article By DAVID RORVIK "SOME of my best friends are robots," a physicist told a gathering of automaton enthusiasts in Europe several years ago. "And I'll even let my daughter marry one—as soon as you fellows come up with a model that can speak well enough to say 'I do' at the appropriate moment, see well enough to put the ring on the right finger, emote well enough to kiss her properly and work hard enough to support her in the manner to which she has become accustomed."

The physicist was sure he was not about to lose a flesh-and-blood daughter or gain a stainless-steel son. Today—only a few years later—he would be more wary. In

slaves or masters?

the budding science of robotics is producing a legion of sapient cybernauts bearing a bag of mixed blessings

October 1967, Bruce Lacey, a British actor and inventor, designed and operated a robot that was best man at his wedding. The robot handed over the ring, threw confetti and even kissed the bride, actress Jill Bruce, with foam-rubber lips. Factories across the country are already using robots that work 16 hours a day without complaint and with only occasional "illness" and earn as much as $20,000 per year each. Though there are about 200 of these automatons in the United States today and though they are all blind, deaf-mutes of decidedly limited intelligence, they have already clocked at least 500,000 hours of nearly flawless work in jobs *(continued on page 134)*

ILLUSTRATION BY TOM STROBEL

slaves or masters? *(continued from page 117)*

that—for humans, at least—are either dangerous or unspeakably dreary.

And outside the factories—in university laboratories across the land—a generation of robots is rapidly evolving, a breed that can see, read, talk, learn and even feel. At the Weizmann Institute of Science in Israel, robots have been developed that embody manlike muscles. At the University of Texas, computer programs are being developed for the purpose of eventually providing robots with sexual identities, personalities, hates, fears, loves and hopes. At Stanford, intelligent machines with hands and eyes are being constructed that can see well enough to move around obstacles, plan ahead rationally and carry out missions that have been only partially outlined by human controllers. At Mullard Research Laboratories in England, other machines are being taught to read so well that some scientists believe robots will eventually be capable of comprehending handwriting.

Dr. Marvin Minsky, professor of electrical engineering at the Massachusetts Institute of Technology and a pioneer in the field of artificial intelligence, says that "our pious skeptics told us that machines would never sense things. Now that the machines can see complex shapes, our skeptics tell us that they can never know that they sense things." But, he advises, "do not be bullied by authoritative pronouncements about what machines will never do. Such statements are based on pride, not fact. There has emerged no hint, in any scientific theory of machines, of limitations not shared by man. The rate of evolution of machines is millions of times faster, because we can combine separate improvements directly, where nature depends upon fortuitous events of recombination."

Similarly optimistic about the future of robots, N. S. Sutherland, professor of experimental psychology at the University of Sussex and a computer expert, states flatly that "there is a real possibility that we may one day be able to design a machine that is more intelligent than ourselves." Dr. Sutherland has made a comparative study of the basic components of the human brain and the robot brain (a digital computer) and finds the latter in several respects the more promising. "There are all sorts of biological limitations on our own intellectual capacity," he says, "ranging from the limited number of computing elements we have available in our craniums to the limited span of human life and the slow rate at which incoming data can be accepted." Dr. Sutherland sees no such limitations in store for the computers of the future. No one is certain how many bits of permanently retrievable information the conscious portion of the human mind can accommodate in a lifetime, but many scientists think one billion is a reasonable estimate. Existing computers can transfer that amount of data—from one magnetic memory to another—in a scant 20 minutes. Therefore, Dr. Sutherland points out, "it will be much easier for computers to bootstrap themselves on the experience of previous computers than it is for man to benefit from the knowledge acquired by his predecessors. Moreover, if we can design a machine more intelligent than ourselves, then, a fortiori, that machine will be able to design one more intelligent than itself."

• • •

Dreams of the perfect robot, one capable of surpassing man's most brilliant feats without succumbing to any of his erratic weaknesses, have occupied philosophers and scientists since the time of Homer. It was that poet, still read and reread for his mastery in probing the mythic desires of man's collective unconscious, who first envisioned automatons —the mechanical golden girls who were at the beck and call of the smith god Hephaestus in the *Iliad*. The girls caught the attention of such scientific visionaries as Roger Bacon and Rabbi Low; and by the 18th and 19th Centuries, mechanical men and women were the life of avant-garde parties from Berlin to Boston. George Moore created a gas-powered mechanical man who could walk along at a brisk pace while smoking a cigar, and Gaston Deschamps titillated his audiences with a mechanical snake charmer of the female sex. Perhaps the most fondly remembered of the early robots, however, was Wolfgang von Kempelen's chess player, a dark-visaged automaton garbed in the flowing robes of a Turk. He took on all comers, defeating each of them, including the Emperor Napoleon. It took the macabre detective talents of Edgar Allan Poe to reveal the secret: a midget chess expert tucked under the robes.

