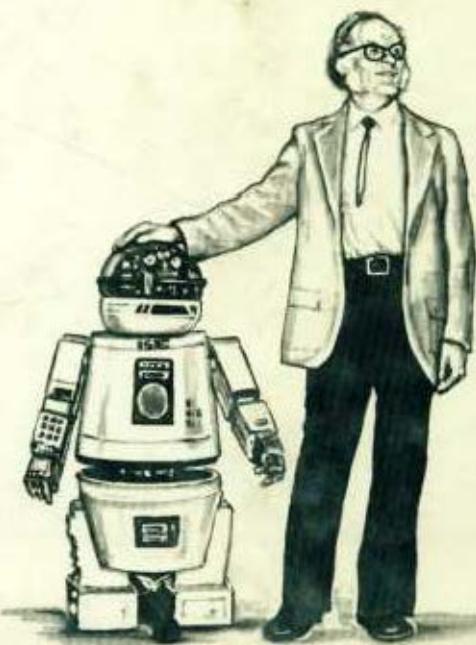


**How Did We
Find Out About
ROBOTS?**

Isaac Asimov



Illustrated by David Wool

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ROBOTS?



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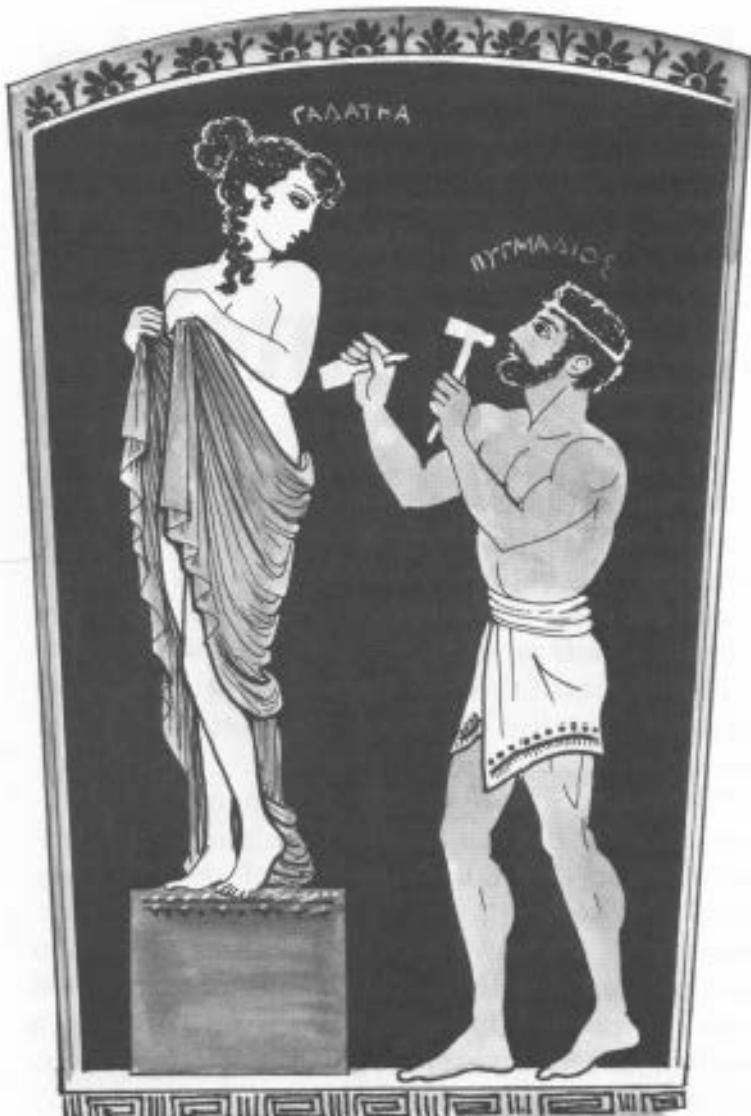
1 Legends and Automatons

WHEN WE THINK of a robot, we usually picture something that's made of metal and that looks a bit like a human being. We also think of it as acting something like a human being, too. In short, we think of robots as mechanical men or women.

True robots of this kind do not yet exist, but they seem to be on the way. Simple robots that are not human in appearance already exist.

The word "robot" was coined about a half century ago, but human beings were already dreaming of robots thousands of years before when they were making little human figures out of clay. Sometimes they would paint pictures of human beings on cave walls or carve statues of them out of wood or stone. This may have been done for a number of reasons: religious, artistic or, perhaps, just for the fun of it.

It may have occurred to some people that if they could make a human figure lifelike enough, it might actually come to life or be brought to life



Pygmalion and Galatea

somehow. Thus, artificial life would be created.

In fact, some people thought that this was the way in which human beings first came to be. Perhaps they were molded out of clay by a god with superhuman power who could breathe life into them. One of the Greek myths tells of a god, Prometheus (proh-MEE-thyoos), who fashioned human figures out of clay and then brought them to life.

In Homer's epic poem the *Iliad*, written about 800 B.C., there is a tale about Hephaistos (hee-FEISSE-tos), the Greek god of fire. He is described as having fashioned young women out of gold. These golden women, who could move, speak and think, helped him in his work. That's the earliest tale we know of today that would be considered a story about robots.

Hephaistos is supposed to have also fashioned a moving bronze figure for the king of Crete (an island south of Greece). This figure, named Talos (TAY-los), constantly circled the shores of the island and protected it from invaders. It was a useful robot indeed.

In one romantic Greek myth, Pygmalion (pig-MAY-lee-on) was a sculptor who shaped the statue of a beautiful woman. He thought the statue was so beautiful that he fell in love with it and prayed to Aphrodite (AF-roh-DY-tce), the Greek goddess of love, to bring the statue to life. Aphrodite obliged him. The statue became a living woman. Pygmalion married her, and they lived happily ever after.

Legends about creating human life, usually by the use of some kind of magic, continued for cen-

turies. One case involved Rabbi Loew, who lived in Prague, Czechoslovakia, in the 1500s. He made a hulking statue out of clay and with certain religious symbols gave it life. The statue was called a "Golem." It was enormously strong and was supposed to protect the Jews of Prague, but its strength made it so dangerous the Rabbi had to destroy it.

All these legends about producing life through magical or superhuman means are just imagined, of course. Could there be any way, though, of producing artificial human beings by working with natural methods, and by using science?

Actually, clever engineers were trying to create machines that did humanlike things automatically, just by making use of natural methods. This was many centuries before modern science was developed.

