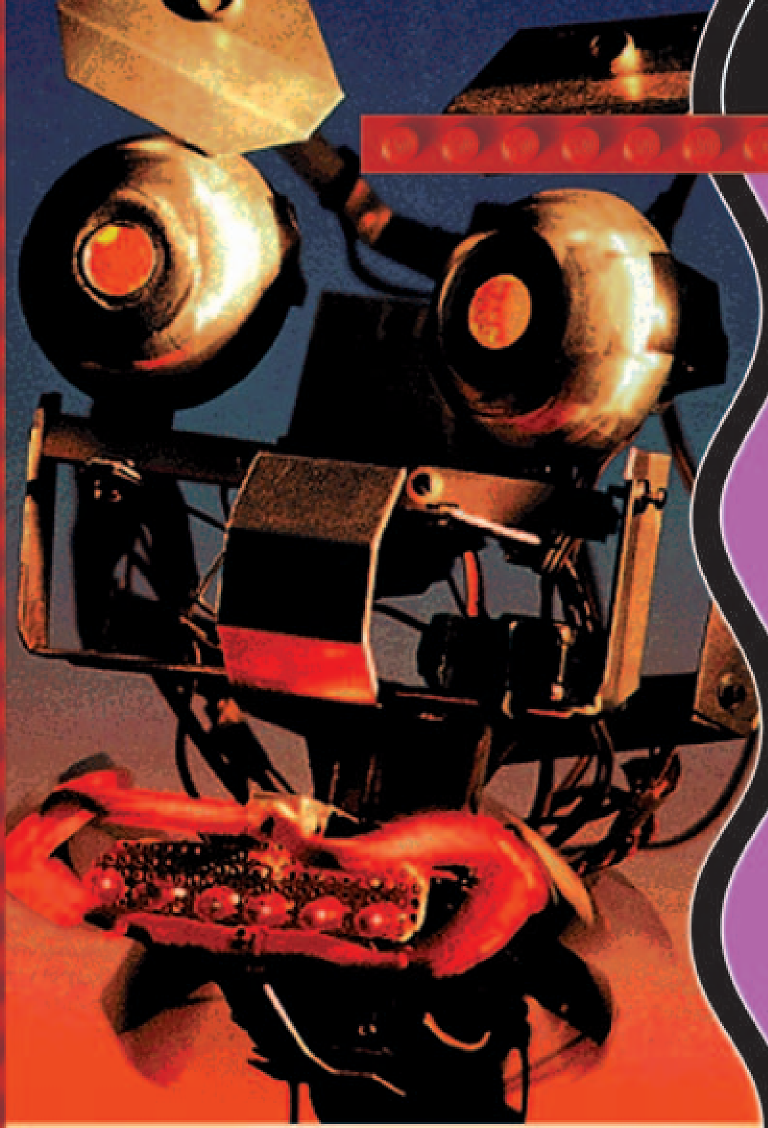
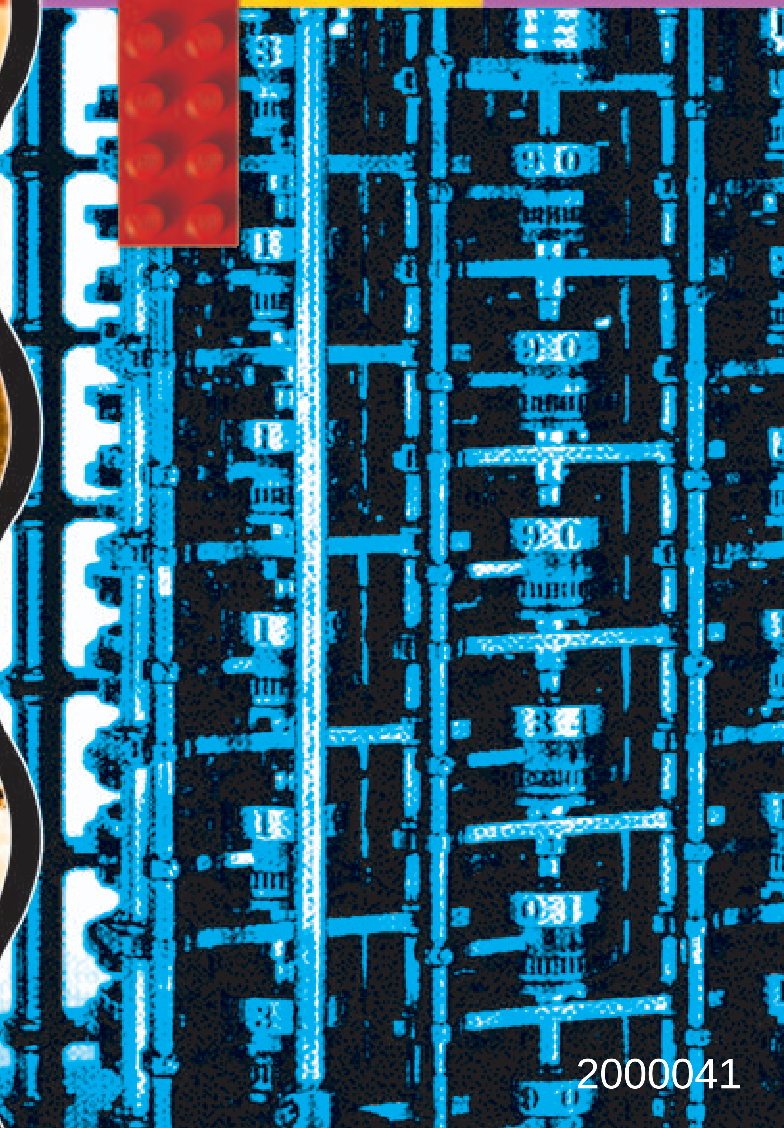
A Concept Guide



