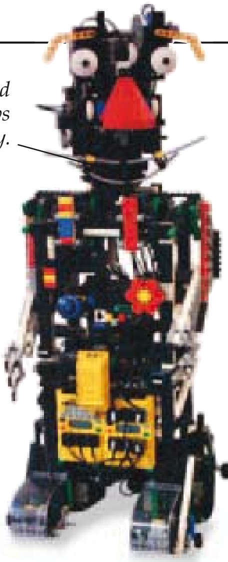
The skin is painted by hand with lifelike colours.

The teeth are moulded from plastic resin.

Power cables and hoses enter through the dinosaur's feet.

3 SCALES AND WRINKLES
The skin is made of silicone rubber. It is cast from the same detailed mould as the sub-skeleton so that the two fit together perfectly. The textured, rubbery skin is stretched over the skeleton. It has to be flexible enough to allow for realistic movement.

4 READY FOR ACTION
When the whole of the skeleton has been covered with skin, details like the teeth and tongue are added. The textured skin is then painted. Finally, the pneumatic hoses and electronic control cables that will provide the dinosaur with power are connected up.

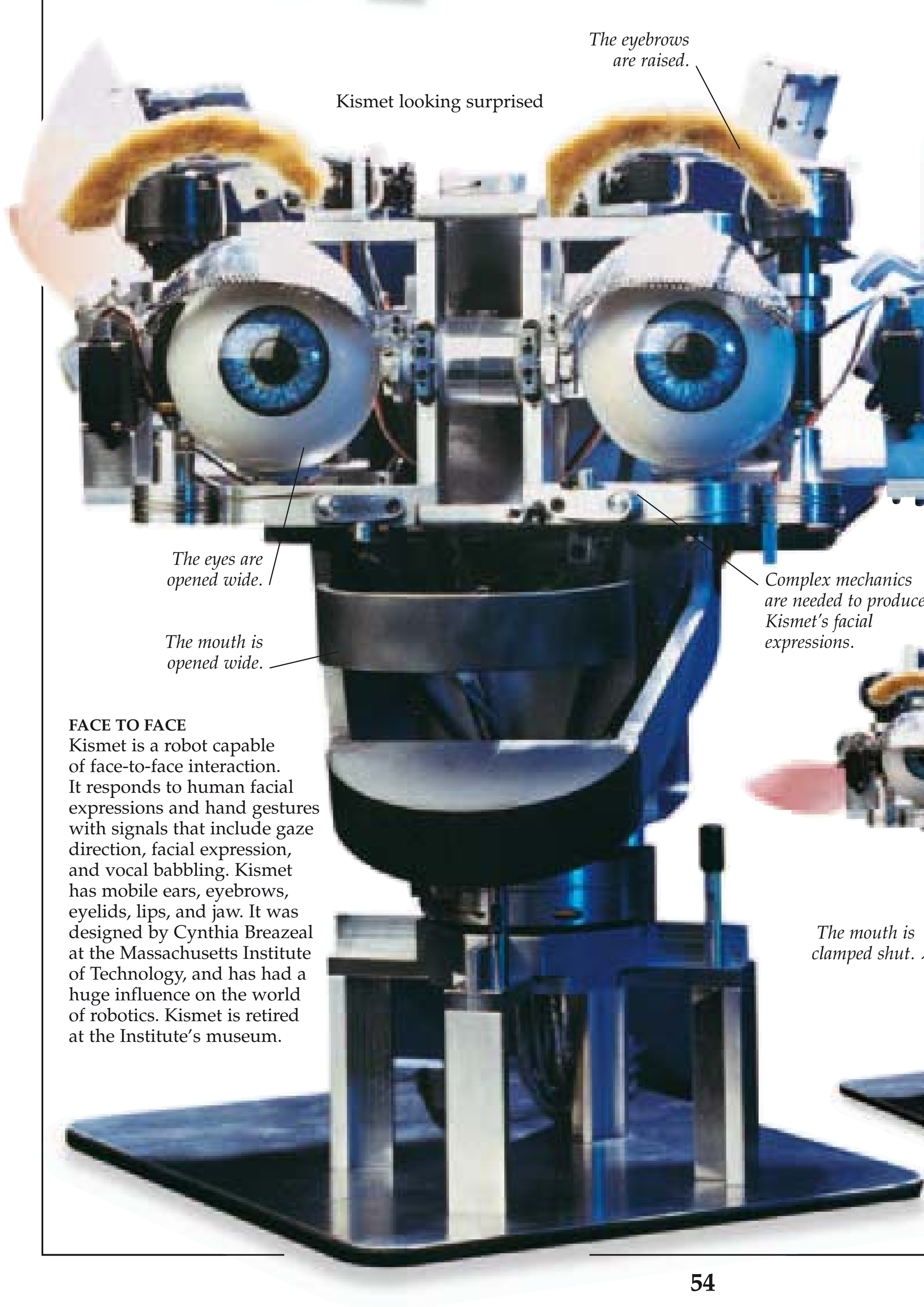


Feelix smiles and raises its eyebrows when it is happy.

SIMPLE SOUL
Jakob Fredslund and Lola Cañamero from Lego-Lab in Denmark created Feelix. It is programmed to react with anger, happiness, or fear when its feet are touched in different ways. Feelix is a simple robot, but it has taught people a great deal about how humans interact with robots that seem to show feelings.

Machines with feelings

WE OFTEN ATTRIBUTE emotions to machines, saying perhaps that the car is behaving badly when it will not start. Can an inanimate object really have feelings? Modern roboticists are trying to answer this question by building machines that simply act as though they have feelings. This is a response to the fact that, as machines become more complex and powerful, they need richer ways of interacting with human beings. People are more likely to accept robots as part of their lives if they can communicate emotionally with them.



Kismet looking surprised

The eyebrows are raised.

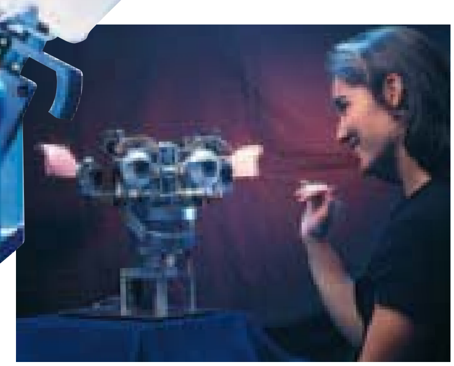
Kismet's ears can move to contribute to its expression.

The eyes are opened wide.

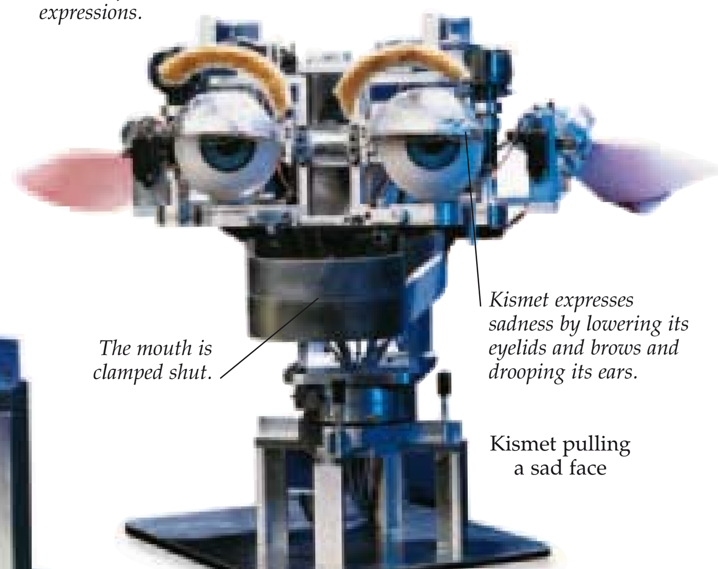
The mouth is opened wide.

Complex mechanics are needed to produce Kismet's facial expressions.

FACE TO FACE
Kismet is a robot capable of face-to-face interaction. It responds to human facial expressions and hand gestures with signals that include gaze direction, facial expression, and vocal babbling. Kismet has mobile ears, eyebrows, eyelids, lips, and jaw. It was designed by Cynthia Breazeal at the Massachusetts Institute of Technology, and has had a huge influence on the world of robotics. Kismet is retired at the Institute's museum.



Kismet interacting with Cynthia Breazeal

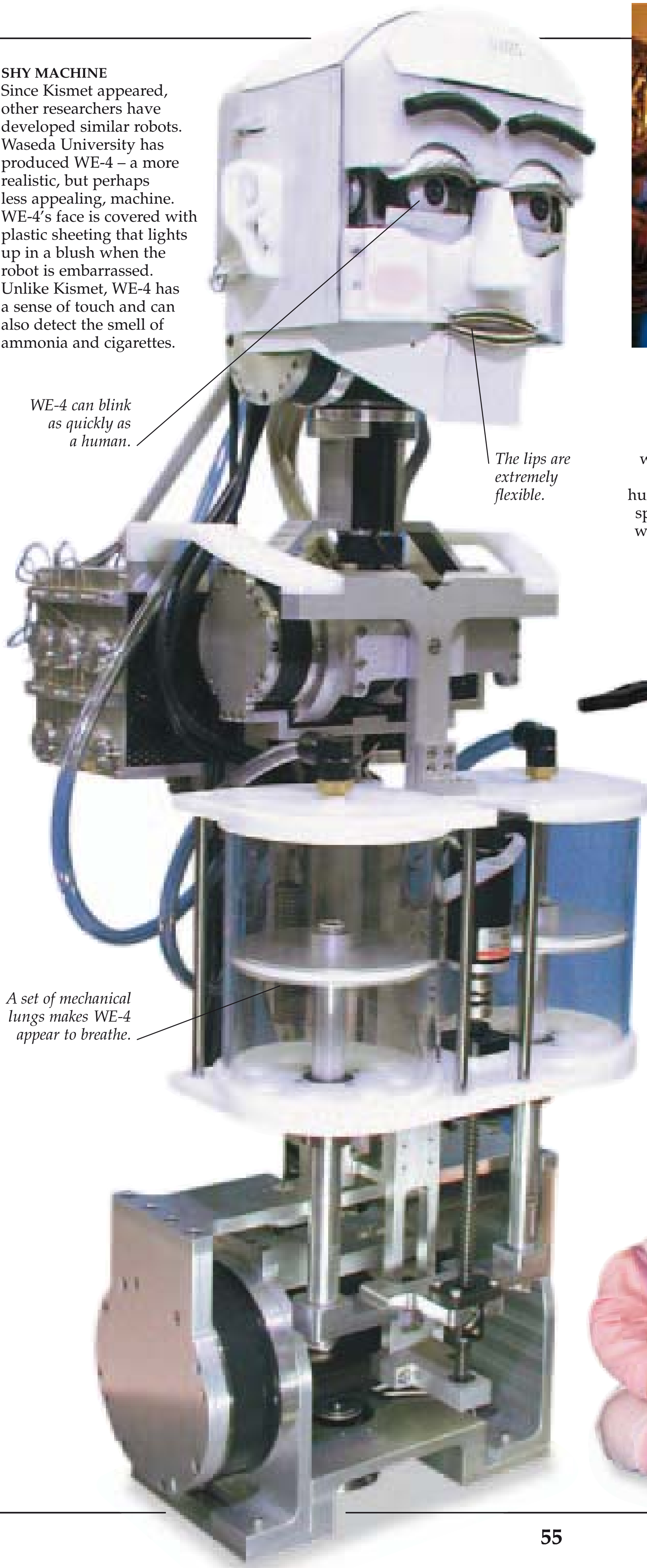


The mouth is clamped shut.

Kismet expresses sadness by lowering its eyelids and brows and drooping its ears.

Kismet pulling a sad face

SHY MACHINE
Since Kismet appeared, other researchers have developed similar robots. Waseda University has produced WE-4 – a more realistic, but perhaps less appealing, machine. WE-4's face is covered with plastic sheeting that lights up in a blush when the robot is embarrassed. Unlike Kismet, WE-4 has a sense of touch and can also detect the smell of ammonia and cigarettes.