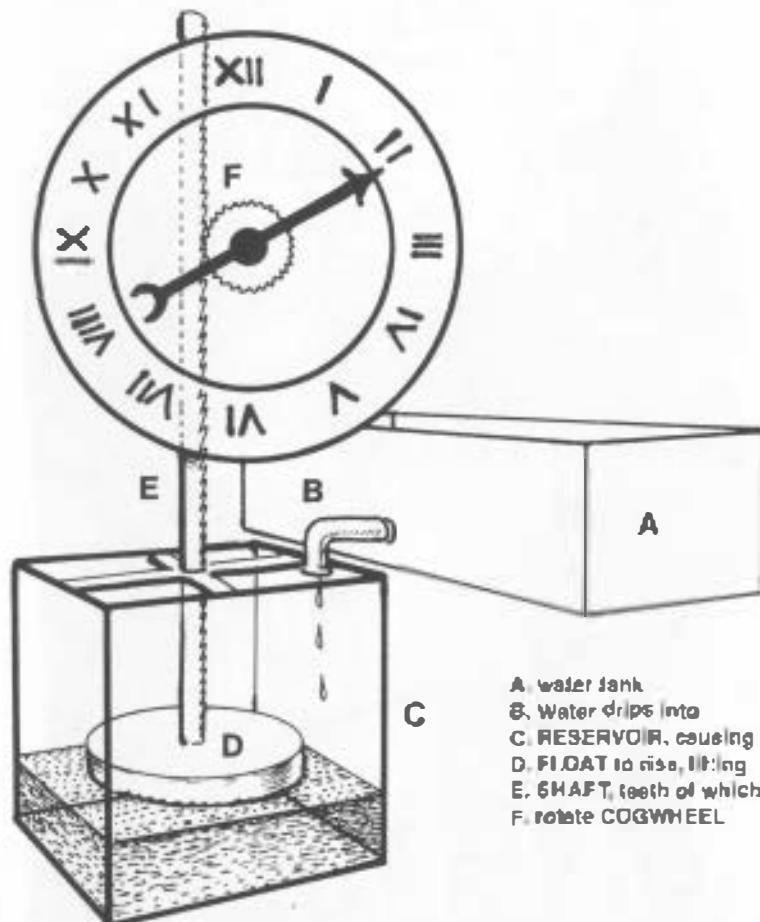
For instance, about A.D. 50 there lived in Alexandria, Egypt, an engineer named Hero. He worked out ways of moving things by the power of steam, compressed air, or jets of water. These devices would make things move apparently automatically. Any such device is sometimes called an "automaton" (aw-TOH-muh-tuhn, from Greek words meaning "acting by itself").

Hero arranged a device that would deliver a squirt of water if you put a coin in a slot. By using other inventions, he could make doors open, or statues move, without his having to touch them.

Hero's devices were amusing and admired, but they were really very crude and only the simplest people who watched would think for a moment



Scene from the movie *The Golem*



Water Clock

that there was any life in them.

The cleverest and most useful mechanical device worked out in ancient times was an automatic clock.

Such a clock was invented in Alexandria by Ctesibius (tch-SIB-ee-us), who lived about 250 B.C. It consisted of water dripping into a container at a steady rate. As the water got higher and higher, it raised a lightweight object that floated on top. To the object was attached a pointer that indicated a line of numbers marked on the outside of the water container. By reading the number, you could tell the hour.

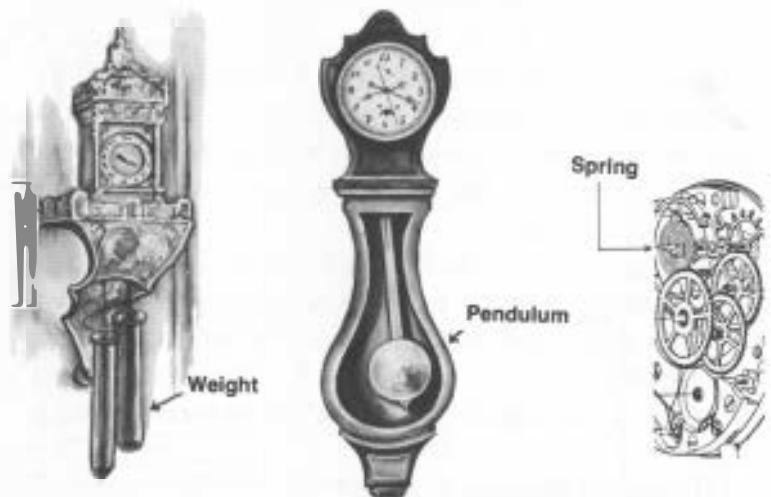
Such a "water-clock" had to be made quite complicated in order to work reasonably well, but this was managed. For many centuries, they were the best clocks anyone could find, and they showed what could be done by natural means only.

Of course, the use of water was inconvenient. It evaporated, was messy, could be spilled, and a new supply might be hard to get in a hurry.

In the Middle Ages, therefore, a waterless mechanical clock was invented. Instead of water, weights, which were pulled downward by gravity, forced a wheel to turn little by little. The wheel had gears that caught for a while before letting go, so that it moved very slowly and made a "ticktock" noise as it caught and let go, caught and let go. As the wheel turned, a pointer attached to it also turned and marked off the hours.

Without water, these mechanical clocks needed hardly any care, except for the winding up of the

weights to the top once in a while. The worst trouble with these weight-clocks was that they weren't very accurate. They were no worse than the water-clocks, but neither could be relied on to tell time to better than the nearest quarter of an hour or so.



Gravity clock, Pendulum clock, Watchspring clock

Then, in 1656, a Dutch scientist, Christian Huygens (HÜY-genz, 1629–1695), worked out a way of using a pendulum in a clock. A pendulum can be made to swing back and forth in a very steady rhythm. With each swing, it would allow the wheels and gears in the clock to move by a fixed amount. As a result, the hands of the clock were made to go around the dial very steadily.

Once the "pendulum clock" was invented, it was possible to tell the time to the nearest minute,

even to a few seconds. From 1656 on, science began to advance much more rapidly than before because scientists had clocks that were accurate enough to use in scientific measurements.

Small clocks ("watches") were made that were powered by springs rather than by weights and pendulums.

As clocks and watches were made more and more complicated and accurate, there came to be specialists who learned how to work with the wheels and gears and levers and other little devices used in clocks. They became expert in "clockwork."

If clockwork could make clocks go automatically and keep good time, couldn't clockwork be arranged differently in order to make machines go through other kinds of automatic motions, once you wound up the spring that powered it? Instead of attaching the clockwork to a pointer that went round and round a dial, could it be attached to a doll in such a way as to make its hand go up and down?

It could be. From 1670 onward, it became quite fashionable for skilled workmen to devise clock-work automatons of one kind or another. Louis XIV, the King of France, had toy soldiers that could march along by themselves made for his son. An Indian ruler, who was fighting the British at the time, had a six-foot mechanical tiger constructed, with clockwork inside so arranged as to make it jump at a toy British soldier.

The most famous automaton-maker was Jacques de Vaucanson (voh-kahn-SÖN, 1709–1782), who



Pierre Jaquet-Droz's 18th century automaton

built a mechanical duck in 1738. It was made of copper, it quacked, bathed, drank water, stretched out its neck to take grain and swallow it, and so on. Vaucanson intended to make money out of it and he did. He put it on show for three years, charging admission, and then sold it to someone who continued to exhibit it all over Europe. De Vaucanson also constructed a mechanical mandolin-player that tapped its foot as it strummed.

In 1774, Pierre Jaquet-Droz (zhah-kay-DROZE), constructed a writing automaton. It was in the shape of a boy holding a pen. The boy would dip the pen in an inkwell and write a letter. This automaton still exists today in a Swiss museum.

However impressive these automata were, they remained toys. They were a little more advanced but were on the same level as Hero's machines of sixteen centuries before. The automata could only do the same thing over and over again. Just as the hands of a clock can only go round and round the dial as the clockwork moves, so the letterwriting boy can only go through the same motions over and over and write the same letter in exactly the same way.

Nevertheless, the automata fired the imagination. They helped give rise to thoughts about artificial life that might be something more than mere clockwork. And as long as people keep thinking about a subject, there continues to be an urge to do something about it.

2 Science Fiction



IN 1771, THE Italian scientist Luigi Galvani (gahl-VAH-nee, 1737–1798) made a startling discovery. He was working with muscles he had taken from frogs' legs, and in his laboratory he also had an electric device that scientists were frequently experimenting with in those days. When the device was used, it could produce electric sparks.

As it happened, such a spark touched the frog muscles and those muscles twitched just as though they were alive. In fact, when the electric machine was going, Galvani could make the muscles twitch just by touching them with a piece of metal. His report created a sensation and it was discussed all over Europe.

Electricity was still something quite new to science and at once people began to wonder if it might not be the secret of life. (Actually, we now know that tiny electric currents move along nerves and set muscles to contracting, but there's a lot more to life than just that.)