ROBOTIC SYSTEMS

A Guide to Understanding the Robots Around Us



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The World Of

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Robotics

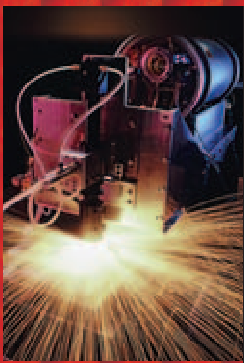
A Guide to Understanding the World of Robotics

A Concept Guide

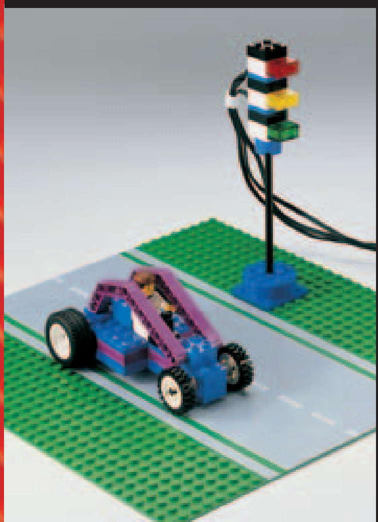
What you will find in this Concept Guide:

Robots Around Us

What do you think a robot looks like?
You will be surprised!



What do an automatic garage door and a traffic light have in common? They are both robots! You might have guessed that there are robots in factories, but there are also robots in your neighborhood such as the cash machine on the corner, the school photocopier, a pager, and the vending machine that sells tickets for the train. How about the smoke detector in your home? Yes, it's a robot, too.

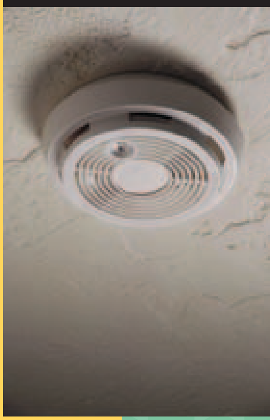


Look out! We're surrounded.

If you think robots exist only in space exploration, high tech laboratories, or science fiction novels and movies, this guide will surprise you. In fact, robots are everywhere. They are all around us, performing many tasks that we find very useful in our everyday lives.

This guide will give you a closer look at "robotics" — which means the study and use of robots. When we use the term "robotic system," we refer to the different components that make up a robot.

We will explain what robots are and how they help us. In addition, we will look at some of the simplest and most common examples of robots, as well as some that are very complex and unusual. Last but not least, we will share some interesting facts and stories about the fascinating world of robots... the very world we live in today.



A robot by any other name... will still have a job to do.

We interact with robots every day without even realizing it. They are in our homes, our schools, our stores, our cars... they are everywhere we go. Robots answer our telephones, open doors for us, turn on our lights, make sure we are warm or cool enough, sell us food and beverages, dispense money, and even make sure we do not miss our favorite television shows.

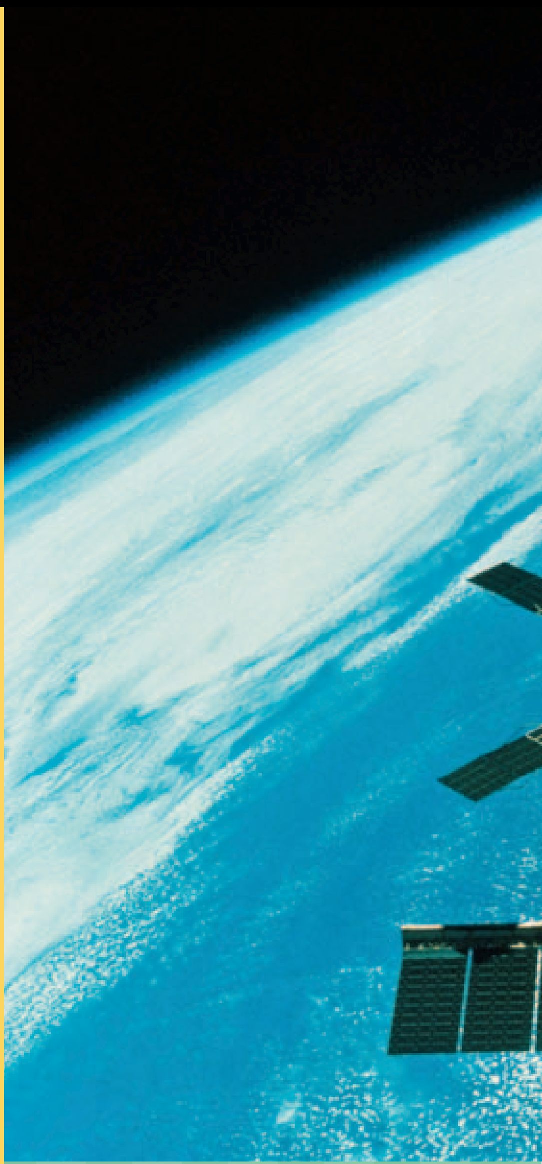
Often, these robots do not look anything like those portrayed in movies and books, so we don't realize that they are, indeed, robots.

A traffic light, an electric door, the VCR that tapes a movie for you, the microwave that heats your dinner... these are all robots. The more you know about robots, the easier it is to spot the robots around us, and how they make our lives more convenient.

What does it take to be a robot?

Most of us have seen robots portrayed in movies and books as mechanical imitations of people. This is one way of thinking about a robot. Yet a robot does not have to follow these guidelines.

The truth is, robots come in many forms. Actually, a robot is any machine that does work on its own, automatically. For instance, our home heating systems work without our having to do anything, as do most of the electronic appliances all around us. The components of the thermostat system are spread throughout a building.



They must have three things in common:

There is a simple way to tell if a machine is a robot. Robots all have these elements in common:

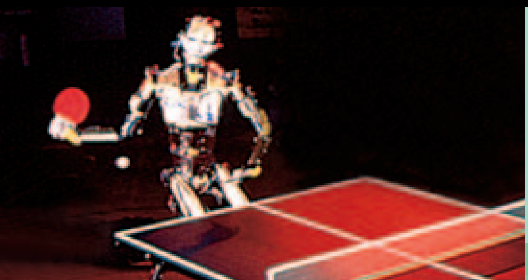
1. BODY
A physical body of some type

2. CONTROL
A program to control the robot

3. BEHAVIOR
They exhibit some type of behavior

An automatic watering system is robotic because it has a body designed to distribute water across fields. It is programmed to turn on and off automatically depending on certain conditions, such as the time of day. Its behavior is to successfully execute this program.