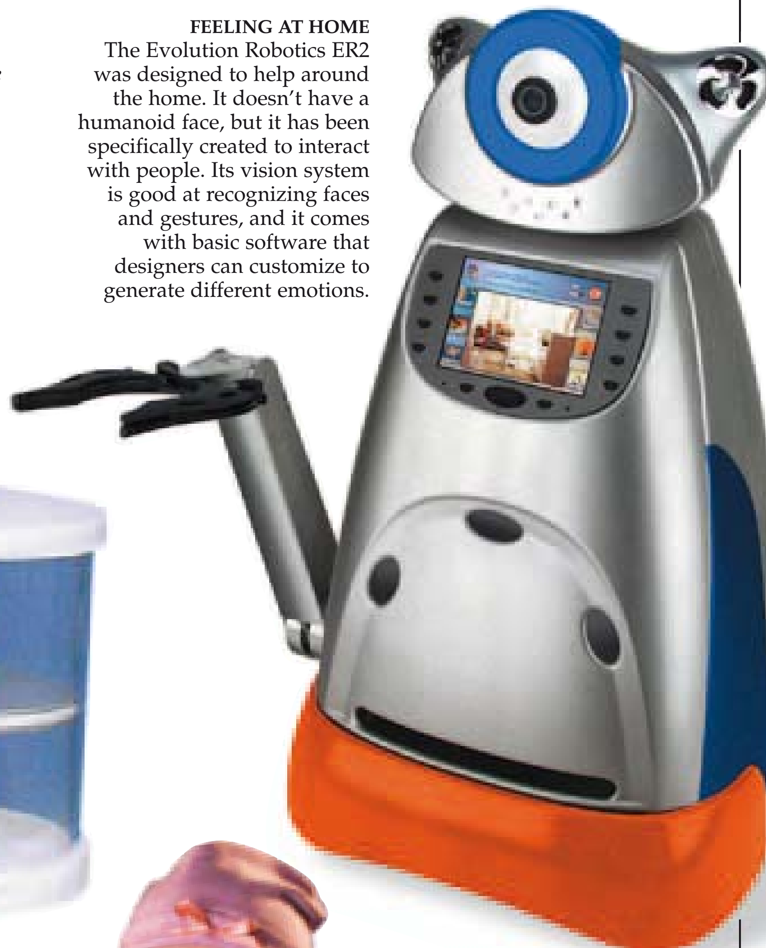
WE-4 can blink as quickly as a human.

The lips are extremely flexible.

A set of mechanical lungs makes WE-4 appear to breathe.

FRIENDLY GUIDE
The robot Sage was used as a tour guide at the Carnegie Museum of Natural History in the USA. When its batteries got low, Sage behaved as if it was tired, and a lack of visitors made it lonely. If people got in Sage's way it became angry, but anyone in the way of a lonely Sage made it happy – it was pleased to see them! If museum visitors paid it attention, it grew cheerful and told jokes. The robot was developed in the 1990s by US engineer Illah Nourbakhsh.

FEELING AT HOME
The Evolution Robotics ER2 was designed to help around the home. It doesn't have a humanoid face, but it has been specifically created to interact with people. Its vision system is good at recognizing faces and gestures, and it comes with basic software that designers can customize to generate different emotions.



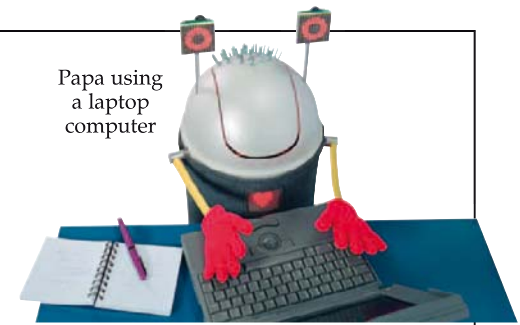
Flexible skin and motors modelled on human facial muscles gave My Real Baby hundreds of different expressions.

REALISTIC BABY
My Real Baby was developed in 2000 by US toy maker Hasbro and Rodney Brooks, director of the US company iRobot. It had an expressive face and voice, and also touch and motion sensors. The doll knew when it was being fed, rocked, or ignored and reacted with one of 15 human-like emotions.

Teams and swarms

THE CLEVEREST OF today's robots is only about as intelligent as an ant. This lack of brains could be less of a disadvantage than it seems. Ants, despite their limited intelligence, are highly successful animals. Their secret is to act not as individuals, but as a team. Many other animals, including birds and bees, also benefit from this type of group behaviour – forming flocks or swarms increases their chances of survival. Roboticists are beginning to work on this idea, hoping that the group intelligence of a team of small, simple robots can replace the individual intelligence that has proved so elusive for their larger cousins.

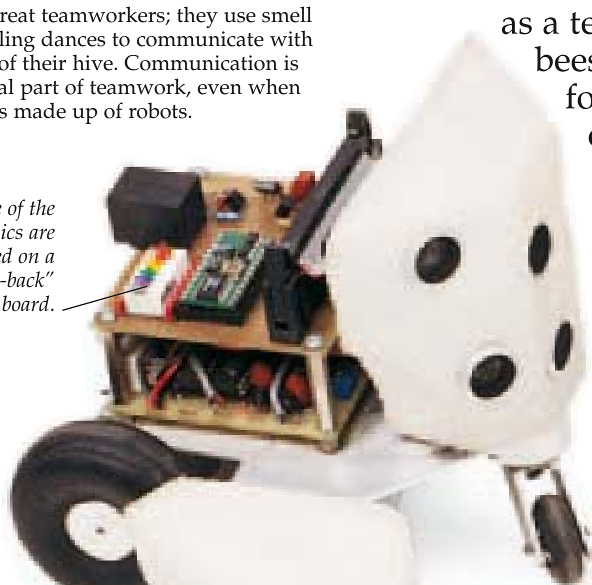
BEE TEAM
Bees are great teamworkers; they use smell and waggling dances to communicate with members of their hive. Communication is an essential part of teamwork, even when the team is made up of robots.



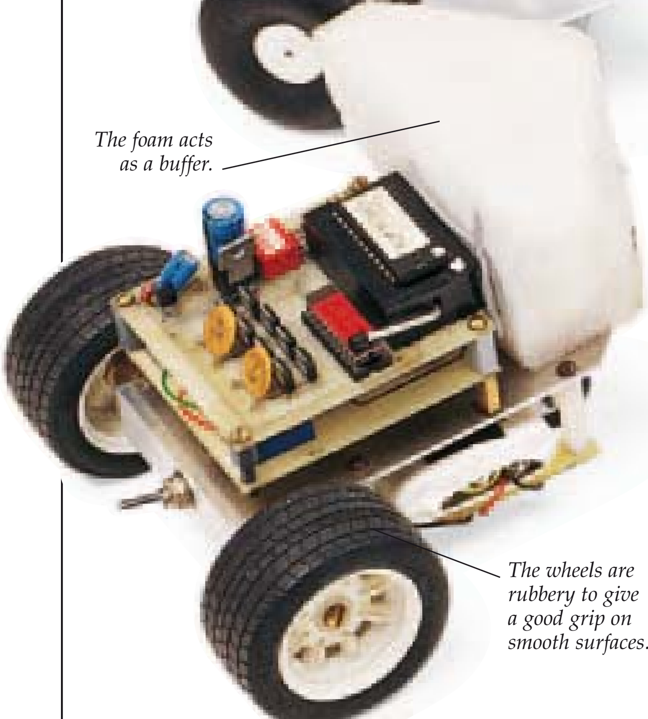
Papa using a laptop computer

Mama answering the telephone

ACTING TOGETHER
A robot theatre created by Ethno-Expo toured Switzerland in 2000–2002. The actors, four Koala robots, could find their places on stage, interact, speak, and move their arms and mouths. Kids and parents loved the play, which was called *Small Children – Joy and Burden*.



Some of the electronics are mounted on a "piggy-back" circuit board.

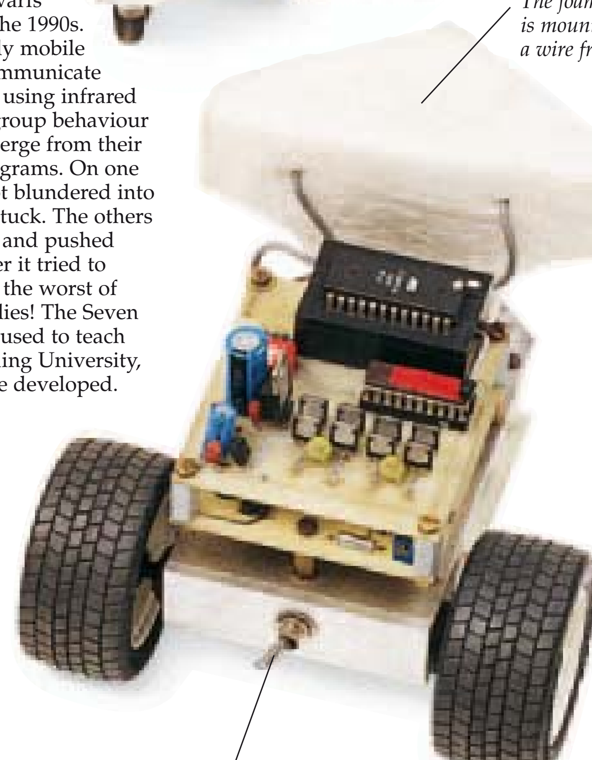


The foam acts as a buffer.

The wheels are rubbery to give a good grip on smooth surfaces.

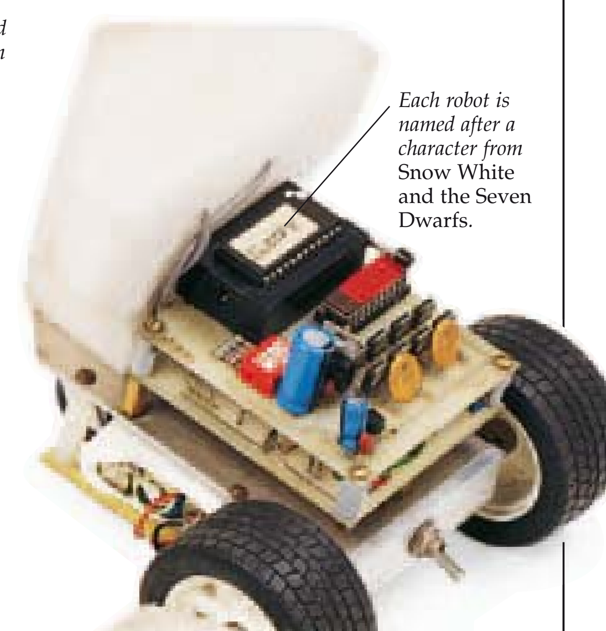
The sonar sensors point in three directions.

BULLY BOTS
A robot swarm known as the Seven Dwarfs was created in the 1990s. The small, highly mobile robots could communicate with each other using infrared light. Realistic group behaviour would often emerge from their very simple programs. On one occasion, a robot blundered into a wall and got stuck. The others crowded round and pushed it back whenever it tried to escape, just like the worst of playground bullies! The Seven Dwarfs are still used to teach robotics at Reading University, where they were developed.

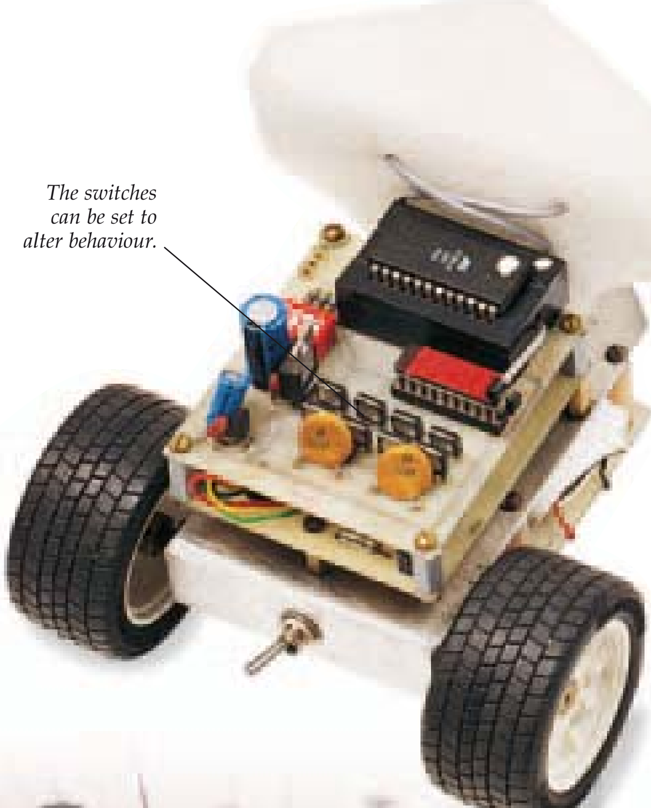


The foam head is mounted on a wire frame.