In 1816, the two great English poets George Gordon Noel Byron (1788–1824) and Percy Bysshe Shelley (1792–1822) were living in Switzerland. With them one evening were Byron's doctor and Shelley's nineteen-year-old friend Mary Wollstonecraft (1797–1851), who married him later that year. They talked about scientific advances such as Galvani's and then decided that they would all write stories about strange and unusual things.

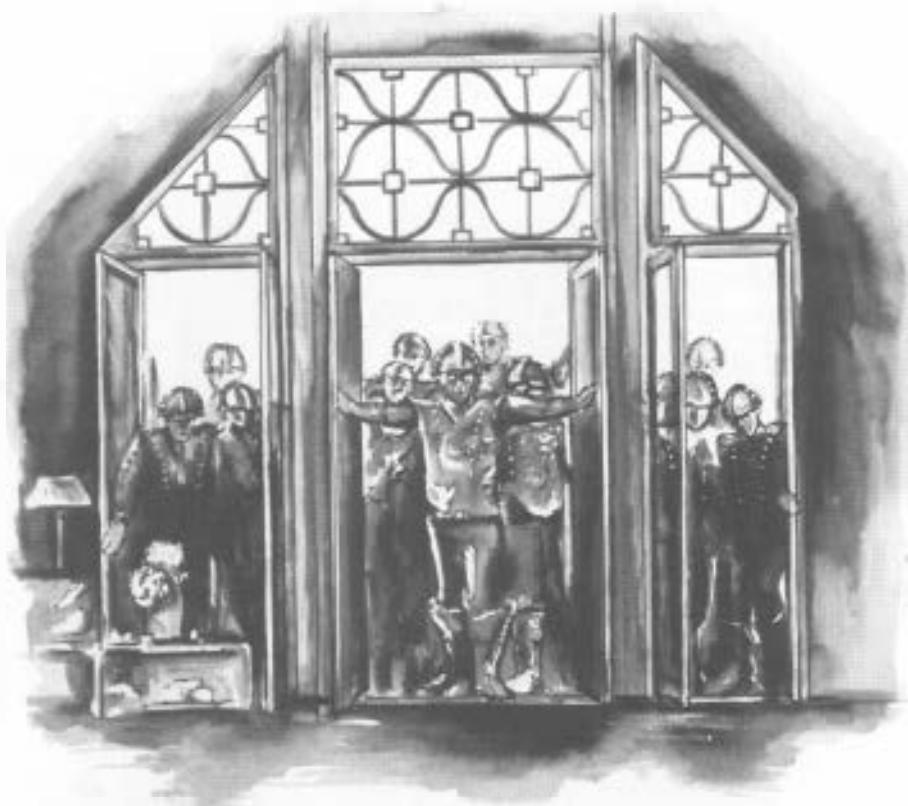
Byron and Shelley didn't come through, and the doctor wrote a story that was not of much account. Mary Shelley, however, published a book in 1818, when she was still only twenty-one, that arose out of this conversation, and it proved to be an enormous success. In fact, it has continued to be a success to this very day. The book was named *Frankenstein*.

Mary Shelley made use of the new feeling that science was on the verge of solving the riddle of life. She had her scientist-hero, Victor Frankenstein, put life into a dead body. (She doesn't describe how this is done.) The body was large, ungainly and ugly, and it is referred to only as "the Monster."

The book's subtitle is *The New Prometheus*, so Frankenstein is compared to the Greek god who created human beings. However, Prometheus cared for his creations and underwent great hardship for them. Frankenstein, on the other hand, was horrified by the Monster and abandoned him. The Monster, who could find no kindness at the hands of anyone, finally despaired and took a bloody revenge on Frankenstein and all his family.



Frankenstein's monster



Scene from the play R.U.R.

This is no happy story like that of Pygmalion and the statue that was brought to life for him. *Frankenstein* told its readers that the creation of artificial life was a dangerous thing.

Frankenstein is considered by some people to be the first true science fiction story. Its plot was not likely to come true at the time it was written but depended upon new scientific discoveries to make it so. This is exactly what makes a story science fiction.

For a hundred years afterward, science fiction stories continued to be written, and once in a while, artificial life was included, but none was as memorable as the *Monster*.

Then, finally, in 1920, a Czechoslovakian writer, Karel Capek (1880-1938), wrote a play called *R.U.R.* It was produced on the stage the next year.

It was a science fiction play. An Englishman named Rossum has built a factory in which he manufactures automatons. These look exactly like human beings and they are designed to do the work of the world and to free human beings from the curse of labor.

It doesn't work out that way. Just as the *Colem* and the *Monster* became dangerous, so it was with these automatons. They developed emotions, didn't feel they should be enslaved, and wiped out humanity. Finally, Rossum, still alive, sent off two of the automatons, a man and a woman, to start a new race and begin things all over.

"Rossum" seems to be derived from the Czech word "rozum," meaning "reason" or "intelli-

gence." The initials R. U. R. are the name of Rossum's factory and stand for "Rossum's Universal Robots." The word robot (R-O-H-bot) is from a Czech word for an involuntary worker, that is, for a slave. Rossum's robots are "universal" because they are designed to do all the work humans do.

Because of this play, the word "robot" came to mean an artificial human being. It replaced "automaton" completely. Robot is now used for the purpose in almost every language.

As science continued to advance, science fiction grew more and more popular. In 1926, *Amazing Stories* was introduced. It was the first magazine to be devoted exclusively to science fiction, but others followed soon enough. Dozens of writers began to write for the new magazines, and hundreds of science fiction stories came to be published each year.

A number of these stories involved robots, but the influence of Mary Shelley and Karel Capek was strong. In almost every science fiction story, the robots proved dangerous, and even murderous.

In 1939, a young science fiction writer named Isaac Asimov* (AZ-ih-nov, 1920), then only nineteen years old, decided to write a robot story of another kind. He wrote one in which a robot was simply a machine, designed to do a specific job (although a very human one—it was a nurse-maid). What's more, it was constructed with built-in safeguards, so it couldn't do any harm.

Following that, he wrote a series of such stories with the encouragement of John W. Campbell, Jr.,

*See The author of this book.

editor of *Astounding Science Fiction*, the magazine in which the stories appeared. This new type of robot story proved very popular, and helped make Asimov's reputation.

The built-in safeguards that Asimov invented were called "The Three Laws of Robotics." Since they are now quoted in almost all books that deal with robots, I will quote them here.

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

These laws were first quoted in an Asimov story entitled "Runaround," which was published in 1942. As it happened, that was the first time that the word "robotics" was ever used in print. The word is now used by everyone to stand for the study of robots, for their design, construction, maintenance, and repair.

The Three Laws were the first serious attempt to cancel out what Asimov called "the Frankenstein complex"—the fear that robots would turn murderously on human beings. To a great extent, this worked. Asimov's robot stories made the older



C3PO and R2D2—from the movie *Star Wars*

kind seem out-of-date, and the better science fiction writers stopped writing them.

Increasingly, robots were pictured as harmless, useful—even lovable. Thus, in the motion picture *Star Wars* the two robots, C3PO and R2D2, all but stole the show.

Science fiction, of course, cannot produce anything by itself. Not all the robot stories in the world can bring a robot into existence, or even make one possible. Science fiction might be viewed as just a new kind of legend and myth, one based on nature and science, rather than on magic and the supernatural.

There is this difference, though. Legends and myths that involve magic and the supernatural aren't likely ever to come true. Legends and myths that involve nature and science just might. In fact, the legends and myths we call science fiction sometimes inspire scientists and engineers to work toward some of the advances described in the stories.

In 1950, for instance, nine of Asimov's robot stories were put together and published as a book called *I, Robot*. This was widely read and proved surprisingly influential.