An answering machine is a robot because it has a body (shaped like a box) and is programmed to answer the phone. Answering and recording messages day after day is its behavior.



Sarcos is a robot because he has a body shaped like a person. He is programmed to play ping pong against an opponent. His playing of the game is his behavior.

"I reject all responsibility for the idea that metal contraptions could ever replace human beings."

KARL CAPEK
Czech playwright who coined the word "robot" in 1921

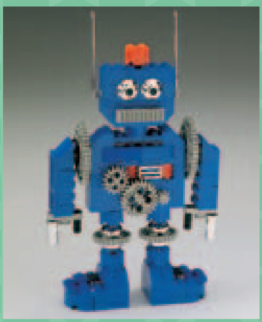
Focus On: The First Robots

Early robots had to "punch a card" to go to work

The world of robotics is a fascinating place, with roots dating back to well before the 20th century.

In the 18th century, Jacques de Vaucanson of France designed one of the earliest examples of a mechanical robot – his loom, which was controlled by perforated cards. Later, Joseph Marie Jacquard improved and expanded upon this invention with another loom that created even more intricate patterns with less intervention by the operator.

In 1834, Charles Babbage also made use of the idea of punched cards for his "analytical engine" — the first mechanical computer, made of hundreds of precisely constructed brass parts which could be programmed.



They have got to get with the program.

To know what a robot is, it's helpful to know what it isn't. At first glance, you might think the weathervane atop an old barn, a toy robot, or a watch are robots. The weathervane "tells" us which way the wind blows, the toy robot "moves" across the floor, and the watch "tells" time – right? Well, no.

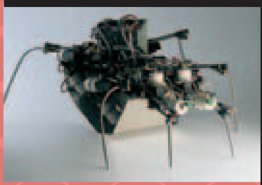
Although each has a physical body, they are missing a program that tells them how to act in different circumstances. Also, they take no action. They are only acted upon… the weathervane is acted upon by the wind, the toy robot moves in one direction in response to a wind-up key, and the clock is merely a mechanical device that keeps going and going until it runs out of power. That is why we cannot consider them robots.

Robotics: Body

Don't expect a robot to look like anyone you know.

Some famous science fiction robots, like C3PO from the movie "Star Wars" (played by Anthony Daniels), were meant to look like people. A stereo is also a robot, but its body doesn't look anything like ours.

Focus On: Robots that walk and run



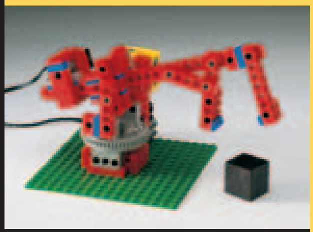
The first step is sometimes the hardest

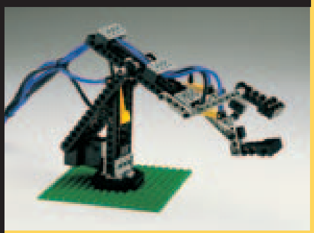
One reason so many mobile robots use wheels is that the act of walking — though it seems natural to us — is a lot more complicated than you might think. It involves a complex interaction of balance and movement.

Marc Raibert of the Massachusetts Institute of Technology Leg Laboratory (Cambridge, USA) has been developing robots that run, walk, and hop on one leg. One of the advantages of robots with adjustable legs is that they can move across terrain that wheeled robots cannot, such as uneven or pitted surfaces.

In 1893, English scientist George Moore built a steam-powered "man" that could walk as fast as 9 miles per hour.

There are two basic types of arms used for robots. *Cartesian arms* are built on a rectangular frame and cannot reach outside their own frame. They are suited for pick-and-place operations, such as on an assembly line. *Revolute arms* have at least one elbow joint, so they can bend in many directions and approach a target from different angles, making them useful for tasks such as spray painting the curved surfaces of cars.



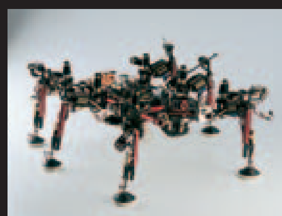


Every body has an ideal shape and weight.

Wherever you encounter robotic systems, it's interesting to note their varying physical attributes. They may have light or touch sensors similar to our own senses. They may even have torsos, arms, legs, or hands. Whatever their parts, whether robots look like us — or more like a box or a bug — depends on what functions they are designed to fulfill.

The choice of shape, size, material, and even style depends first on function. A VCR could be round, but it would be more expensive to manufacture and probably would not fit into your home entertainment system very well. A vending machine could be small, but a small machine has to be refilled often. Plastics are used for their lighter weight, metals for their greater strength. Smoke detectors could be red and green squares or triangles, but are styled to be unobtrusive in the home.

Weight is another important factor in designing a robot. An inexperienced designer might make the mistake of building a robot too heavy to move itself or its payload, or too heavy to allow any speed or maneuverability. You want to make a robot stable and strong enough to support all its parts. Robotic engineers have to balance the needs for lighter weight and greater strength, for example, when building robots to travel deep into the ocean or off into space.



Some robots need to be able to move around to perform their functions. For example, there are rover robots designed to explore the surface of other planets, and factory robots that move freight. Many robots — even those meant to look like humans — use wheels to get around. The wheels themselves vary in size, shape and material according to the surface over which the robot is meant to travel. For instance, the wheels you use for sandy surfaces would be different from those used for rocky, muddy or smooth surfaces.

ROBOTICS: CONTROL

It's not a robot unless it takes control.