The robot can be switched off when not in use.

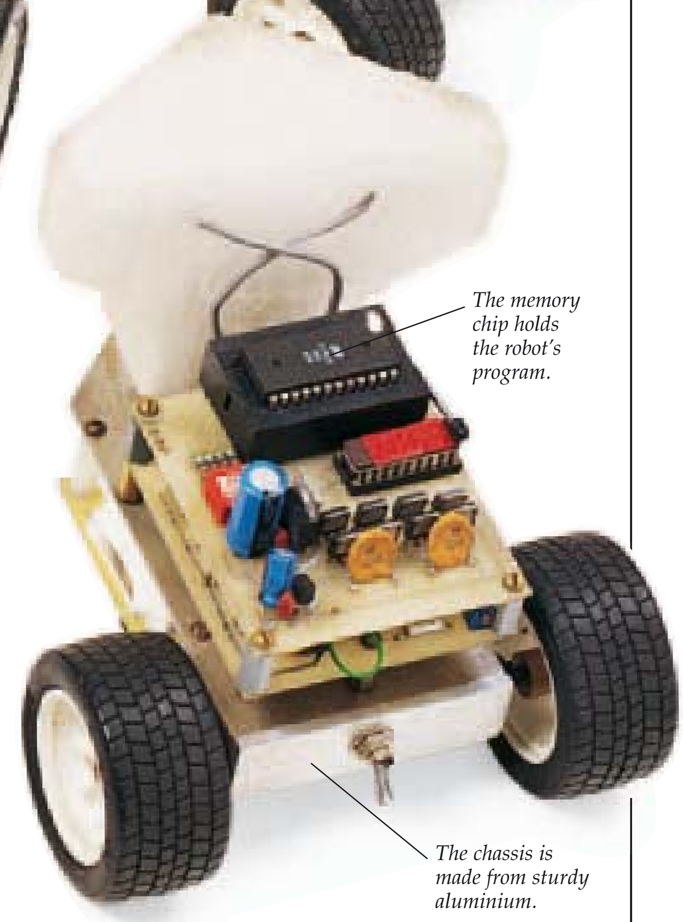


Each robot is named after a character from Snow White and the Seven Dwarfs.



The switches can be set to alter behaviour.

SHARED KNOWLEDGE
Tupperbots – robots made with kitchen containers – were built in the 1990s to see if a group of robots could evolve like natural organisms. When they get together, the robots exchange sections of their computer programs. This may create a new program that works better, so that its owner is more likely to survive. Research of this kind is ongoing.

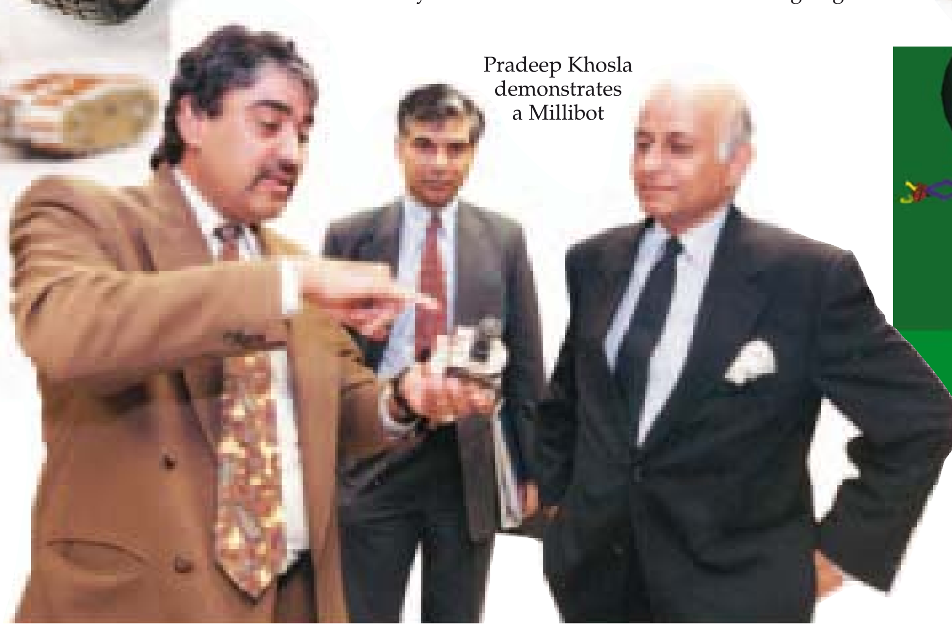


The memory chip holds the robot's program.

The chassis is made from sturdy aluminium.

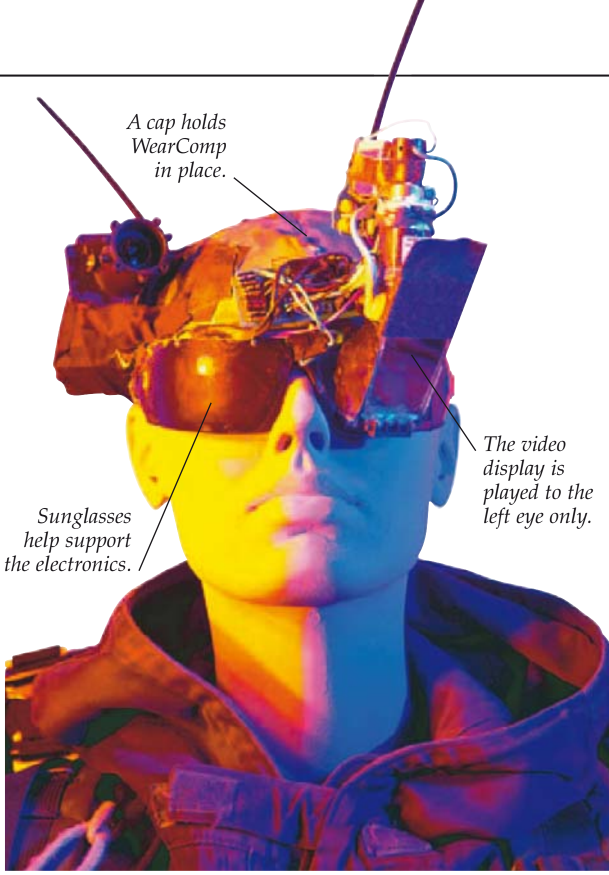
Team of Millibots

MILITARY MILLIBOTS
Pradeep Khosla at Carnegie Mellon University believes that a team of specialized robots can often do better than a single, larger robot. He is working on a robotic team for military reconnaissance and surveillance. Each little Millibot carries a different sensor, such as a camera or temperature probe. The Millibots can also join together to cross gaps.



Pradeep Khosla demonstrates a Millibot

JOINT EFFORT
Swarm-bots are under development in Belgium. They are robot colonies that are made up from smaller, autonomous units called S-bots. The idea is that 30 or so of these will communicate with each other and join together as a Swarm-bot. Unlike a single S-bot, the Swarm-bot will be able to lift heavy objects and bridge chasms.

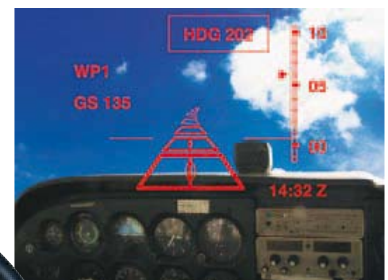


CYBORG MANN
This model is wearing a computer called WearComp. It was developed by Steve Mann, a Canadian engineer and artist, who wears one day and night. WearComp allows him to transmit to the Internet, block unwanted sights, and turn his world into hyperlinks. Mann could be described as the first cyborg – the first person to live in intimate contact with a computer, seeing everything, including himself, through its eyepiece.

Cyborgs

If you can't make machines more like people, you can try making people more like machines. The word cyborg (cybernetic organism) was coined by the Austrian scientist Manfred Clynes in 1960. His original meaning, of an ability-enhancing partnership between human and machine, has changed to mean something that is part human, part machine. There have been several attempts to make this a reality. The main problem is that humans and machines work differently. However, both human nerves and computers use electricity to convey their messages, so it is possible to link people and machines electrically.

Engine overlay used by an engineer

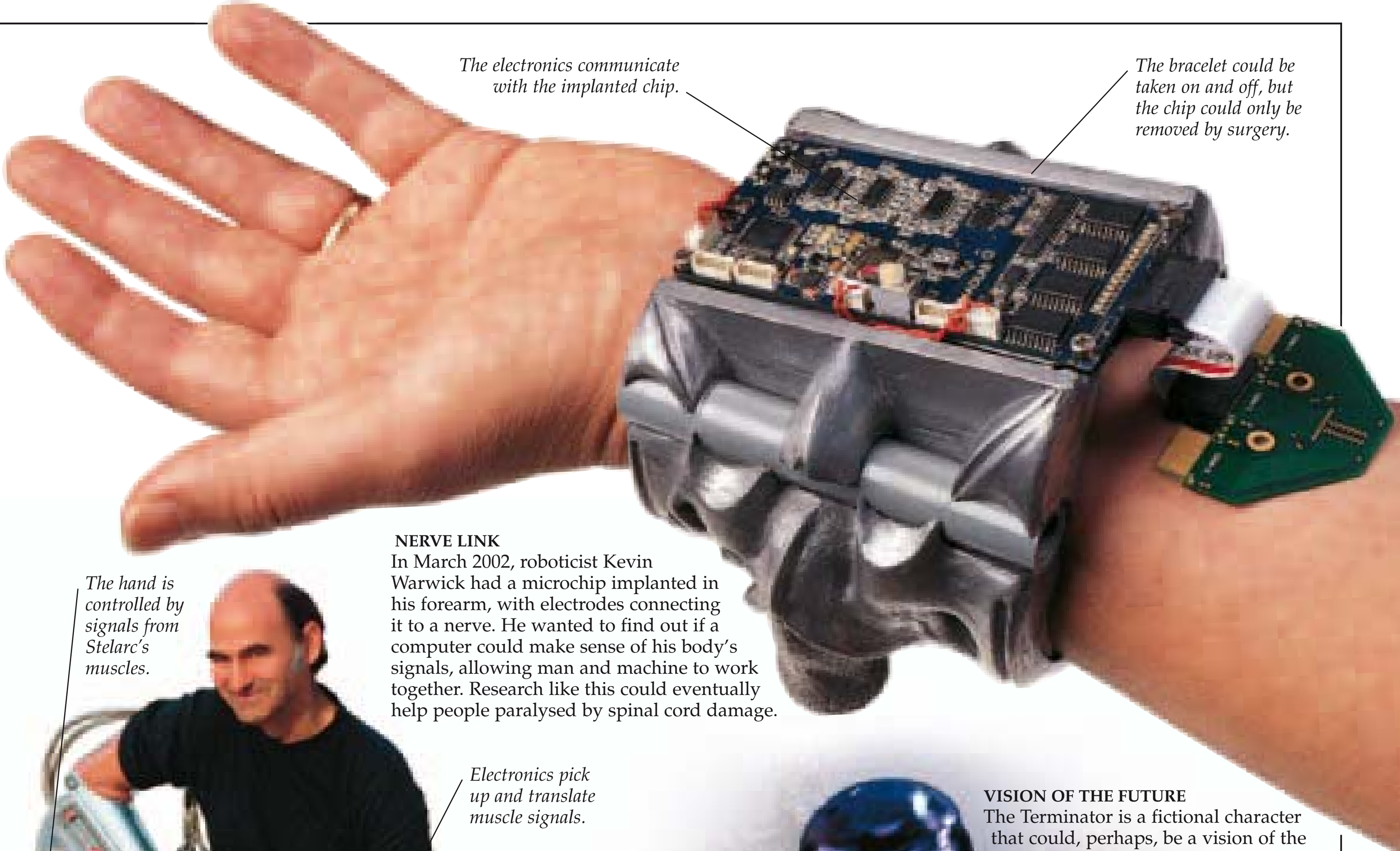


Cockpit overlay used by a pilot

VIRTUAL VIEW
Nomad lets engineers view calculations, such as voltage measurements, without putting down their tools to use a computer. Pilots can also use the system to access flight information while keeping their eye on the job.