One of the early readers was a Columbia University undergraduate, Joseph F. Engelberger (1925—). He was sufficiently inspired by the book to make up his mind to devote his life to the development of robots, and that had very important results, as I shall explain in the next chapter.

Almost everyone active in robotics today has read and was influenced by *I, Robot*. Not long ago,

Asimov met an Israeli roboticist who said he had been influenced by the book, which he had read in Hebrew translation.

Asimov himself is only a writer. He is not interested in working on robots, only in making up stories about them. He is, however, completely satisfied (and a little surprised) with his part in their history.

3 Industrial Robots and Computers

HOWEVER MUCH SCIENCE fiction writers might dream, real robots can't be built as long as simple clockwork is all we have with which to run them. Such clockwork can only make robots do one routine thing over and over again.

In order to have a useful robot, there must be some way to give it complicated instructions. These instructions should be easy to change from time to time so that a robot can do one thing now and another thing later.

Still, clockwork can be made more complicated.

In 1822, an English mathematician, Charles Babbage (BABB-ij, 1792-1871) began to imagine a kind of clockwork machine made up of gears and levers and other parts; one that would be so complicated it could be given instructions that would

enable it to solve any kind of arithmetic problem and print out the answer. He dreamed of an enormous kind of calculating machine; something that today we could call a "computer".*

He dreamed of a computer that would store numbers, so that it would have a memory. He dreamed of one that could be instructed to do any kind of problem, with instructions that could be changed at any time. But none of it came true for him.

Babbage's machine didn't work for several reasons. First, Babbage was a very old and impatient man. He kept getting newer and better ideas all the time, and he wanted nothing but the best machine possible. Therefore, he would tear down his machine and begin to build a bigger one instead. Finally he had no money left with which to build.

Besides, even if he could have finished his machine it probably wouldn't have worked. The gears, levers, and other parts would have had to fit together very well, or they would be breaking down and going out of order all the time. In Babbage's time, all those parts couldn't be made so accurately as to fit together closely enough. Then, too, the whole machine would have been so heavy that cranking it in order to make it work would have been difficult indeed.

Babbage's machine was therefore forgotten for a hundred years.

Just the same, as time went on, simple adding machines were built. If someone pushed the proper buttons for the numbers, and pulled a

lever, an answer would be cranked out. The problems solved would be of the simplest kind. Such adding machines are nothing like the complicated kind of computer of which Babbage dreamed.

Then electricity came into use. A current of electricity is much more easily handled than clockwork. An electric current can be allowed to pass, or forced to stop, very quickly and easily. If it passed, it could set up a magnetic field that could be made to close and open switches. It could do what clockwork did, but much more quickly and surely.

In the 1880s, the American inventor Herman Hollerith (HOL-uh-rith, 1860-1929) worked out a way of handling all the statistics gathered by the United States census. He used stiff cards into which a number of holes could be punched. The position of each hole stood for some kind of statistic. Electricity could pass through the holes but not through the card material itself. The way in which electricity passed through (according to the pattern of the position of the holes) managed to gather data, automatically, and to solve problems.

Hollerith worked out improvements and in 1896, he founded The Tabulating Machine Company. It grew large and, eventually, changed its name to International Business Machines Corporation or IBM. IBM is now the largest computer firm in the world.

Even electricity isn't fast enough for robots. The electric currents couldn't be handled quickly and easily enough by stopping and starting them with cards and switches.

If an electric current is forced through a vacuum,

*See *How Did We Find Out About Computers?* (Walker, 1984)



Hollerith's punch card

however, it comes through as a stream of tiny particles called "electrons" (ee-LEK-tronz). In 1904, a British engineer, John Ambrose Fleming (1849-1945), forced a stream of electrons through an evacuated glass container and showed how that stream could be controlled much more delicately, quickly, and easily than an ordinary electric current.

Such a container is called a "tube" in the United States, and it was the first "electronic device." Such tubes were rapidly improved and came to be manufactured in all sorts of varieties. Because they were used in radio sets to begin with, they were often called "radio tubes."

Could calculating machines be built that made use of such tubes to control electricity? An American engineer, Vannevar Bush (1890-1974) thought so.

He got the idea for the same sort of calculating device that Babbage had dreamed of, and in 1925, he built one. Bush's success came about because the technique for making the parts that made up the machine had progressed greatly since Babbage's machine. Besides, the machine was run by electricity, not by hand.

Bush's machine had a memory. It could also be given complicated instructions (that is, it could be programmed); the program could be changed at

any time. It was the first working computer.

Even so, Bush's machine was still mostly clock-work. In 1946, two American engineers, John William Mauchly (MAWCH-lee, 1907-1980) and John Presper Eckert, Jr., (1919-), completed a computer in which the electric current was controlled entirely by tubes. They called it the Electronic Numerical Integrator and Calculator. For short, this is ENIAC and it was the world's first "electronic computer." ENIAC could solve complicated problems a thousand times as fast as human beings could with any other kind of calculating device then known.

Such computers were rapidly improved. Various programs could be stored inside the computer memory, for instance. That meant you didn't have to go through a lot of fiddling every time you wanted to change a program. You just pushed one pattern or another and the machine switched quickly from one program to another.

In 1951, Mauchly and Eckert built an improved electronic computer called UNIVAC (Universal Automatic Computer). It was the first computer to be sold commercially.

It was about this time that young Joseph F. Engelberger became interested in robots. Robots were no longer just dreams. Now that electronic computers existed, robots could have the necessary programming.

In fact, in 1954, the American engineer George C. Devol, Jr., got the first patent ever for a computer-programmed robot. He called his system "universal automation," or "unimation," for short.

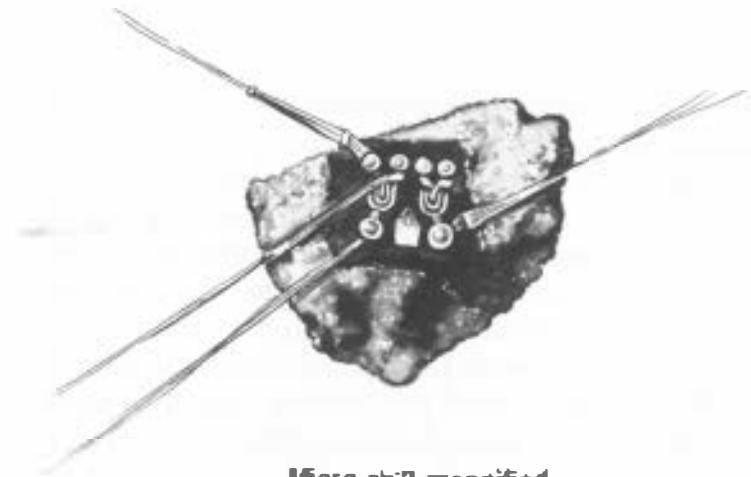
In 1956, Engelberger happened to meet Devol at a cocktail party and they got together to found Unimation, Inc. Devol would do robot designs and Engelberger would handle the business end.

There was no question at first of building robots that looked like human beings and that could do all the things Asimov's robots could. They had to start simply—to build not mechanical people, but simply mechanical arms. If these arms could be instructed to make certain complicated sets of motions, they could be set up on factory assembly lines.

On such assembly lines, some device moves along past a line of workers. Each worker in line does one particular job, such as add a part, fit it, polish it, or bolt it. By the time the device reaches the end of the assembly line, it is complete. Each worker does one job and if each robot arm can be instructed to do that job, the robot will do it instead. The robot could do it more accurately, without ever getting tired, bored, hungry, or sleepy. The worker could be freed to work at some job that was more interesting than doing the same thing over and over.

Such a robot is called an "industrial robot," because it is used in industry, and it was for this type that Engelberger and Devol aimed at first.