How does a scanner work at the cash register? The laser helps the light sensor see the pattern of the bar code (input). The computer within the cash register then "reads" this information (program). Next, it sends a signal to display the price of the item on the readout panel of the register (output).

You tell it what to do and when to do it.

Did you ever wonder how we get robots to "understand" and do what we want them to do? How does the telephone answering machine know when to answer the phone and record a message? What makes the electric door open when we walk in front of it? How does it know we're there? And what about that remote control car we love to play with? What makes it back up, turn, go forward, or stop when we say so?

It all lies in control. Every robot needs to be told what to do. When you set up control of the robot, you need three factors working together:

1. INPUT

The information that comes from the robot's sensors.

2. PROGRAM

The instructions or set of rules you give a robot to follow.

3. OUTPUT

The action the robot takes, usually involving motors (movement), lights, or sound.

Using your VCR as an example, we can easily see how control encompasses these three parts: INPUT, PROGRAM, and OUTPUT.

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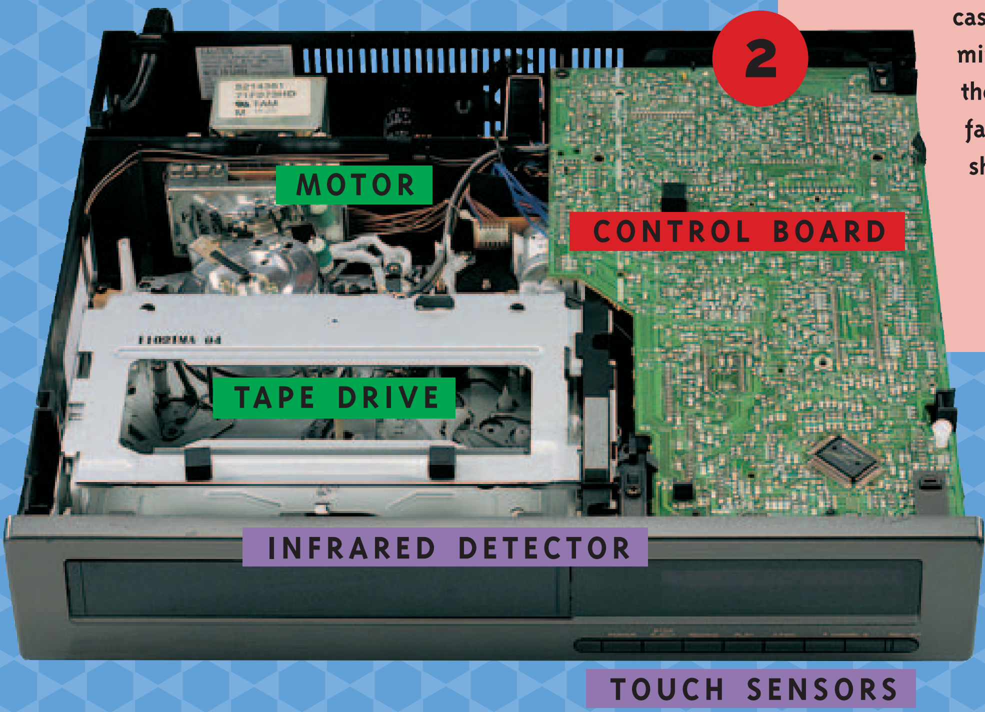
PROGRAM - The program (also known as the "algorithm") is the robot's set of instructions. In this case, we are programming (or instructing) the VCR to record our favorite television show for one hour.



1

INPUT - When you use the remote control to program your VCR, you send input via infrared signals that tell the VCR that it's time to take a particular action.

3

OUTPUT - Finally, we look at the output, which means the action we want the robot to take. Here, the action is to turn the VCR recorders on at the start of the hour, and off at the end of the hour. We can hear the motors moving inside the VCR as it begins to record. We may also see certain lights come on to indicate the VCR is taking action. The control loop is complete as the VCR records our television show.

"The computer is no better than its program."

ELTING ELMORE MORISON

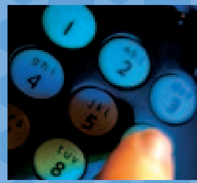
How robots come to their senses.

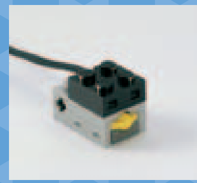
All robots have sensors, which provide input for the robot. Some of these sensors are much like our own senses in the way they "see" and "feel." For instance, any switch or button that turns on the power of an appliance is a touch sensor. It responds when it "feels" the pressure of your touch.

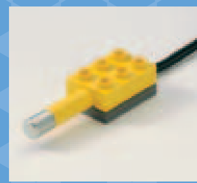
You will find many different kinds of sensors at work in robots. Refrigerators use touch sensors to turn off the light inside when the door is closed. Telephone answering machines have a circuit that measures voltage and indicates that the phone is ringing. Ovens and toasters use temperature sensors to control the amount of heat produced by heating coils.

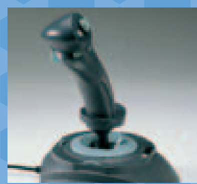
Similar robotic systems may differ in the sensors they use to get the job done. Some automatic lights, such as outdoor floodlights, may use motion detectors to activate them when someone approaches. Others may use a light sensor to gauge when it becomes dark and turn on the light.

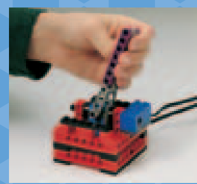
Programs for robotic control can be as simple and purely mechanical as turning a switch to begin a set of actions, such as when you press the "Reheat" touchpad on your microwave to heat up your dinner. Or they can be as complicated as the computer-based programs found in automatic cameras or in NASA space rovers.