Nomad headgear

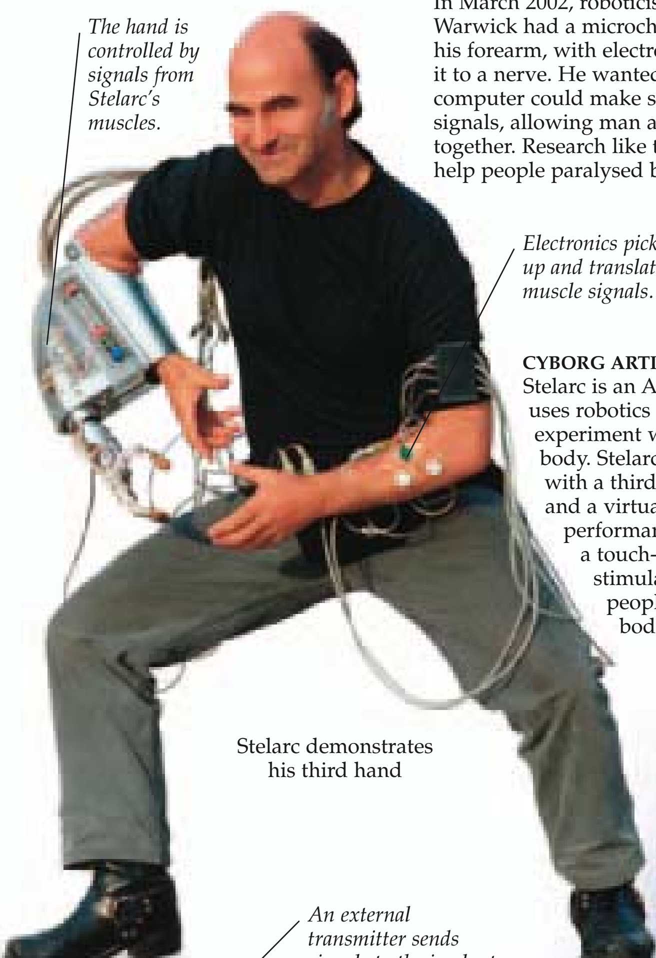
QUITE AN EYEFUL
Cyborg technology is now available to the public. The Nomad Augmented Vision System is designed for people who have to use a computer while doing jobs that need both hands. It allows them to work freely without the problems created by a fixed computer. Nomad creates an overlay, or transparent computer screen, that seems to float in front of the user wherever they look. It does this by using the eye's own lens to focus the image from a laser right onto their retina.



The electronics communicate with the implanted chip.

The bracelet could be taken on and off, but the chip could only be removed by surgery.

NERVE LINK
In March 2002, roboticist Kevin Warwick had a microchip implanted in his forearm, with electrodes connecting it to a nerve. He wanted to find out if a computer could make sense of his body's signals, allowing man and machine to work together. Research like this could eventually help people paralysed by spinal cord damage.



The hand is controlled by signals from Stelarc's muscles.

Electronics pick up and translate muscle signals.

Stelarc demonstrates his third hand

CYBORG ARTIST
Stelarc is an Australian artist who uses robotics and the Internet to experiment with extensions to his body. Stelarc has performed with a third hand, a virtual arm, and a virtual body. For one performance he developed a touch-screen muscle stimulator that enabled people to operate his body remotely.

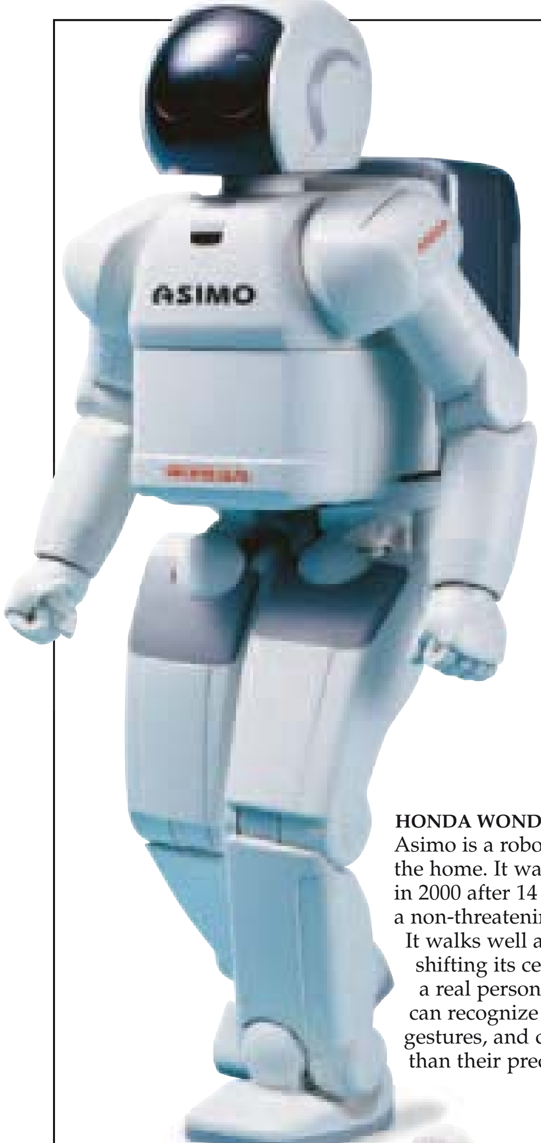
VISION OF THE FUTURE
The Terminator is a fictional character that could, perhaps, be a vision of the distant future. Created in 1984, the cyborg surfaced for the third time in 2003, played as ever by Arnold Schwarzenegger. In the film, he tries to stop evil robot network Skynet destroying humanity, and, of course, succeeds.

Marching machines from *Terminator 3, Rise of the Machines*

An external transmitter sends signals to the implant.

ELECTRONIC EAR
Cyborg technology can help some people who cannot hear. A device called a cochlear implant is embedded in the skull and connected to an external microphone and sound processor. The implant electrically stimulates the nerves in the inner ear, partially restoring the sounds of everyday life, including speech.

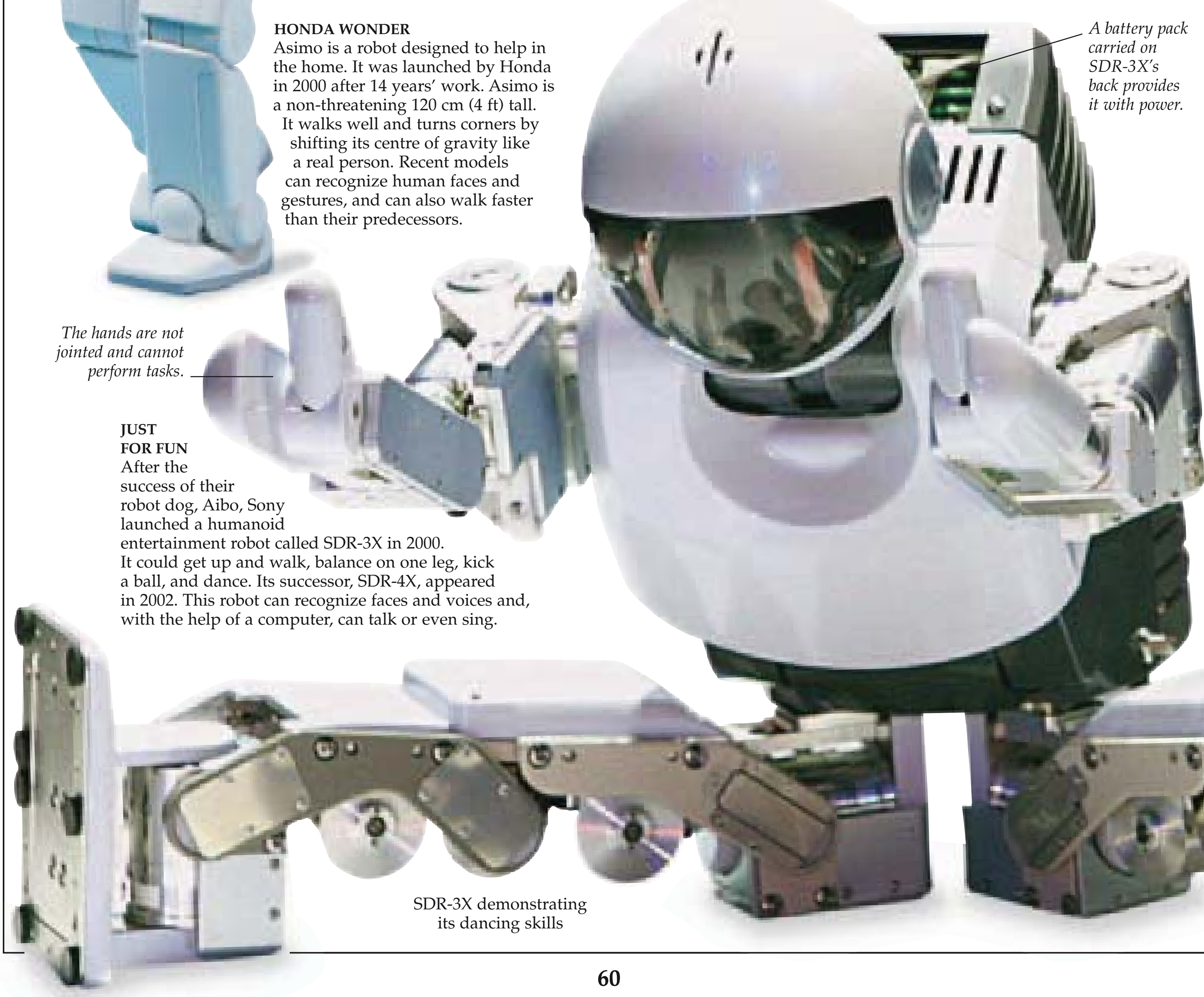
Humanoids



A MACHINE THAT looks, thinks, and behaves like a human being has been a dream of artists and engineers for centuries. One reason for this could be that in the process of building such a machine, they would learn a lot about how people work. There are also some practical reasons. A robot shaped like a human being can adapt quite easily to stairs, chairs, and all the other parts of an environment designed for humans. The human body is extremely complex, however, and creating a robot that is capable of simply walking effectively is an enormous challenge.

STREET SMART?
When Tmsuk 04 was let loose on the streets of Japan to see how people reacted, things went seriously wrong. The robot was kicked to "death" by members of the public, suggesting that people are not yet quite ready to live alongside robots.

HONDA WONDER
Asimo is a robot designed to help in the home. It was launched by Honda in 2000 after 14 years' work. Asimo is a non-threatening 120 cm (4 ft) tall. It walks well and turns corners by shifting its centre of gravity like a real person. Recent models can recognize human faces and gestures, and can also walk faster than their predecessors.

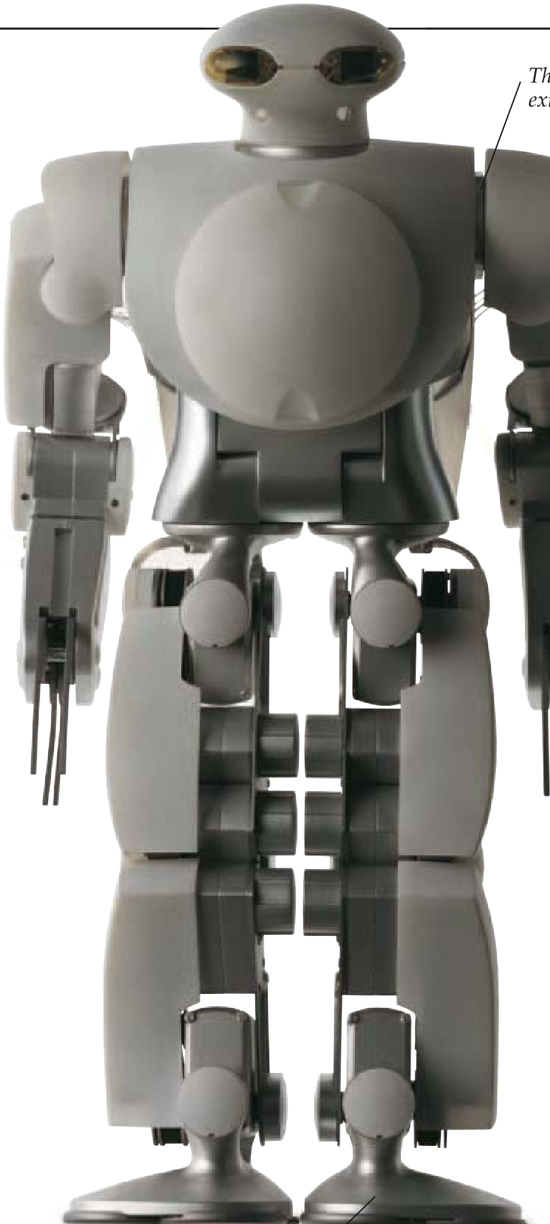


A battery pack carried on SDR-3X's back provides it with power.