The robots developed by Unimation, Inc. worked, but they couldn't be sold because they were too expensive. Computers were good, but they were so large and bulky, and required so much energy, that nobody could afford to buy robots that were guided by them—nor would they



Micro chip magnified

have enough space for them.

Engelberger had faith, however, that computers would grow smaller and cheaper, and they did.

In 1948, the "transistor" was developed. This consisted of a small piece of solid matter made of metals such as germanium (jer-MAY-nee-um) or silicon (SIL-ih-kon). Certain other substances were added and then the transistor would do the same work as a vacuum tube. The transistor was a "solid-state" device.

A vacuum tube is quite large and is made of glass which can break. It contains a vacuum into which air can leak. The wires inside the tube must be heated and that takes time and a great deal of energy. Transistors are small, unbreakable, un-leakable, and take no time and hardly any energy to do their work.

At first, transistors were hard to make, expensive, and unreliable. However, scientists soon learned how to improve their methods of manufac-

ture. Transistors grew even smaller and cheaper—and steadily better.

In the 1960s, engineers were substituting transistors for tubes in computers, so that computers at once became smaller and cheaper. Scientists learned how to economize on space for the connections, or "circuits," between the transistors, too. They started with small, thin squares of silicon (a "chip"), and carved the surface into tiny parts each of which behaved like a different part of a circuit.

All this could be made so small that by the 1970s, people were talking about "microchips." The equivalent of ENIAC could be carved onto a single chip. Computers could be made so small that they would cost only a few dollars and could fit into a person's jacket pocket or a small purse, and yet be faster and more powerful than early computers that filled entire rooms.

At Unimation, Inc., they couldn't make use of computers that small, but the ones they did have to use were small enough, cheap enough, and good enough to make the price reasonable. In 1975, Unimation, Inc. finally started selling enough robots to make a profit. Each year, thereafter, they sold more and more and more, so that now Engelberger is many times a millionaire.

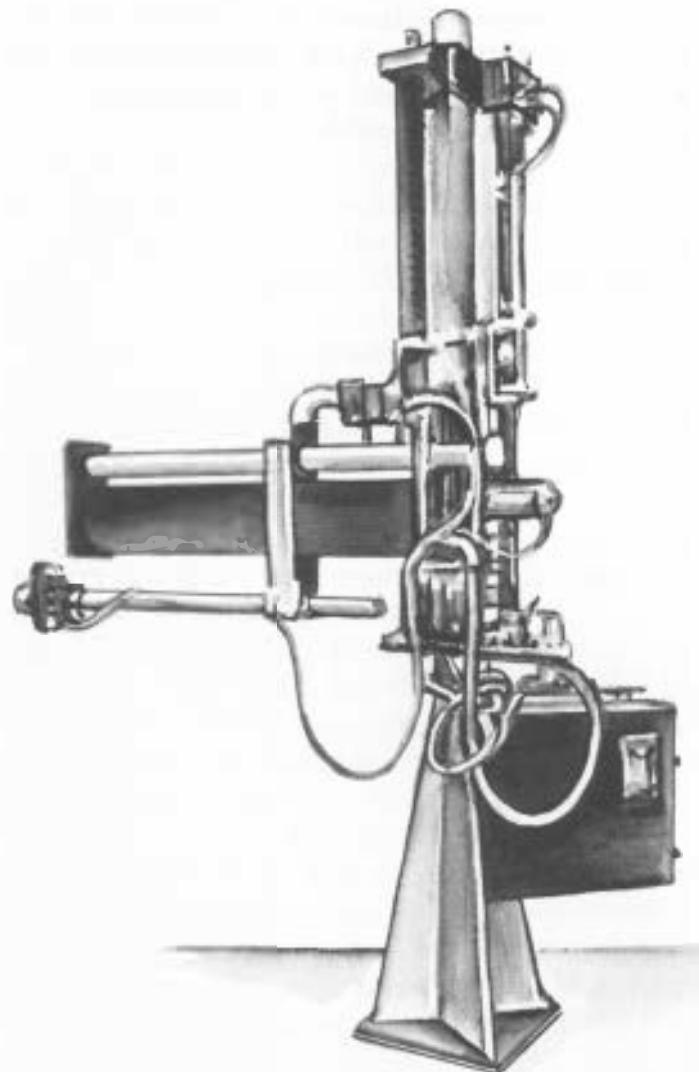
Other firms began to put out industrial robots, but Unimation, Inc. remains the most important of these. It produces about one third of all the industrial robots in use.

There are now many thousands of industrial robots in use in the world and the number is

increasing rapidly each year. More than half of these robots are in Japan, which is anxious to become even more robotized. The United States is being more cautious and although it is here that robots have been developed, this nation is only in second place in its use of them.

4

Robots to Come



Industrial Robot that does loading and unloading

INDUSTRIAL ROBOTS ARE only the beginning. They are like the very first airplanes or automobiles. If you ever saw pictures of the early stages of those inventions, you would see they don't compare to what we have now. They were small, flimsy, clumsy, and slow. It would be hard to look at the first plane and imagine a huge airliner carrying a hundred people across the Atlantic Ocean at faster than the speed of sound.

In the same way, the industrial robot of today won't be able to compare to the devices that will be available in years to come.

The most important thing would be to make such robots look and act more and more like human beings.

You might wonder why it is important for a robot to be human in appearance. If it can do its job by just being a computerized arm, why bother sticking all the other parts on it?

The answer to that is that all the things human beings make are designed for the convenience of human beings. Our houses, our furniture, and our tools are designed to fit the human body. They must adjust to the way the human body bends and

turns and stretches; everything must fit our hands and suit the way we walk.

If a robot can fit everything that fits us, and move and bend and stretch and twist as we do, it will adjust to the world we have already created. We won't have to adjust the world to it.

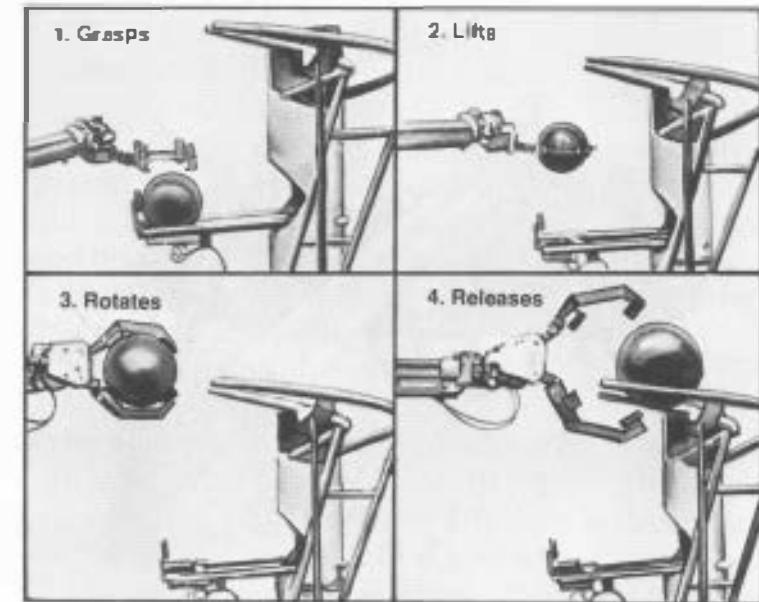
For instance, industrial robots are bulky. They might weigh up to 1500 pounds, ten times as much as a person does. Naturally, they take up more room than a person does. Generally, they have large, bulky "hands" that are very strong and can do heavy work, but those hands are a little clumsy for fine work with small parts.

Unimation, Inc., has therefore developed industrial robots that are as small as men, or even smaller. They have some that weigh only 90 pounds, computer included, and can do delicate work like changing light bulbs.