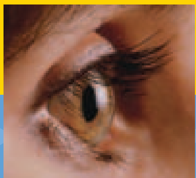


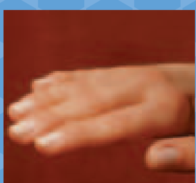


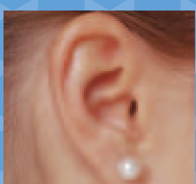


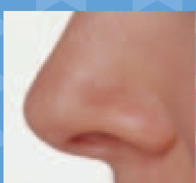
The program that controls a robot relies on several factors:

- the type and number of sensors used
- where the sensors are placed
- the potential outside stimuli
- the combinations of resulting actions









Did you know that the human body has a visual sensor, a touch sensor, a sound sensor, and a smell sensor? We commonly call them an eye, a hand, an ear, and a nose.

FOCUS ON: THE LEGO® RCX BRICK

THE PROGRAMMABLE LEGO BRICK

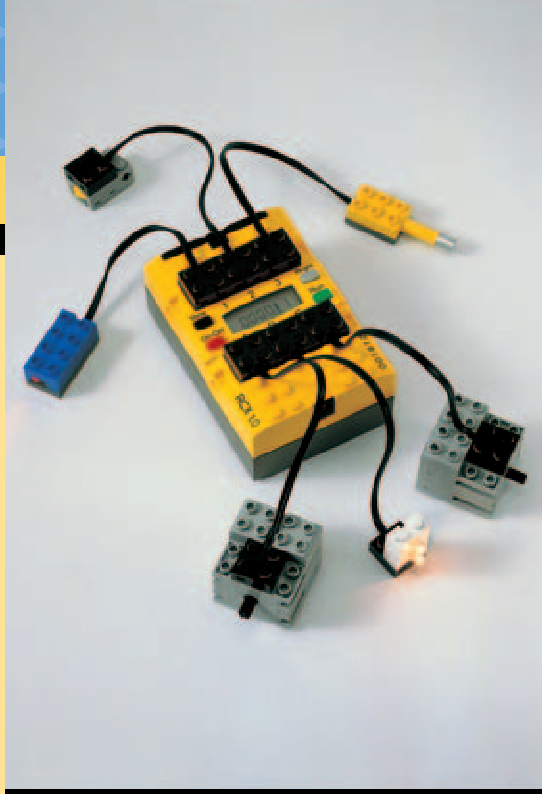
The RCX brick is a LEGO microcomputer. It is the brain behind any robotic system built with LEGO bricks, motors, and sensors.

The RCX brick allows you to build a system of control over your robots and robotic systems. Three sensors at a time can take input from the environment. The sensors are touch, light, rotation, temperature and the infrared receiver of the RCX brick itself.

You program the RCX brick using a simple icon-based programming language. The program instructions for the robotic system are downloaded from your desktop computer using an infrared transmitter.

The RCX brick can now control output — the lights, sounds, robotic motors attached to the mechanical parts, or infrared signals sent to other RCX bricks.

Because the RCX brick itself is a microcomputer, your robotic systems act independently of the computer. You can build anything from a light-sensitive intruder alarm for your intelligent house to a rover that can follow a trail or play basketball.

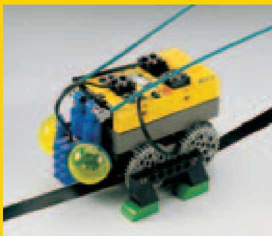


The LEGO Intelligent House model incorporates sensors and robotic systems like those in a real house. You can build in sensors to detect temperature, and your RCX program can instruct the fan to come on in response. A light sensor can act like a break beam sensor, so the program governing the garage door can tell it to automatically open at your approach.

"A house is a machine that we live in."

LE CORBUSIER

A robot is always ready for action.



The actions taken by current robots vary enormously, from the precise and repetitive movements of robotic arms found in many factories, to a garage door remaining open as long as someone is standing under it, to a lawnmower mowing the lawn on its own, to robots that "drive" themselves through warehouses to transport products.

Sometimes, the action programmed for a robot may be to take no action at all, such as when the thermostat doesn't trigger the heating or cooling system as long as it senses the correct temperature in a room.

The more variables and the more interdependent they are, the more complex the program for your robot will be. For something that seems easy to us, such as walking, your control program must take into account factors such as support, posture and propulsion — which turns out to be

Focus On: The Airbus A320

Nobody likes a bad program

In the late 1980's, the Airbus A320 was the first commercial airliner to use total "fly-by-wire" technology. Previously, aircraft were controlled mechanically – the pilot's controls were operated by levers, cables, pulleys and hydraulics. "Fly-by-wire" meant that the A320 was operated electronically – the input from the pilot was connected to the flight control output systems by way of the plane's computers.

This "state-of-the-art" control system came under attack after two fatal crashes. The control program had been written to limit how fast the pilot could accelerate the plane, in order to reduce structural stress on the aircraft. Unfortunately, the designer of the control program had not considered all possible conditions. His program put the plane and its passengers in danger because the plane could not respond to unanticipated conditions, such as suddenly needing to abort a landing and pick up speed to gain altitude.

no simple matter. Designing and analyzing robots is usually a team effort that brings together experts in mechanical and electrical engineering, logic, mathematics, and programming, to name just a few.

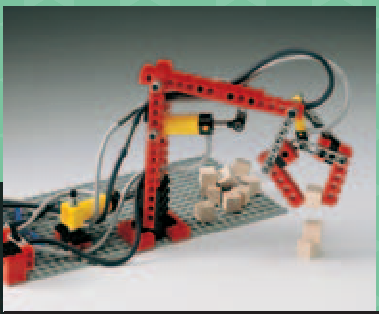
NASA put a man on the moon and a robot on Mars.