The hands are not jointed and cannot perform tasks.

JUST FOR FUN
After the success of their robot dog, Aibo, Sony launched a humanoid entertainment robot called SDR-3X in 2000. It could get up and walk, balance on one leg, kick a ball, and dance. Its successor, SDR-4X, appeared in 2002. This robot can recognize faces and voices and, with the help of a computer, can talk or even sing.

SDR-3X demonstrating its dancing skills



The joints are extremely mobile.

Morph3 can stand, crouch, and walk smoothly and swiftly.

BARGAIN BOT
Low-cost humanoid Robo Erectus is the work of Singapore engineer Zhou Changjiu. The robot, which was designed to walk and kick balls, came second in the 2002 RoboCup Humanoid Walk League. But Changjiu's real goal is to build a more affordable humanoid.

HELPFUL BUILDER
Morph3 is a 38-cm (15-in) robot intended as a construction kit for the development of humanoid technology. It was made in Japan by Hiroaki Kitano. Morph3 is light in weight, and its motors, gears, and sensors can fit together in a variety of different ways.

Pino has a long nose, like its namesake Pinocchio.

Pino stands just 75 cm (30 in) tall.

PERSONAL PLAYER
Hiroaki Kitano developed Pino for RoboCup. Kitano sees its human shape as more than an aid to playing football. He thinks that in the future, humans will be more likely to work alongside humanoid robots if they like them. That's why Pino has an appealing shape and a totally unnecessary nose.

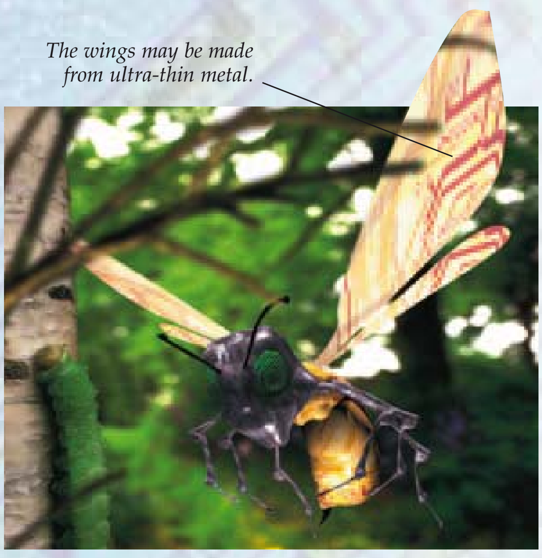
Into the future

NO ONE CAN TELL where robotics is leading us. Even experts cannot agree on what the future with robots might be like. Some say we may become dependent on intelligent machines that think for themselves. Others say that robots will never be that sophisticated. This uncertainty centres on a basic question: what is intelligence? If we can find out enough about intelligence to reproduce it with a computer, then we may soon have machines that are cleverer than we are. If understanding intelligence proves to be beyond us, however, the sci-fi future of humanoids and cyborgs may elude us forever.

HRP-2's "clothes" can be changed if required.

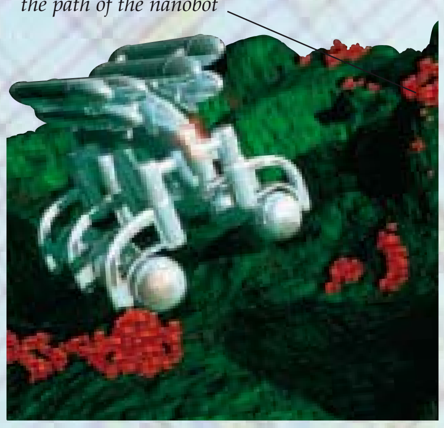
Jointed ankles give it a smooth walking action.

MIGHTY MECHA
This could be the worker of the future. Seen here in its 2003 Mecha costume, HRP-2 is being developed by Kawada Industries in Japan. Their aim is to build a robot that can operate on a real building site. HRP-2 stands 154 cm (5 ft 1 in) tall, and is one of only two humanoid robots that can get up unaided if it falls over.



The wings may be made from ultra-thin metal.

INSECTS ADVANCE
New knowledge is making new kinds of robot possible. Scientists have recently worked out exactly how insect wings work, while engineers are developing nanotechnology – ways of making very small objects. Together, these could produce insect-sized robots in the future – some as fearsome as this computer-generated wasp.



Harmful organisms in the path of the nanobot

IN THE BLOOD
Nanotechnology could promise great medical advances for the future. Nanorobots small enough to pass through blood vessels, and armed with chemical weapons, could seek out and destroy deadly bacteria and viruses. The robots could even be trained to group together after the job was done and exit at a chosen point so that they could be used again.

Sonar transmitters and receivers are located on the front of the head.

Video cameras are mounted in the eye sockets.

Microphones are positioned where human ears would be.

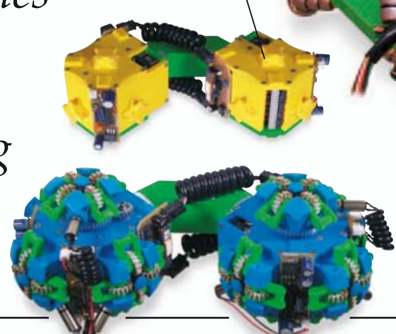
Infrared sensors are positioned on the top lip.

HOME HELP
Home robots of the future may look humanoid, like this computer image, but are just as likely to look like fridges on wheels. They are unlikely to wield a normal mop and bucket, but they should be able to do more than today's robot vacuum cleaners and lawnmowers.

MAGIC MORGUI
K-28, or Morgui (Chinese for magic ghost), a new robot at Reading University, is a scary skull whose gaze really does follow you around the room. It can even make a video recording of you while it does this, which for under-18s requires parental consent. But K-28 has a serious purpose. Equipped with sight, hearing, infrared, radar, and sonar, it is being used in research that will enable future robots to combine all these senses much more effectively.

FUTURE FEAR
Some authors have suggested that robots could become as intelligent as humans in the not too distant future. Unless we take urgent action, they claim, the robots might take over. But this is just one view. Other experts dismiss it as fantasy, saying that while computers are advancing rapidly, our knowledge of how to use them lags far behind.

The parts are linked by magnets.



The smaller parts are referred to as "female".

SHAPE SHIFTERS
What shape will tomorrow's robots be? They will be whatever shape they need to be, if Daniela Rus of Dartmouth College, USA, gets her way. She is one of several roboticists working on robots that can change their shape for different jobs. Their bodies are made of separate parts that can slide and link in various ways to change shape in seconds.

"We're going to see machines that are more intelligent than we are perhaps by 2030 ... how are we going to cope with that?"

KEVIN WARWICK
Professor of Cybernetics, Reading University, UK

Did you know?

FASCINATING FACTS

Robotic crane, Australia

The world's largest robot is 75 m (246 ft) tall. It is a crane that works in a coalfield in Australia, and which uses laser vision to shovel up more than 4,000 tonnes of soil per hour.

Honda Asimo humanoid

The world's fastest robot hands belong to a machine developed in 2002 at Tokyo University in Japan. The robot produces 1,000 images and does 1,000 calculations each second, allowing it to catch a ball falling at 4 m (13 ft) per second.

Ika-saku, a robot developed by Japanese company Mayekawa in 2003, can cut up squid, a Japanese favourite, hygienically and quickly. It removes the squid's insides and cuts its tentacles and body into strips, which are then either dried or smoked.

Ika-saku squid-cutting robot

An advanced version of the intelligent Honda humanoid Asimo (an acronym for Advanced Step in Innovative Mobility) can now access information via the Internet. This means that Asimo can be ready with news and weather updates, for example, in response to people's queries.

Robots are beginning to take over from fire-fighters in the most dangerous situations. Carlos, designed in the UK, is small enough to be carried in a van but strong enough to drag up to 50 m (165 ft) of water-filled hose deep into the heart of a fire.

One of the longest-lived fictional robots is Astroboy. He was created in 1951 by Japanese cartoonist Osamu Tezuka, and was originally called Tetsuwan Atomu (Mighty Atom). Recent appearances of Astroboy include a television series in 2003 and a film in 2004.

An Australian shellfish could help to improve a robot's ability to explore distant planets. Scientists are studying a freshwater crayfish known as the yabby. It has limited intelligence, but explores its environment using sensitive antennae, grasping pincers, jointed legs, and a powerful paddle tail. Researchers hope to mimic the yabby's simple control systems in robots that are built to explore the planet Mars.

A kit is now available that converts any laptop computer into a robot. The kit consists of a wheeled platform on which the laptop is mounted, plus a camera for vision, and software to provide intelligence. Once the laptop is converted, it will trundle around its environment under remote control and will even respond to spoken commands.

The most successful chatterbot, or conversational robot, was created way back in 1966. Eliza, a computer program written by Joseph Wiezenbaum, was a virtual psychotherapist that used simple tricks to produce convincing dialogue. Many people preferred talking to Eliza to talking to a real therapist.

In 2001, US artist Paul Guinan created a website revealing his discovery of a steam-driven mechanical soldier. The robot, called Boilerplate, was supposedly invented in 1893. It was, of course, a hoax. Victorian technology was not that advanced, but many people were fooled.

Boilerplate, a hoax Victorian robot

QUESTIONS AND ANSWERS

Q How many robots are there in the world?

A It depends on what is meant by a robot. The number of small mobile and experimental robots is not known. The current estimate of the number of robots in industry – mostly fixed arms on production lines – is about one million, and rising fast. That's about one robot for every 6,000 people in the world.

Q Will artificial intelligence (AI) ever be of any use?

A It already is. If you shop on the Internet, watch out for robots! Guessing what people might like to buy, based on their previous choices, is one way in which artificial intelligence helps business. The AI market is growing at a rate of 12 per cent a year and could be worth £13 billion by 2007. At present, robot intelligence is limited to specific problems. The capacity for solving less specific problems is harder to program.

Q Which currently available robot is the most human?

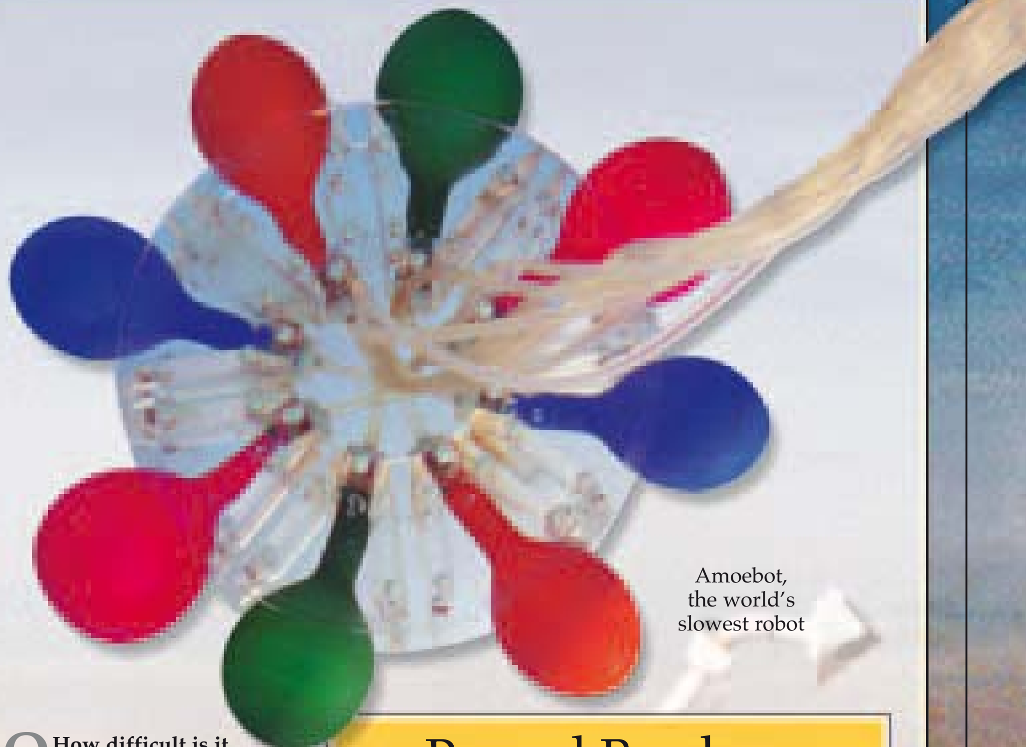
A In terms of how human a robot looks and how well it walks on two legs, Honda's Asimo or Sony's SDR-4X are probably the winners. Less human-looking robots, such as Mitsubishi's Wakamaru, may be more human in other ways. Wakamaru was designed to care for elderly people. It knows 10,000 words and reacts appropriately to situations in the home, even calling 999 for help if necessary.