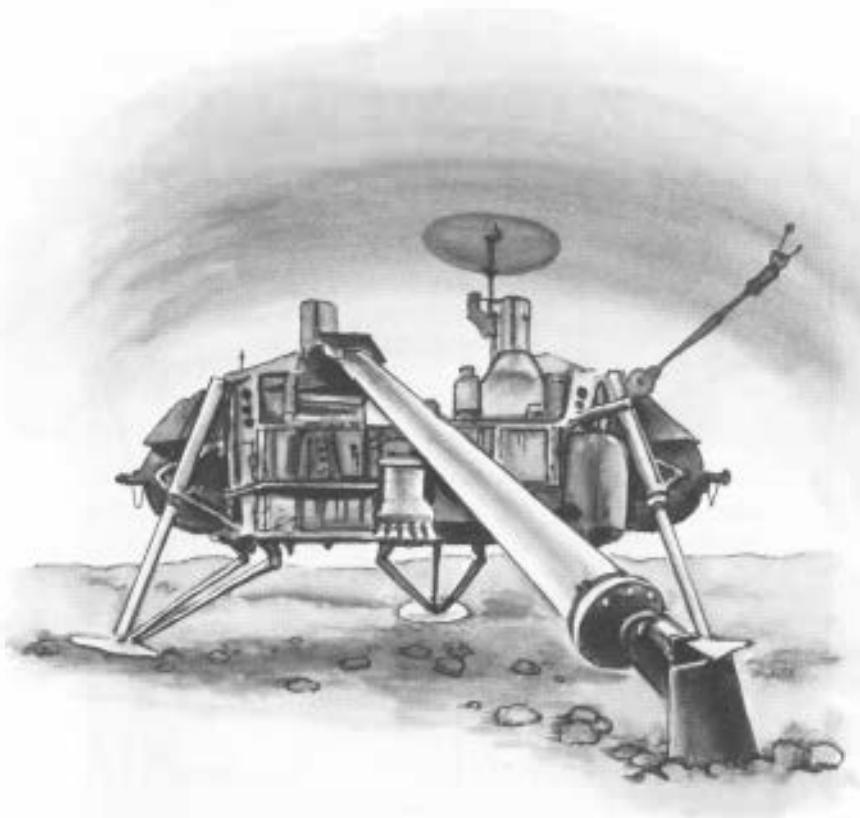
Then, too, robots usually have fingers that are more like stubby claws, strong but not delicate. They are nothing at all like the human hand, with its five long fingers that have two or three joints each and can move independently.

It would be nice to develop a robotic hand that was stronger than a human hand, but just as delicate and maneuverable. That is not an easy thing to do.

Again, robots tend to be motionless. If they move, they glide along on wheels, which is something human beings (or any other living thing, for that matter) can't do. Wheels have their advantages, for they move smoothly and without using much energy, but they only work well on smooth



Industrial Robot doing a job in bowling ball factory



The Viking Science Test Lander on Mars

surfaces. What if it becomes necessary for robots to climb over obstructions or to make their way over broken ground? In that case, they should be able to walk.

Devices have been built with six legs, each of which can be maneuvered independently. The device, when walking, lifts three legs, the middle one on one side and the two back ones on the other. That leaves it standing on three legs, so that it doesn't tip in any direction. Then it puts down the first set of three legs and lifts the other set, and it is still rock steady.

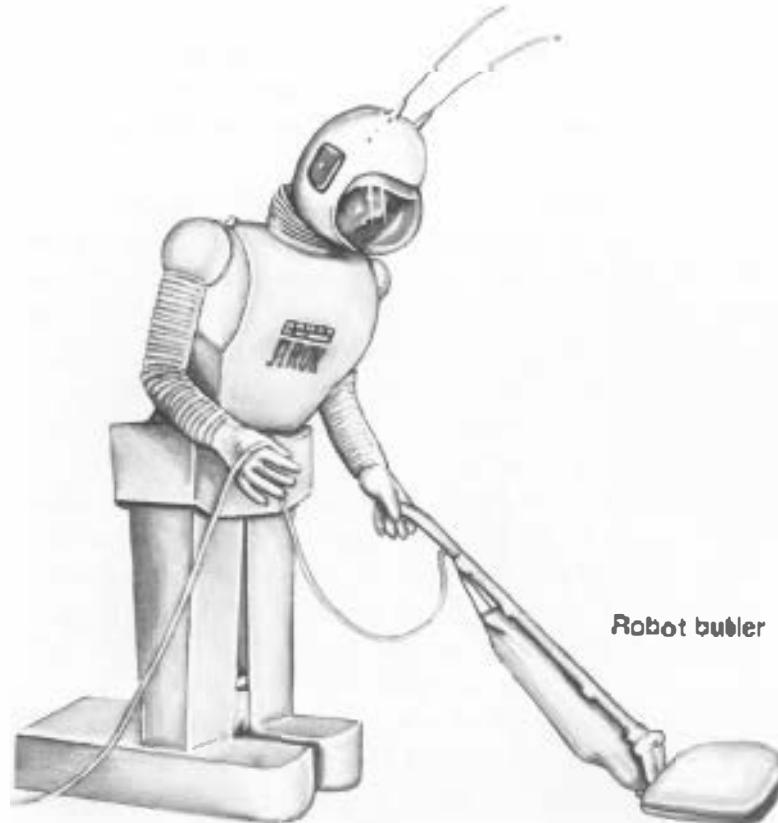
The trouble is that six legs is the number that insects have, and the walking device looks exactly like a large bug. People may find this unpleasant and be more attracted to a walking device with two legs, if one can be worked out that doesn't fall down when it tries to walk.

What about a robot with human senses?

For instance, if a robot must tighten a nut, it has to be given clear instructions as to how many times to turn the nut so that it will be tight. A different nut and bolt would require different instructions.

It would be convenient if a robot had some way of feeling the resistance when a nut grew tight. In that case, it would require no special instructions. Whatever nut it tightened, it would stop when it could tell by feel that the nut was tight enough. In the same way, it could tell by feel when it was holding a heavy object tightly enough to lift it without having it slip out of its grasp—but not tightly enough to dent or break it.

Just as important, or more so, would be to



develop a way to have a robot see. It could then tell, just by looking, when a nut was defective, or when it wasn't seated squarely. The nut would then be discarded or reseated.

It would be convenient to have it hear as well, for some things that go wrong can be detected through the sense of hearing. What's more, if it could hear, it could respond, perhaps, to a spoken command. Programming could be changed at a

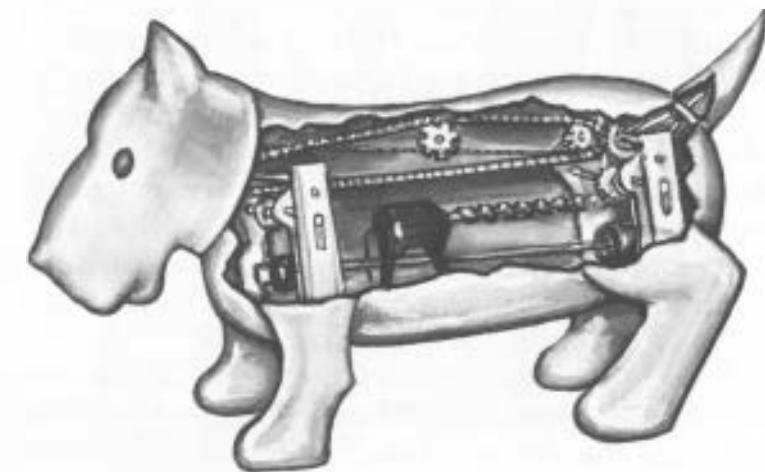
word. The robot might even be equipped to make sounds of its own and to answer a human being in a useful way.

Surely, if we could carry on a conversation with a robot, it would instantly seem more intelligent and companionable to us.