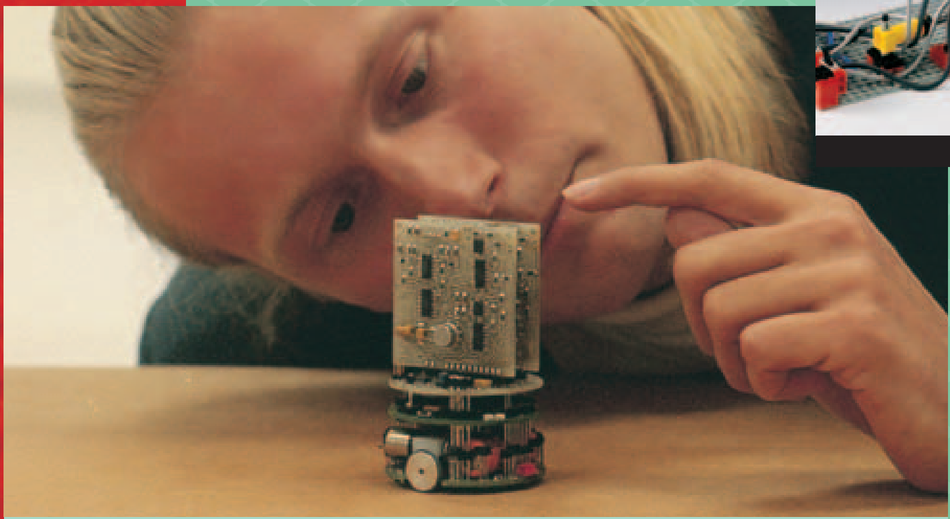
The Sojourner Microrover of NASA's Pathfinder Mission is the first robotic roving vehicle to be sent to the planet Mars. It has two control systems for performing its functions: a telerobotics (remote control) system and its own onboard system.

The distance between Earth and Mars causes an 11 minute delay between the sending and receiving of signals, which prevented NASA from relying solely on the use of telerobotics to control the Sojourner. Instead, NASA uploaded goal locations to Sojourner ahead of time. Sojourner would then use its own sensors and control programs to direct the motors to move safely towards these locations on its own.

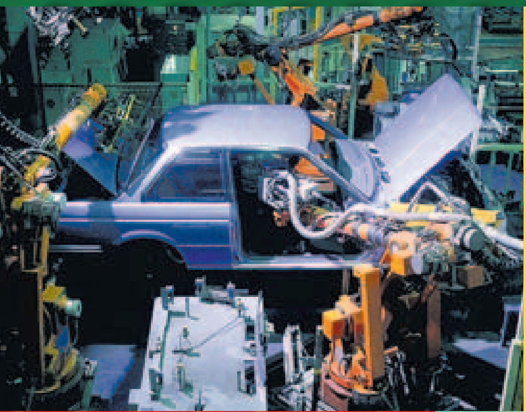
Robotics: Behavior

If it doesn't do what it's told, don't blame the robot.





Some robots, such as the robotic crickets designed at the University of Edinburgh (Scotland), mimic biological behavior. The "female" robot crickets find the "males" by listening for a specific song. By designing robots with animal or insect behaviors, researchers hope to learn more about both robots and living creatures alike.



Most of the time, robots "just do it."

Just how much we think of robots in human terms is clear when we talk about their "behavior." Put simply, behavior means, "what does the robot do?"

Robots are often meant to perform tasks usually undertaken by people. Robots like the ones controlled by computers in car factories can perform jobs that are too boring and repetitive for people, such as welding, drilling engine parts, and spray painting cars.

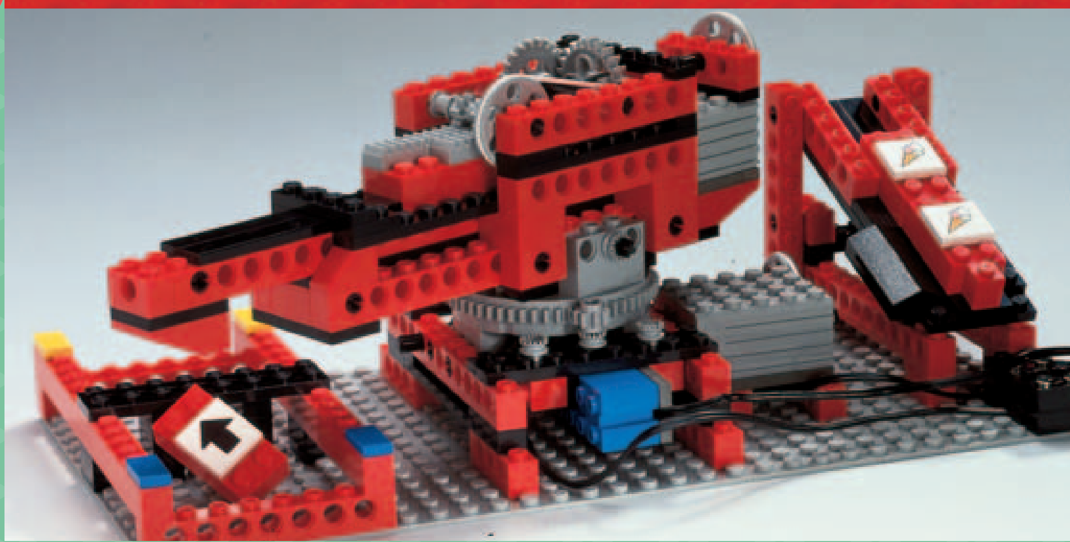
Whether a robot is patterned after a living creature or not, every robot exhibits behavior. An electric door will open when it senses motion, a fire alarm will sound when it senses smoke, a burglar alarm sounds and calls the police when it senses motion, loud noise, or a broken window. These are all behaviors.

Behavior is the action the robot performs… even if it's no action at all.

Sometimes there is a big difference between the actions we intend when we set up the robot's control system, and the way the robot actually behaves. This may be due to faults in the control program. The fault may also lie in the placement, choice or quality of the sensor or acting mechanism, or in unanticipated external stimuli.

For instance, if you have a two-story home with only one thermostat, the location you choose for the thermostat will determine how well it behaves. Since hot air rises, it makes more sense to place this temperature sensor on the bottom floor to ensure that all areas of the house reach the desired temperature. For an air conditioner, we might wish to do the opposite.

MODELING THE INNER WORKINGS OF A MACHINE AFTER THOSE OF AN ANIMAL OR PERSON IS CALLED CYBERNETICS.