Q Can robots have feelings or experience emotions?

A This is a very difficult question, and one that is getting a lot of attention from researchers at the moment. It is certainly possible to make a robot that seems to display emotions and behaves as if it has feelings. This is achieved by writing a computer program that takes account of what is happening to the robot and makes it react as if it is happy, sad, angry, or shy.

Q How long does it take to build a combat robot? Is it expensive?

A Combat robots have to be extremely well designed and built if they are to survive for long in the arena. They can take up to four years to create, although six months is more typical. Unfortunately, it does cost a lot of money to build a really good battlebot. On average, the bill comes to about £3,000, although robots that have been built for far less have gone on to win competitions.



Amoebot, the world's slowest robot

Q How difficult is it to design a robot?

A Famous robots like Asimo can take hundreds of people several years to design. But interesting robots can also be designed by one person in a few weeks. If you want to design your own robot, it is best to start by building one from a kit. You can later use what you have learned to branch out on your own.

Q Do robots steal jobs from people?

A This would be true if robots simply replaced people in industry. In reality, robots make production more efficient, which saves factories a lot of money. Much of this money is spent on expanding the business, which creates new jobs for people doing all the things that robots cannot.

Q Will robots become more intelligent than people?

A Some scientists believe it could happen by 2050. The effects of this depend on the kind of intelligence the robots have, and what safety features are built in. Robots could take over the world, but humans might see this coming and do something about it.

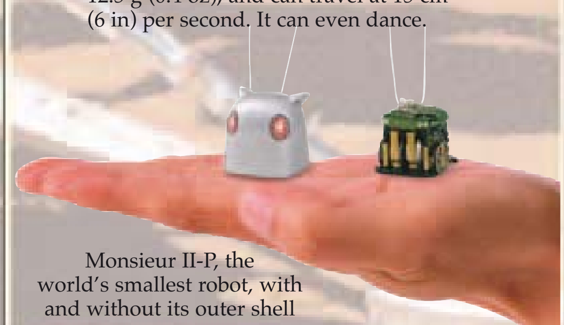
Record Breakers

WORLD'S SLOWEST
Amoebot, created in Singapore, is made up of balloons that inflate and deflate, pushing it slowly through water. With a top speed of 1 cm (0.4 in) per minute, it is the slowest-moving robot in the world.

BIGGEST BRAIN
The largest robot brain so far belonged to Robokoneko, a virtual robot kitten devised by Hugo de Garis in 1999. The on-screen cat had 37.7 million artificial brain cells.

LOWEST COST
The record for low cost construction is held by a robot called Walkman. It was made for £1.10 out of parts from a personal stereo at the US Los Alamos National Laboratory.

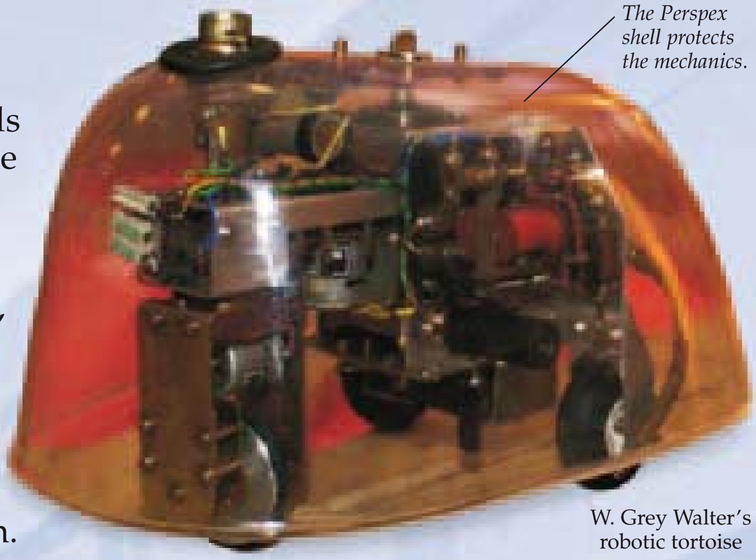
WORLD'S SMALLEST
The world's smallest commercial robot is Monsieur II-P, developed by Japanese watch company Seiko in 2002. It weighs 12.5 g (0.4 oz), and can travel at 15 cm (6 in) per second. It can even dance.



Monsieur II-P, the world's smallest robot, with and without its outer shell

Timeline

THE STORY OF robotics began thousands of years ago with basic ideas such as the wheel. Many more years passed before people began to make machines that imitated life. Early robotic animals and musicians were built to entertain. Later, the development of electronics allowed inventors to make intelligent robots, which could cope with some aspects of the world as well as a human. A robot with all the abilities of a real person, however, is still a distant dream.


The Perspex shell protects the mechanics.

W. Grey Walter's robotic tortoise

C. 3500 BC
WHEELED VEHICLE
In Mesopotamia (now Iraq), the potter's wheel is adapted for use on vehicles. Prior to this, vehicles were pulled on runners.

C. 400 BC
ROBOT BIRD
Philosopher Archytas of Tarentum builds a wooden pigeon that simulates flight. It is carried through the air on a rotating arm powered by water or steam.

C. 270 BC
PNEUMATIC POWER
Greek inventor Ctesibius of Alexandria discovers that compressed air can be used to make machines move.

C. 1500
AUTOMATIC MUSIC
The first instruments that can play tunes without a human musician start to appear. They use a rotating barrel carrying pins placed to strike the keys of a harpsichord.

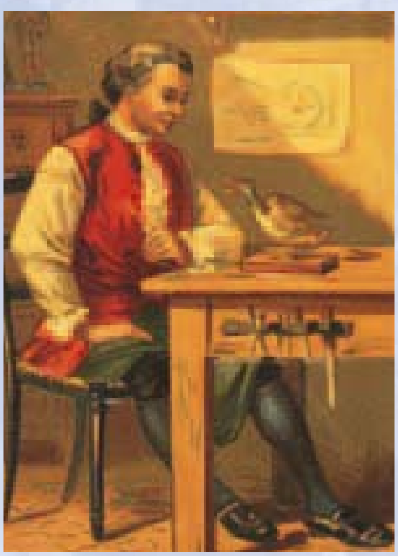


Illustration showing Vaucanson at work on his mechanical duck

1533
LEGENDARY FLYERS
In his Nuremberg workshop, German scholar Johann Müller, also known as Regiomontanus, creates an iron insect and an artificial eagle. It is alleged that both of these mechanical creatures can fly.

C. 1600
AUTOMATIC CONTROL
Dutch engineer Cornelis Drebbel invents the first automatic control, the thermostat. It is a mechanical device for controlling the temperature inside a furnace.

1725
ANIMATED ACTORS
In Heilbrunn, Germany, craftsman Lorenz Rosenegge creates a mechanical theatre. It features 119 animated figures that perform a play about village life to the accompaniment of a water-powered organ.

1726
VISION OF THE FUTURE
In his book *Gulliver's Travels*, Anglo-Irish writer Jonathan Swift imagines (and makes fun of) a future in which books are written by machines.

1739
VAUCANSON'S DUCK
French inventor Jacques Vaucanson creates a mechanical duck that can drink, eat, paddle, and seemingly digest and excrete.

1801
PATTERN-WEAVING LOOM
French inventor Joseph-Marie Jacquard perfects a loom, based on the ideas of Vaucanson, that automatically weaves cloth in patterns that are determined by a set of punched cards.

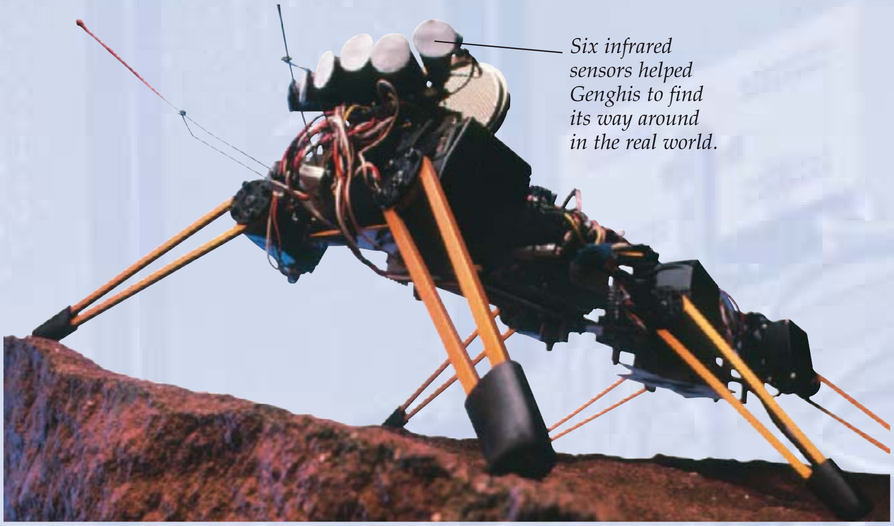
1820
CALCULATOR
French insurance agent Thomas de Colmar invents the first practical calculating machine. It can add, subtract, and (with difficulty) multiply and divide.

1854
LOGICAL ALGEBRA
British mathematician George Boole publishes *An Investigation into the Laws of Thought*, which contains the logical algebra later used to design computers and robots.

A robot from Karel Capek's play *Rossum's Universal Robots*

1921
THE WORD ROBOT
Czech author Karel Capek uses the word robot for the first time in his play *Rossum's Universal Robots*.

1941
LAWS OF ROBOTICS
Isaac Asimov writes three laws of robotics. 1) A robot must not hurt a human, or, through inaction, allow one to come to harm; 2) It must obey orders from a human, unless this conflicts with the first law; 3) It must protect itself, as long as this does not conflict with the other two laws.



Genghis negotiating rough ground

1945
MODERN COMPUTER
Mathematician John von Neumann creates the first computer design in which programs and data are stored in exactly the same way, giving the speed and flexibility we know today.

1948
GREY WALTER'S TORTOISES
At the Burden Neurological Institute in Bristol, UK, pioneer William Grey Walter creates two robot tortoises, Elmer and Elsie. They produce lifelike behaviour from very simple electronic circuits.

1950
TURING TEST
British mathematician Alan Turing says that if people converse with a hidden human or computer, and cannot tell which is which, the computer must be considered intelligent. To this day, no computer has passed the Turing Test.

1956
ARTIFICIAL INTELLIGENCE (AI)
US mathematicians Marvin Minsky and John McCarthy organize a conference that coins the phrase artificial intelligence.

1960
NEURAL NETWORK
US researcher Frank Rosenblatt develops the first artificial neural network, called the Perceptron. Its electronics imitate the way a human brain deals with information.

1961
INDUSTRIAL ROBOT
US engineers George Devol and Joe Engelberger create the first industrial robots, sold under the name Unimate.

1973
INTELLIGENT VISION
The AI department of Edinburgh University demonstrates Freddy II, a robot that can assemble an object by picking up the right components from a random heap.