All these things probably can be done eventually, and therefore will be done. In fact, robots might even be equipped with senses we don't have. They might be made able to detect and respond to electric and magnetic fields, which we don't do, or to sound and light of types we can't detect.

Then, too, why only factories for robots? Eventually, they will be everywhere.

In general, if we consider any computerized tool a kind of robot, we find them elsewhere already.



Sparks, robot dog from 1939 World's Fair

The Space Shuttle is thoroughly computerized and wouldn't run without that. Many space satellites and probes are now computerized, and we may look forward to robotic devices helping to mine the moon and build structures in space.

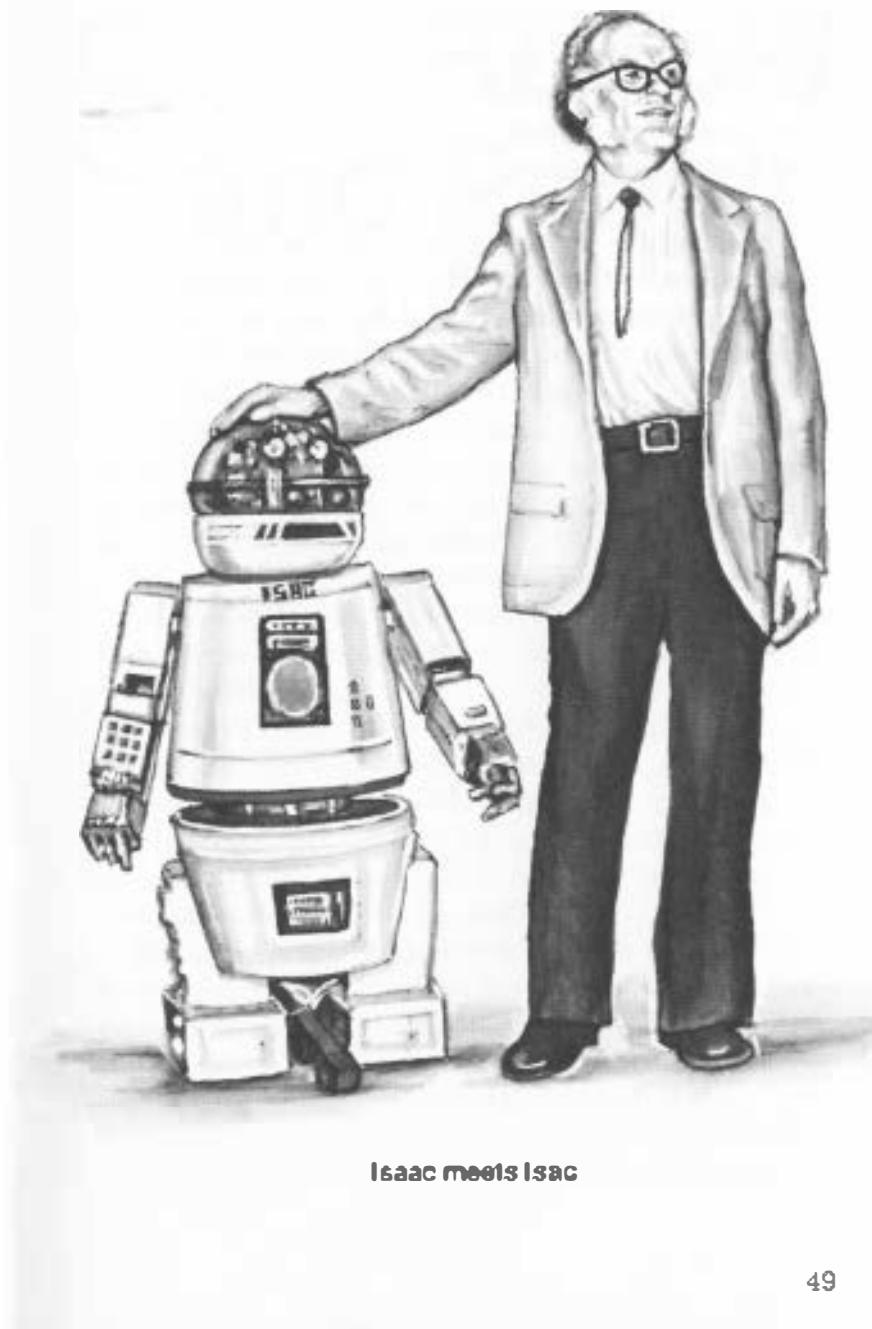
Even automobiles are being computerized and are therefore becoming robots in a small way.

Also there are now in existence "show robots," which may be becoming big business in the United States. They are usually small and simple. They look a bit human because they generally have heads, torso and arms (though they don't have to). They move about freely on wheels, and they can even speak a little in many cases.

So far, these are amusing toys, and it may be they will be bought as such. Certainly, they will be one way of familiarizing people with robots and making us feel more comfortable with them.

One successful show robot was built because a young man named Fred Haber was inspired by *I, Robot*. With the help of others, he built a three-foot robot with a round head; arms that have shoulder, elbow, and wrist joints, together with a hand and simple, movable fingers. It has stubby legs that are on wheels so that it can move in any direction. It does nothing by itself, but is remotely controlled, so it is not a true robot. Its voice is the radio-transmitted voice of its operator.

Fred Haber has displayed the device at conventions and other such functions with great success. He calls the device "Isac," in honor of Asimov, and the two, Isac and Isaac, have had their picture taken together.



Isaac meets Isac

The real future may be with the "home robot," however. This would be a true robot, at least vaguely humanoid in shape, that could act as a butler or maid. It could take coats from visitors, announce their names and hand out drinks; or it could vacuum the rugs, move beds and furniture on request, and so on.

Engleberger is attempting to perfect a true home robot of this sort. He has a preliminary device in operation already and he calls it "Isaac."

5 Robots and People

ONE OF THE reasons why the United States is hesitating about going full speed ahead with industrial robots is probably the fear of unemployment. As more and more robots are put into factories, what happens to the men and women who used to have the jobs?

Of course we can argue the matter this way—

Until the 1970s, there were many jobs that only human beings could do. Animals weren't smart enough. Machines weren't complicated enough.

Some of these jobs that only human beings can do are dangerous. Working in mines, or on building construction, or with dangerous chemicals or explosives, or under difficult weather conditions—all are jobs that it would be better for human beings not to have to do.

Besides, some jobs, even though they require human brains, don't require too many. Many people have to spend day after day doing simple things like filing cards, or typing routine letters, or tightening bolts, or carrying something from here to there. No animal or machine might be able to do it, but people who must do it don't really get to use

their brains very much. If muscles aren't used much, they get flabby, and that's true of the brain, too.

The kind of jobs many people do—the same simple thing all the time—can be terribly boring and depressing. Eventually, people who do such things find they have led dull lives that never gave them a chance to think properly and expand their minds.

Now we have devised robots that are much more complicated than any other machines we have ever had. They are complicated enough to do jobs that until now only human beings could do, but that are too simple for the marvelous brains we all have. The robots, even though they are smarter than other machines, are still only capable of very



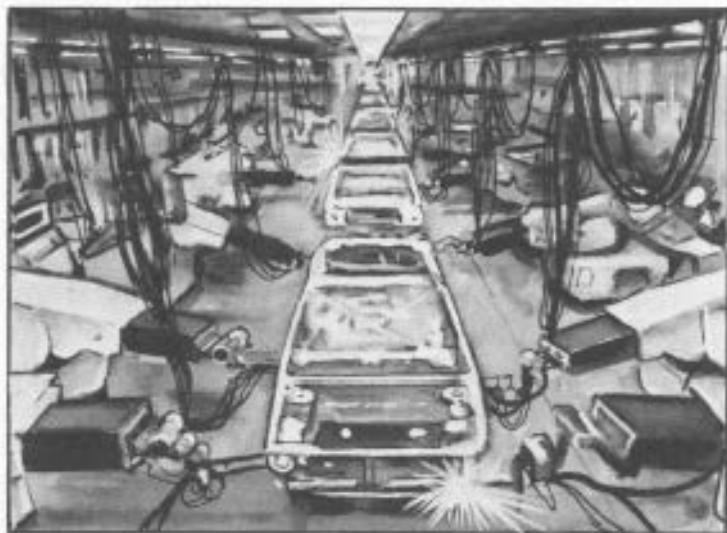
simple tasks—the kind of tasks human beings ought not to waste their time doing.