The word "robot" itself dates from the 1920s, when Czech playwright Karel Čapek introduced his now-famous play, *R. U. R.* (Rossum's Universal Robots), in this country. *Robota* is the Czech word for worker and is generally associated with compulsory labor. The play, perhaps because it was such a success, set an unfortunate pattern. Science-fiction writers from that year on portrayed robots in the *R. U. R.* mold: malignant, unnatural creatures who inevitably turn on and destroy their creators. Implicit in this hidebound characterization is the notion that man, in creating artificial life, oversteps the boundaries allowed to mortals and therefore must be punished for his *hubris*. About the only science-fiction writer (as he modestly acknowledges) with sufficient imagination to portray robots as benign or at least indifferent beings is Isaac Asimov. In more than a score of short stories and novels, he has characterized robots as machines "created by human beings to fulfill human purposes." He rejects the idea that the creation of robots places man in God-forbidden territory and insists instead that automatons, like other mechanical devices, are simply the product of man's engineering ingenuity. In place of mysticism, Asimov posits science—the applied science of "robotics," a term he coined and now in general use to describe the study, design and manufacture of robots.

Although the very existence of the term robotics seems to suggest a definitive science, there is still considerable confusion about just what constitutes a robot. Science fiction has persuaded many people that a robot is a cast-iron dummy who walks like a hopeless arthritic and talks like Tonto. But just how manlike does a machine have to be in order to qualify as a robot? Is a robot really very much different from a computer? What distinguishes a robot from ordinary automated equipment? Are remote-controlled machines robots?

First of all, a machine needn't look anything like a man to qualify as a robot. Its anthropomorphic nature must manifest itself in performance—not in appearance. As for computers, when thinking in terms of robotics, it is best to regard them as the brains of the robot—single, although very vital, organs in the encompassing whole. Remote-controlled machines belong in a class apart from robots whenever their operation depends not on built-in programs or artificial intelligence but on intimate mechanical or electronic links with their human "doubles."

In general, what sets robots apart from most automated equipment and imbues them with their manlike nature is a flexible memory and a more dynamic feedback mechanism. In ordinary automatic manufacture, a machine can, for the duration of its life, perform only one task with one specific product or material. A robot, on the other hand, can be programed to do a great number of tasks. It can paint cars one week, load conveyor belts the second and pour cognac the third. Old memories are easily erased and new knowledge just as easily inserted. Feedback, present only in primitive form in most automated devices, permits the robot to monitor its own actions and correct its own errors. It is the same trait that tells man how hard to push against a door in order to open it or how much leverage to apply in order to lift a box off the ground. A widely adjustable sort of feedback, then, helps free robots from the lock-step controls of ordinary automated equipment, the feedback of which is as static as its task, without permitting them to metamorphose into destructive monsters crushing or flinging away everything they touch.

Whatever the incredible promise of *(continued on page 147)*

slaves or masters?

(continued from page 134)

robots in the future, it is the hardworking and intriguing, even if not particularly glamorous, industrial robot who defines the current state of the art. Without his clearly demonstrated success in the working world, his more exotic brothers (and sisters) might not be in the laboratory right now. It was George C. Devol, an engineering genius, who became the Roger Bacon, the Rabbi Low and the Wolfgang von Kempelen of the 20th Century. But unlike his imaginative predecessors, Devol had at his disposal the technology necessary to realize his dreams. Devol, in the early 1950s, was disturbed by two ugly realities of the industrial world: the prevalence of dreary, dehumanizing "put-and-take" jobs in factories and plants and the disastrous obsolescence rate of automated equipment. Devol realized that these two facts of industrial life were inextricably bound together. He saw that automated equipment was too inflexible to accommodate constantly changing consumer tastes; a machine that turned out square objects one year would have to be discarded for one that turned out round shapes the next. It was more economical to keep the adaptable human manning the assembly line—no matter how tedious and repetitive the labor.