1984
CYC
US researcher Doug Lenat, realizing that robots know nothing about the real world, starts the Cyc project. The ambitious aim of the project is to create a computer database containing the whole of human common sense.

1989
GENGHIS
One of the first hexapod robots, Genghis, is developed at the US Massachusetts Institute of Technology AI Lab. Each of its legs has two motors. Feedback from these tells the robot if a leg hits something.

1997
HONDA P3
Honda unveils humanoid robot P3, ancestor of Asimo. P3 can walk, climb stairs, shake hands, and get up from a kneeling position, but it is slow by today's standards.

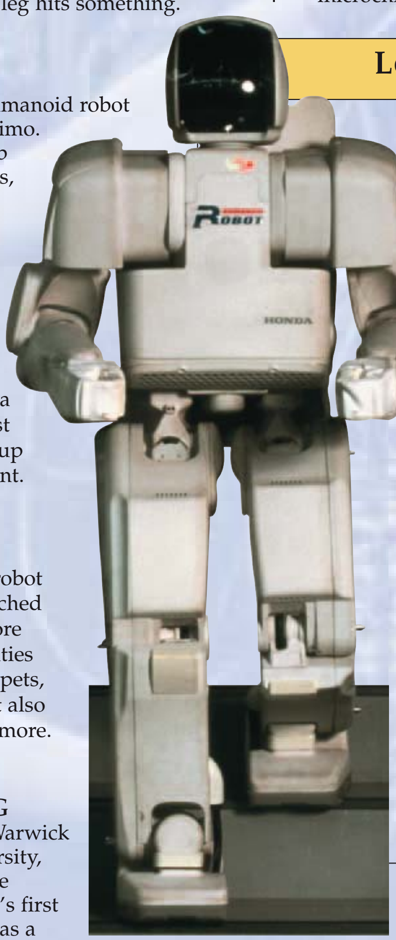
1997
ROBOCUP
The city of Nagoya in Japan plays host to the first RoboCup football tournament.

1999
AIBO
The world's first robot dog, Aibo, is launched by Sony. It has more advanced capabilities than earlier robot pets, such as Furby, but also costs a great deal more.

1999
FIRST CYBORG
Professor Kevin Warwick of Reading University, UK, claims to have become the world's first cyborg when he has a microchip implanted in his left arm. The implanted chip allows machines in his laboratory to respond to his presence when he goes near them.

2003
MARS EXPLORATION ROVERS
In June and July, NASA rovers *Spirit* and *Opportunity* are launched towards Mars. The pair of Mars Exploration Rovers (MERs) will make geological explorations of the red planet, using special tools to analyse the surface rocks, soil, and dust.

Professor Kevin Warwick with the microchip that was implanted in his arm



Honda P3 humanoid robot, launched in 1997

Looking forward

The future of robotics is extremely difficult to predict. Technology is advancing so fast that almost anything could happen in the next 50 years. Here is a possible view of some things that might happen before you reach 80.

2010 A robot takes its GCSE exams and passes.

2020 Crawling, flying, and swimming nanorobot spies work together to gather top-secret information.

2030 There are more robots than people in some countries.

2040 Robots are as clever as people and begin to evolve on their own.

2050 A team of humanoid robot footballers beats the reigning human world champions in the ultimate RoboCup game.

Find out more

ROBOTICS IS A HUGE and growing subject, so there are always new things to learn. You can find out more by getting involved in practical activities, such as building and operating robots or writing your own computer programs to control them. It is sometimes possible to visit robots in museums, or even in factories and research laboratories. There are also robot societies and clubs you can join, plenty of robot books to read, and hundreds of robot websites to explore. The more you find out about them, the more fascinating robots will seem.

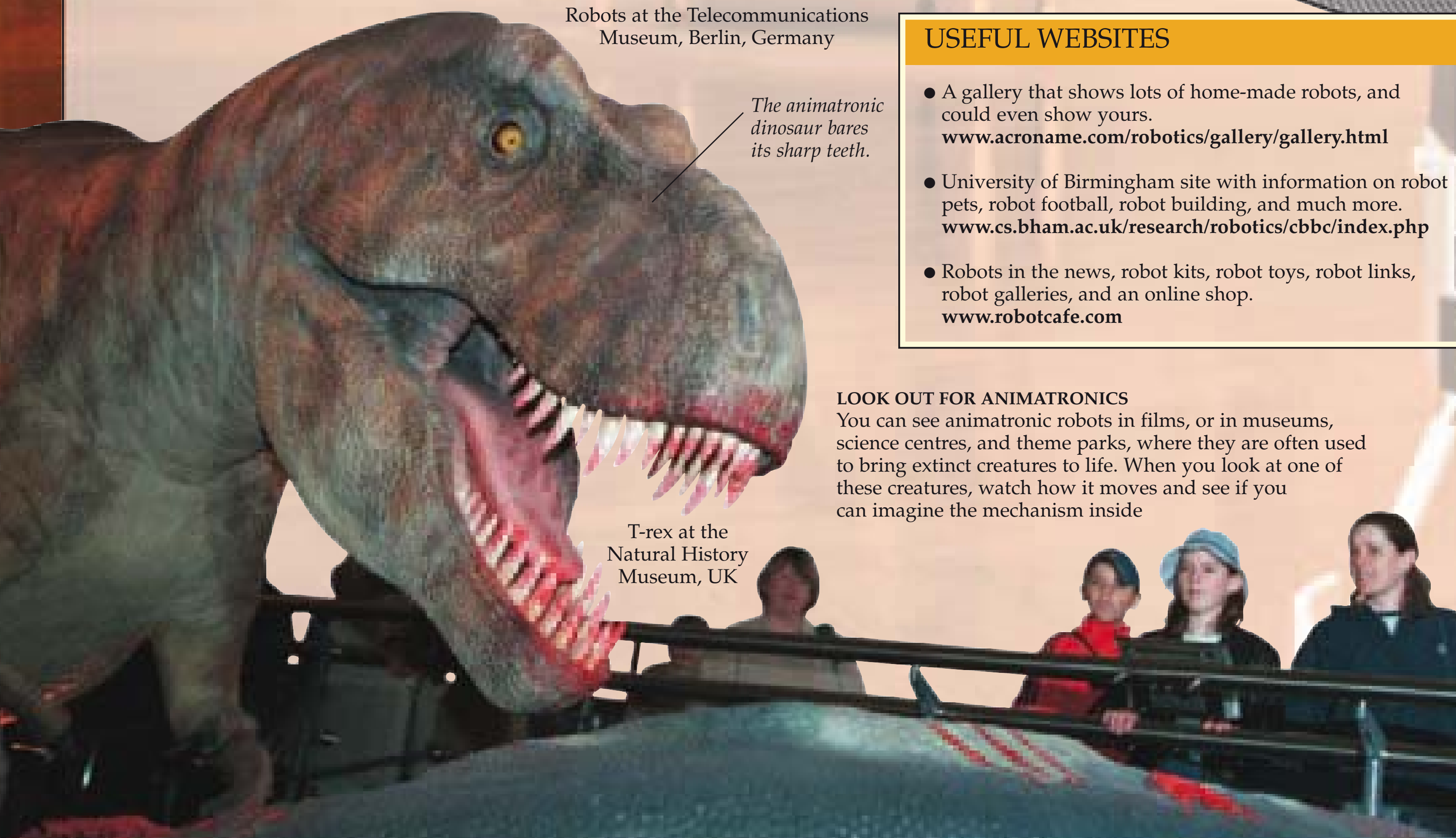
The robotic shell was made for a mutant creature known as a Dalek.

Robots at the Telecommunications Museum, Berlin, Germany

VISIT MUSEUMS AND EXHIBITIONS
Look out for advertisements and web information about temporary robot exhibitions at museums and science centres. Some museums have robots on permanent display, but they may remove them for maintenance at short notice. It is a good idea to check before making a special visit.

USEFUL WEBSITES

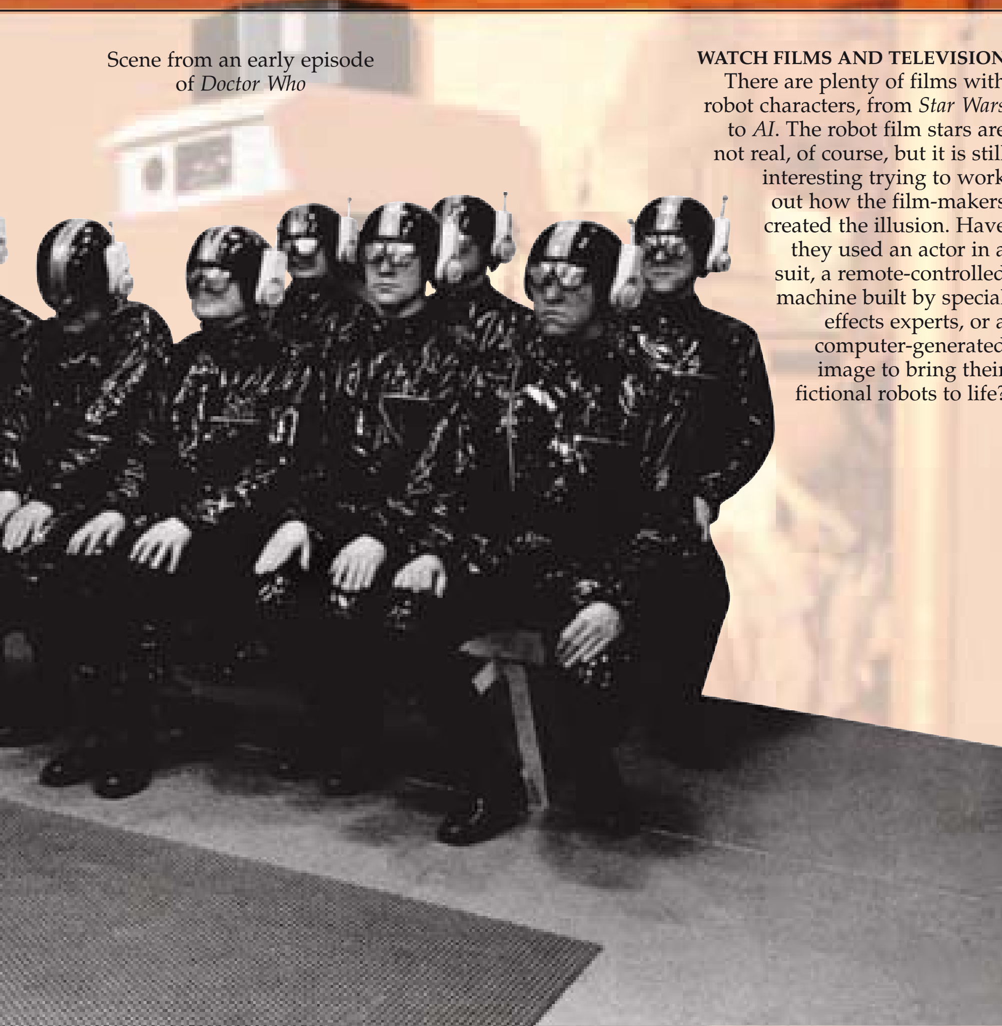
- A gallery that shows lots of home-made robots, and could even show yours.
  www.acroname.com/robotics/gallery/gallery.html
- University of Birmingham site with information on robot pets, robot football, robot building, and much more.
  www.cs.bham.ac.uk/research/robotics/cbbc/index.php
- Robots in the news, robot kits, robot toys, robot links, robot galleries, and an online shop.
  www.robotcafe.com



The animatronic dinosaur bares its sharp teeth.

T-rex at the Natural History Museum, UK

LOOK OUT FOR ANIMATRONICS
You can see animatronic robots in films, or in museums, science centres, and theme parks, where they are often used to bring extinct creatures to life. When you look at one of these creatures, watch how it moves and see if you can imagine the mechanism inside



Scene from an early episode of *Doctor Who*

WATCH FILMS AND TELEVISION
There are plenty of films with robot characters, from *Star Wars* to *AI*. The robot film stars are not real, of course, but it is still interesting trying to work out how the film-makers created the illusion. Have they used an actor in a suit, a remote-controlled machine built by special effects experts, or a computer-generated image to bring their fictional robots to life?

Places to Visit

CALIFORNIA SCIENCE CENTER,
LOS ANGELES, USA
Top attraction:
- A 15 m (50 ft) animatronic body simulator called Tess. She can move her lips, blink, and turn her head. At the end of the show, she raises her hand to turn off the lights.