In that case, why not let the robots do it? Why shouldn't human beings do other and better things?

After all, whenever there is an important new invention, some jobs are lost. When the automobile came into use, there was a gradual, but steady, loss of jobs that involved horses. There were fewer stables, fewer manufacturers of buggies and wagons, fewer whips, fewer spurs. On the other hand, think of the jobs the automobile created. Think of all the garages that came into being, all the auto mechanics needed, all the tire manufacturing, highway building, oil-well drilling. Automobiles created hundreds of times as many jobs as they destroyed.

That's the way it will be with robots, too. Lots of assembly-line jobs will vanish, but think of all the jobs needed to design robots, manufacture their parts, put them together, install them, and keep them in good repair. There will be many times as many jobs coming into being as are destroyed. The jobs that are destroyed will be very dull ones anyway, so dull that even a robot can do them. The jobs that will be created will be interesting ones that will stretch the mind.

Of course, there is a catch. We can't just tell a person who has been working on an assembly line for twenty-five years to stop and take a job designing robots instead. It takes a special kind of education to be able to work with robots, and the assembly-line worker won't have it.



Computerized robots building cars

If we are going to have a large changeover in types of jobs, there will have to be a careful program of retraining and reeducation for people with old-style jobs. It will have to be done even if they take rather simple new-style ones. That will be expensive and hard, but it will have to be done.

There are also sure to be people who are too old, or too beaten down by the dull job they had to do all their lives, to be able to take advantage of retraining. Some sort of jobs will have to be found that they can do.

Eventually, of course, things will be different. Children going to schools in the future will be educated in ways of using and understanding computers and robots. They will grow up and be

able to take the new jobs, and no one will ever consider the old jobs or want them. Everyone will be glad to leave the dull jobs and the dangerous jobs to robots.

Still, there will be a "transition period," a time between the present, when so many people are still in the old jobs, and the future, when everyone will be in the new jobs. The American people and, perhaps, the whole world, will have to be patient and intelligent so that we can get through the transition period with as little trouble and unhappiness as possible.

There is another problem that may face us. Robots aren't going to stay in the same place. Computers will get more and more complicated, and robots will have more and more abilities, and be able to do better and better jobs.



Man running automated factory

Are there any jobs that robots won't some day take? What if human beings are driven out of job after job, and robots take them all? Will robots take over, as they did in the play *R. U. R.*?

Actually, that doesn't seem likely.

Just because robots do things that till now only human beings have been able to do doesn't mean that robots are intelligent in the same way we are. They just work automatically under the direction of computers that we have programmed.

For instance, computers are very good at solving mathematical problems. They can solve them much faster than we can, and they can do it without making errors. That's because we know all the rules of arithmetic. They happen to be simple and we can describe those rules in the programming so that the computer knows what to do. Through those rules the computer can instruct the robot how far to turn, how far to bend, how many times to do something, and so on.

But that's the very sort of thing that human beings are not very good at. Human beings can do arithmetic, they know the rules but that sort of thing, if done for very long, quickly gets boring and the human brain gets tired. We begin to make more and more mistakes.

The human brain, however, is very good in other directions. It has imagination. It can suppose and wonder. It can make intelligent guesses. Most of all, it is "creative." It can think up new and sometimes startling ways of doing or understanding things. Computers and robots can't do any of these things. And as long as they can't, they are a

long way from being intelligent in the same way we are, and they're not likely to "take over."

We can't even program computers and robots to be imaginative and creative, since we ourselves don't know how we do it.

For instance, I write books—a lot of them. Because I write many books, I write them quickly. I learn about a subject and then try to explain it. I try to be clear. I try to tell things in the right order. And it works. Even when I do it quickly, I write exactly the way I feel I ought to.

How do I do it? How do I decide what to say first, what to say next?

I honestly don't know. It's just something I can do, and have been able to do all my adult life.

Can I program a computer so that it will write my book for me—so that it will choose the right words and phrases—and then have a robot type them all down? No, I can't, because I don't know what the rules I follow are, so I don't know how to program the computer.

Probably all human beings, if they are given a proper education and aren't spoiled by being set to work at lifelong dull jobs that turn their brains flabby, will have some ability or other they can't explain, and that no computer or robot will be able to imitate.

Still, suppose that as computers and robots get more complicated, they develop abilities that make it possible for them to think for themselves. What if they develop imagination without our instructing them, just as the robots in *R. U. R.* developed emotion?

Even then, it is not likely they'll be very good at it at first, and it won't be worth all the complication of computer structure that would be required.

Look at it the other way around. Every once in a while a human being is born who is a "mathematical marvel." He can multiply huge numbers in his head very quickly and solve complicated problems. Sometimes he can do it without even knowing how. Even a person who is not born with this ability can train himself into doing it pretty well if he spends a lot of time and practice at it.

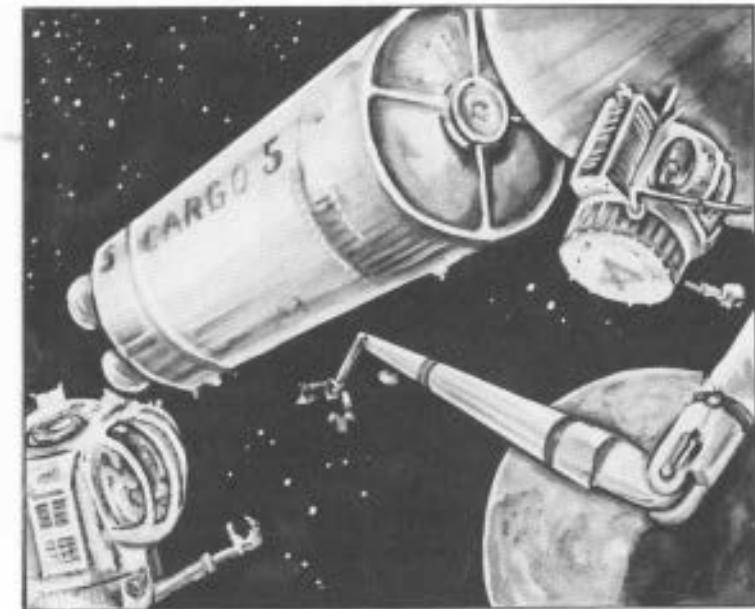
But why bother? What good is it? Even the best mathematical marvel isn't as good as a fairly simple computer. All the training in the world will make no human being better than a computer in doing mathematical problems.

And the other way around—with the human brain so easily capable of so much in the way of imagination and creativity, why should computers compete in that way?

It would be much better if human beings continued to make computers and robots better at what machines can do most easily by giving them abilities and programming to help that along.

Meanwhile, we human beings should improve ourselves at what we do best through proper education and through a deeper understanding of how our brain works. We should try to make more and more people imaginative and creative.

In this way, we may end up with two kinds of intelligence on earth, two entirely different kinds. There will be the computer/robot intelligence and the human intelligence. Each one will work in a



Robot arms reach out to receive cargo in space

different way and each will cooperate with the other.

Together the two intelligences will be able to do much more than either could alone, so that some day human beings will wonder how they ever got along without robots.