"The world of the future will be an ever more demanding struggle against the limitations of our intelligence, not a comfortable hammock in which we can lie down to be waited upon by our robot slaves."

NORBERT WIENER

Reliability

If you can't count on a robot, what's the point?

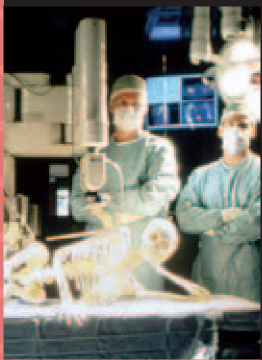
This LEGO robot is programmed to react to touch sensors which are pressed when its arms hang down - such as when it reaches the end of the table. It then backs up and turns to avoid falling off the edge. If its touch sensors were poorly placed, or its program told it to go forward at the edge instead of back, this robot would fall crashing to the floor.

"The real problem is not whether machines think but whether men do."

B.F. SKINNER

THE FIRST WEATHER SATELLITE, TIROS, WAS LAUNCHED INTO ORBIT AROUND PLANET EARTH IN 1960.

Focus On: "Robodoc"



Surgical robot makes medical history

The surgical robot is one robotic system for which reliability is most critical. On November 7, 1992, robotics technology was used for the first time as part of an invasive surgical procedure. Dr. William Barger, a surgeon at Sutter General Hospital in Sacramento, California, used the "Robodoc" surgical system to perform a total hip replacement in a human.

Robodoc can perform its function more precisely than a human doctor, and this precision may lead to fewer complications for the patient. Worldwide, over 1,000 people have undergone surgery assisted by Robodoc.

It's not enough to figure out what actions we want a robot to take. We have to make sure the robot performs them consistently and reliably. We find out how reliable a robot is by looking at the actions we intended when we designed the robot control system versus the actual behavior of the robot.

Every day we put our very lives in the hands of robotic systems, without a second thought. We are able to do this because, in general, robotic systems are very reliable. If we consider the consequences of failure in common robots – such as smoke detectors, automobile air bags, even elevator doors – we realize how crucial reliabily in robots really is.

The difference between doing a job, and doing it well.

Do automatic doors always open when you approach? Does your home smoke detector sound the alarm only in the case of an actual fire? Does your autofocus camera make your Aunt Betsy blurry while the lamp in the corner looks sharp?

Suppose you intend to have an automatic door swing open when someone walks directly in front of the door's motion sensor. The system may seem to "work perfectly" because the door opens when the sensor is triggered. But what happens if you placed the sensor up too high? When someone shorter comes along, the door won't open. Then the system will not behave reliably. It will not fulfill its intended function, even though it may do exactly what its program instructs it to do.

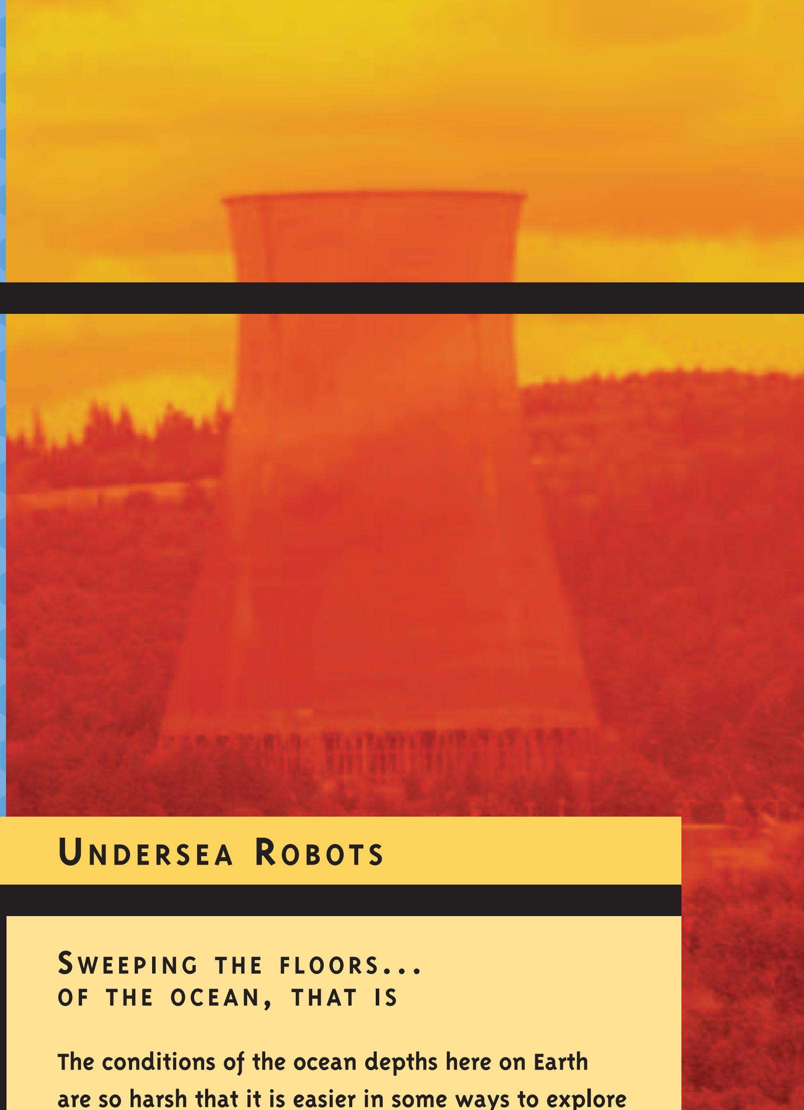
What difference does it make? Plenty!

Because robots are generally assumed to be working without human intervention, reliability can be extremely important. Especially when we consider that robots are now in our home appliances, cars, trains, and in more places all the time.

What if a car's air bag doesn't deploy in a collision? Or the traffic light tells oncoming cars to "Go" when it should say "Stop"? Or a medical robot that drills holes through bone during surgery sometimes misses its mark? It's easy to see how much we count on the robots around us to behave the way they were intended – consistently and reliably.