NATURAL HISTORY MUSEUM,
LONDON, UK
Top attraction :
- Terrifying, three-quarter size *Tyrannosaurus rex*, standing 4 m (13 ft) high, incorporating all the latest animatronic technology.

MIT MUSEUM, CAMBRIDGE,
MASSACHUSETTS, USA
Top attraction:
- An exhibition featuring many famous robots created at the Massachusetts Institute of Technology, including Cog and Kismet.

MUSEUM FÜR KOMMUNIKATION,
BERLIN, GERMANY
Top attraction:
- Three friendly mobile robots in the main atrium welcome, inform, and entertain visitors to the museum.

TECH MUSEUM OF INNOVATION,
SAN JOSE, CALIFORNIA, USA
Top attraction:
- An interactive exhibition explaining how robots are made and used. Robo-artist will draw your portrait and Alphabot will spell your name with alphabet blocks.

Robots locked in combat on the *Robot Wars* TV show

EXPERIENCE ROBOT COMBAT
You can see combat robots in action on television and at live events – most of which are held in the USA. One of the best known is BotBash, held annually in Phoenix, Arizona, but there are others run by members of the Robot Fighting League. In the UK, popular events include the Enginuity Robot Crusade, held at Ironbridge Gorge Museum, and Robot Rumble, held every Easter near Ipswich.

Artbot built using a Lego Mindstorms kit

BUILD YOUR OWN
You will learn a lot if you take the time to build a robot yourself. Introductory and more advanced robot kits are available in some bookshops, toy shops, and electronics shops. You might even be able to sign up for a robot-building workshop at a specialist centre or a science museum near your home. Robot books and magazines also feature robot designs and practical building advice.

Glossary

ALLOY A mixture of different metals, sometimes with a small proportion of non-metals, used to give properties such as strength and hardness not available in any pure metal.

AMPLIFIER A device that increases voltage, current or power. This could be used with a robot sensor, allowing it to control something more high-powered, such as an electric motor.

ANDROID A robot that is a convincing imitation of a living human being, rather than just a humanoid. Androids exist only in fiction at present.

AUTOMATON A machine that imitates the actions of a person or animal, but without having any intelligence. An automaton is only able to perform a set of predetermined movements.

AUTONOMOUS ROBOT A robot that needs no human control, and is able to make all its own decisions and survive in the real world without outside help.

AUV (Autonomous Underwater Vehicle) A crewless robot submarine used for exploring the bottom of the sea.

BEACON A fixed marker set up to help robots to navigate. Some beacons simply reflect back signals given out by robots. Other beacons emit infrared or ultrasound.

Tipoo's Tiger automaton, 1795

BUMP SENSOR A sensor that tells a robot when it has bumped into something. The sensor can be as simple as a pair of springy electrical contacts that are pushed together by the impact.

CCD (Charge-Coupled Device) An electronic chip that receives an image from a lens and converts it into signals that can be sent down a wire. CCDs are used in digital cameras and for robot vision.

CHATTERBOT A computer program that can converse with a human. Current chatterbots are either very limited – just booking flights by phone, for example – or they are fakes.

Elma, a hexapod robot created at Reading University in the UK

CIRCUIT BOARD A sheet of plastic that carries a flat pattern of electrical connections. Electronic components are mounted on this to form a circuit, such as a robot controller.

CRANK A shaft with a right-angle bend used to convert straight-line motion into rotary motion. Bicycle pedals and the handles used to turn simple, mechanical automata are examples of cranks.

CYBORG A robot created by adding electronic or mechanical parts to a human being. The term was coined by the Austrian scientist Manfred Clynes in 1960.

DATA Measurements or other basic information collected and stored by a robot as it operates. A computer uses the data to decide what the robot should do next.

DOMESTIC ROBOT A robot designed to work alongside people in their homes, doing boring jobs such as cleaning and tidying. The most successful types so far are vacuum cleaners and lawnmowers.

ELECTRODE A piece of metal used to make an electrical connection to an object, for example to connect the electronics of a computer to a nerve inside a living body.

FEEDBACK The process by which something being controlled tells its controller what effect the control signals are having. This information makes the control more accurate.

GPS (Global Positioning System) A system for determining position on the Earth's surface by comparing radio signals from several satellites. Time differences between the signals give the position of a GPS receiver to within a few metres.

HEXAPOD A six-legged robot whose motion is based on the walking movements of insects.

HUMANOID A type of robot that walks on two legs and has a body, two arms, and a head. Humanoids look similar to, but are not exactly like, humans.

IMPLANT Anything surgically inserted into the body beneath the skin. Implants used in cyborgs usually communicate with computers by radio or magnetism.

INDUSTRIAL ROBOT A robot used in the manufacturing industry. Most are single arms that can move in several different directions and can use a range of tools.

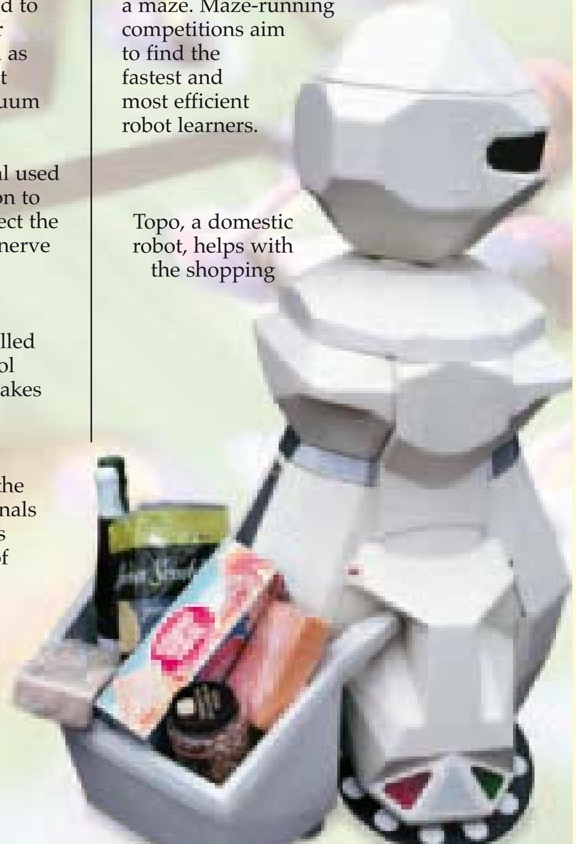
INFRARED A kind of light that lies just beyond red in the rainbow, invisible to the human eye. Robots use it for navigation and communication.

INTERFACE A device through which two different systems can communicate. One example is a remote controller, which allows a human to give instructions to a robot.

LED (Light-Emitting Diode) An electronic component that gives out light when a current is passed through it. The light may be visible, for signalling to humans, or infrared, for use by robots.

LIFT SENSOR A sensor that tells a robot when its wheels or legs are lifted off the ground, for example by running over an object. Basic lift sensors consist of a pair of contacts that are normally pushed together by the weight of the robot.

MAZE-RUNNER A robot that finds and remembers its way around a maze. Maze-running competitions aim to find the fastest and most efficient robot learners.



Topo, a domestic robot, helps with the shopping

MICROPROCESSOR The mathematical and logical parts of a computer contained on a single chip. It can be used as part of a robot controller or as the brain of a microcomputer or a PC.

MODULE A self-contained section of a robot or a computer program. Modules can be designed and tested separately, and then joined to form the finished product.

MUSCLE WIRE Wire made from an alloy of nickel and titanium. It is stretched when cold, heated by passing a current through it, and exerts a pull as it relaxes and shortens.

NANOROBOT A robot so small it is only visible under a microscope. No nanorobots have yet been made, but possible techniques for making them are being explored.

NEURAL NETWORK An artificial brain made by connecting large numbers of electronic nerve cells, often simulated on a computer. Neural networks can do difficult jobs, like recognizing faces.

ON-BOARD COMPUTER A computer that is part of a mobile robot and moves around with it, unlike a fixed computer that controls a robot by wire or radio.

PLATFORM The basic moving part of a mobile robot, without any intelligence. Many so-called robots are really just radio-controlled platforms.

PNEUMATIC A device operated by air. Most pneumatic devices produce movement from a piston inside a cylinder. Compressed air is let into the cylinder to drive the piston.

PROGRAM A set of computer instructions designed to achieve an end result, such as allowing a robot to find its way around.

PROXIMITY SENSOR A sensor that is designed to measure very small distances between a robot and an object.

RADAR (Radio Detection And Ranging) A way of detecting the presence, position, and speed of objects by emitting radio waves and recording the echoes that return.

RANGEFINDER A sensor that can measure how far away a robot is from an object or wall. It may use laser light, radar, or ultrasound.

RETINA The light-sensitive surface inside the eye upon which images are formed. The retina connects to the brain through the optic nerve, allowing us to see.

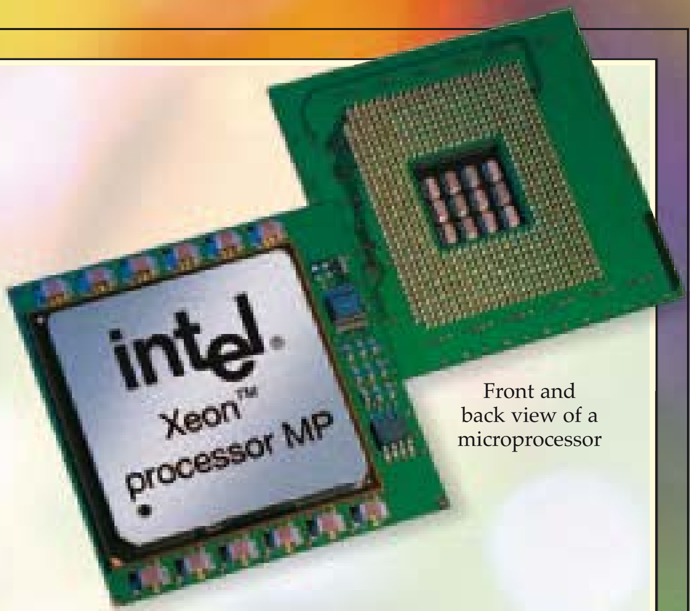
ROBOT ARM A versatile, computer-controlled, jointed arm that can handle tools and do factory work. It is the most common type of robot today.

ROVER A robot designed to roam around, typically on a remote planet, to survey the landscape, take samples, and make measurements for transmission back to base.

SILICONE RUBBER An artificial rubber based on the element silicon rather than carbon, the main element in natural rubber. Silicone rubber is stronger and lasts longer than natural rubber.

SOFTWARE A general term used to describe the programs that are needed to operate a computer, as opposed to the physical components, which are known as hardware.

SONAR (Sound Navigation And Ranging) Using sound to measure how far away objects are. Sonar emitters bounce sound waves too high-pitched to hear off objects. The time it takes for the waves to bounce back indicates their distance.



Front and back view of a microprocessor

SPEECH SYNTHESIZER A device – usually a computer – that can convert text or other coded information into sounds that resemble human speech closely enough to be understood.

SURVEILLANCE Keeping a close watch on something or somebody. Some surveillance robots have to keep out of sight while recording or transmitting pictures of what is happening.

SWARM ROBOT A small robot that has its own intelligence and can act autonomously, but only as part of a swarm of similar robots.

TEAM ROBOT A small robot that has little intelligence of its own but works as part of a team controlled by a central computer.

TETHERED ROBOT A robot that is controlled through a cable, not by radio or other wireless means.

THREE-DIMENSIONAL Having or displaying the full depth of the real world, as opposed to a flat, two-dimensional picture. A sculpture is three-dimensional, or 3D, a painting is not.

TOUCH SENSOR An electronic device, also called a tactile sensor, that responds to the pressure with which a robot contacts an object, giving an artificial sense of touch.

ULTRASOUND Sound with a frequency higher than human ears can hear. Used in sonar devices and robot rangefinders.

VIRTUAL A visual simulation, usually created by a computer and viewed on-screen. Three-dimensional graphics and other devices allow the user to interact with the virtual reality.

WELD To join together two pieces of material – usually metal – by heat, pressure, or both. Robot welders squeeze metal parts together while passing an electric current through them to make them hot.

Robot arms welding on a car production line

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