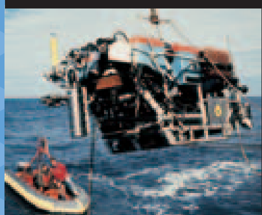
Present & Future

Going where no human has ever gone before.



Dante II was designed to enter a volcano and take readings to help predict volcanic activity. By doing so, Dante II helped to protect the lives of many vulcanologists as well as those living near the volcano.

Focus On: Undersea Robots



Sweeping the floors... of the ocean, that is

The conditions of the ocean depths here on Earth are so harsh that it is easier in some ways to explore the surface of Mars than to map out our ocean floors in detail. For instance, there is a greater difference in pressure 10 meters down in the ocean than there is between the surface of the Earth and Mars. Today, however, we have robotic options for exploring the ocean. For example, the Woods Hole Oceanographic Institution has a dual vehicle ROV (Remote Operated Vehicle) system which gathers information about the ocean floor and water conditions at depths of up to 6,000 meters. "Medea" serves as a survey vehicle. It is linked to "Jason," a multi-sensory imaging and sampling platform. With the help of Jason/Medea, scientists have been able to map sections of the ocean floor, discover hydrothermal vents, and identify hundreds of new species of ocean plants and animals.

A robot's job can be deadly.

Robots not only save us time and effort, they often save our lives — and they do it by going into some of the most dangerous places in the world.

Take Dante II, built by scientists and engineers at NASA and Carnegie Mellon University (United States). In July, 1994, this robot entered Mt. Spurr, an active volcano near the city of Anchorage, Alaska. In the past, several volcanologists lost their lives trying to collect vital information to determine whether and when Mt. Spurr might erupt. By having robots like Dante II collect and send back data regarding such things as temperature and gasses, the lives of several scientists and thousands of people living near this and other active volcanoes can be saved.

It's dangerous, but someone's got to do it.

Robots are also used in hazardous or contaminated industrial settings. Often, it is imperative to take action and gather data, yet people cannot enter without the risk of serious harm or even death. Again, a robot hero comes to the rescue.

The Andros Mark VI is able to climb stairs, cross ditches as wide as 50 centimeters, and maneuver over obstacles as tall as 30 centimeters. It carries a closed-circuit TV system and two-way audio system, which allows for the remote monitoring of pressure lines, meters, and gauges. Because its arm has the strength to turn valves and manipulate devices found on control panels, Andros can take action in contaminated areas where people cannot go.

Everything a robot "knows" it learned from us.

Researchers in the field of artificial intelligence have been studying how to create an intelligent machine. Since mastering the game of chess is considered by many to be a sign of human intelligence, one of the first ways of approaching the challenge of artificial intelligence was to build a champion chess-playing machine. In 1996 this was achieved: Deep Blue, built by IBM, was able to beat Russian chess champion Garry Kasparov.

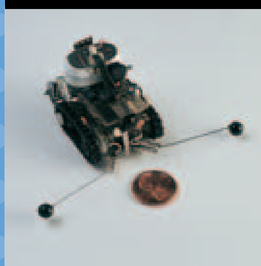
Winning against an international chess champion was an accomplishment. Yet Deep Blue still does not "think" like a person — it is not intelligent. Its advantage is the incredible speed with which it calculates possible moves and outcomes. A human player's approach would be different, identifying higher-level goals and how to achieve them. Machines are not yet capable of this kind of thought.

IBM's Deep Blue chess-playing computer can explore over 200 million positions per second.

"It's time for Deep Blue to start playing real chess. I personally guarantee you I will tear it to pieces, with no question."

GARRY KASPAROV

Focus On: Robot Ants?



Smaller may be better.

One of the more recent approaches to robots and robotic control reflects the artificial intelligence theory of using many smaller "agents" to accomplish a larger goal. The idea is similar to how an insect colony functions — with many small creatures having the same capability to move a pile of food as one large creature.

In the future, we may send millions of tiny, autonomous rovers on interplanetary missions. Separately, they may not have nearly the capabilities of something like Pathfinder's Sojourner, but together they might accomplish a great deal. The tiny robots would be lighter and cheaper to build and send into space. They would also be dispensable. If you have enough of them, the failure of a few robots does not destroy the entire mission.

Microrobots could also be used to clean up oil spills and environmental pollution, collect and dispose of the dust in our homes for us, or pick up the crumbs we dropped at lunch. There may be teams of them everywhere.

One power mover can push 6 ping pong balls at once, which is great as long as you only need to move the balls in one direction. If you want to move the balls in different directions at the same time, you would have to assign the task to several independent agents.

It takes thousands of "agents" to form an intelligence unit.

Scientists of artificial intelligence believe that true machine intelligence may be modeled after biological intelligence. Marvin Minsky, of the Massachusetts Institute of Technology (USA), proposes the theory that human thought is brought about by thousands of competing and cooperating "agents," each mindless in and of themselves, but which together create the human mind. For instance, when we are standing and speaking with a friend, there are agents in our minds which are busy helping us to balance, to think about our topic, to move our muscles in speech, to blink our eyes, to pump our hearts.

Teeny tiny Nano technology may be a huge force in the future.

At a far smaller scale, scientists such as Eric Drexler and Ralph Merkle in Palo Alto, California (USA), are working on simulations involving a robot arm that would actually move molecules one by one. This is called "nanotechnology." The prefix "nano" refers to the scale of a nanometer: just one-billionth of a meter. The idea is that someday we may be able to build more complex things — like food, clothes, computers and even factories — from the bottom up, molecule by molecule. Nanorobots may even one day be able to enter the body and cure disease from within our cells.

"We suggest that within a few years it will be possible, at modest cost, to invade a planet with millions of tiny robots."

RODNEY A. BROOKS
& ANITA K. FLYNN

ADDITIONAL
INFORMATION
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