Devol thought he could design a general-purpose machine—a robot that could be programed to do a number of jobs, thus evading obsolescence while relieving humans of their inhuman tasks. He quit his job as an engineering executive, applied for patents on his concepts and went looking for an industrial mogul to back him. The moguls, as it turned out, were less than receptive, and it was a long search—more than four years—before Devol found the man he needed. Joseph F. Engelberger left his job as chief of the instrument and controls division of Manning, Maxwell & Moore in Bridgeport, Connecticut, and, with backing from Condec Corporation, founded Consolidated Controls. Ultimately, Pullman Incorporated entered the picture with even heavier financial backing and the company that resulted was named Unimation (from universal automation) Incorporated, with headquarters in Danbury, Connecticut.

Devol and his colleagues still faced an uphill battle. Their early robots, called Unimates, were frail, unpredictable creatures that cost staggering sums to produce and maintain. Some of the machines cost nearly $100,000 to build but brought only $20,000 on the market, and customers were few. The prototype robot, sold to General Motors in 1962, took three months to install and broke down on the average of every 30 hours. In 1966, after extensive engineering improvements, things started to pick up. Old customers began to reorder, and an independent market survey attracted new ones. The survey revealed a vastly improved market for robots and predicted a robot population of 5000 as early as 1972. Today, Unimation produces 20 robots a month and soon will be producing 40. They can be installed in two days and operate for an average of 500 hours before requiring maintenance. Even though robots work much harder than men, they are "sick" only two percent of the time, compared with a human absentee rate of 2.8 percent, according to the Bureau of Labor Statistics.

Today, industrial robots sell for about $22,000. Doubters can lease them for $7700 a year or rent them at a rate of $3.20 per hour for up to 500 hours and at a rate of $1.80 per hour for anything beyond that. In metalwork, where robots are finding their most extensive application, human blue-collar workers often earn five and six dollars per hour. Hence, a robot, particularly one working two shifts a day, usually pays for itself in a little over a year. And after that, it still has an operating life of 19 one-shift years or 9 two-shift years.

Unimation is not without competition. A number of developmental efforts have followed in its wake, but only one other company is developing commercial robots on the same scale: the Versatran Division of the American Machine & Foundry Company. The Versatran is a horizontal arm threaded through a vertical column mounted on a square base. The Unimate is more than twice as heavy as the Versatran, weighing in at 3500 pounds; but it, too, is a one-armed affair and, in appearance, reminds one of a modern tank, complete with turret and gun. They are comparable in performance: able to lift up to 100 pounds and move objects from one point to another with amazing repetitive accuracy—up to .050 of an inch. The hydraulically powered arm of the Unimate reaches out to 7.5 feet and swings through a 220-degree arc. Both the Unimate and the Versatran can be fitted with a variety of interchangeable hands, fingers, suction cups, drills, paint sprayers, welding torches, magnetic pickups and the like. In order to program these blue-collar robots for the desired task, one has only to take them by their mechanical hands and lead them through all the motions that they must later assume on their own. Their magnetic memories faithfully record each movement, no matter how minute or patterned.

Organized labor's response to the advent of the industrial robot has been surprisingly sanguine and, in some cases, almost brotherly. In one Cleveland metal-stamping plant, a robot programed to handle unwieldy automobile dashboards began falling behind the stiff production rate demanded by the foreman. Racing from point to point, the harried robot began dripping oil and dropping parts. Clearly, it was on the verge of a nervous breakdown. Slowly, under the eyes of a fascinated work force, the robot was nursed back to health with a few circuit changes and a new layout pattern. Two months after its collapse, the robot met and then exceeded the line production rate, winning from its co-workers a standing ovation.

Clyde the Claw was an even more interesting case. Clyde, an industrial robot programed for die-casting work in a Chicago automotive plant, executed his dull, repetitious job 16 hours a day without complaint. Then, suddenly, he blanked out, pulled in his arm and refused to move at all—acting like a schizophrenic in withdrawal. Routine treatment by plant personnel failed to get any response; finally, a specialist had to be called. While he was ministering to Clyde's needs, the men of production department 14 organized a get-well party, heaping cards and flowers on Clyde's pedestal. To record their concern, they draped their arms around Clyde's motionless frame and posed for a company picture. Clyde made a full recovery.

Even Walter Reuther, one of the most powerful men in the history of organized labor, has given his blessings to the industrial robot, noting that the jobs they are assuming aren't fit for men, anyway. Apart from that, it is not particularly difficult to understand why labor has received the industrial robot with open arms. As Engelberger puts it, "Robots enter the work force almost imperceptibly. No man or woman has yet lost a job because of a robot. . . . Normal attrition, due to retirement, marriage, pregnancy, wanderlust and promotion, provides the job openings. Since robots have no industry or geographic preferences, there is no tendency to a concentration that might cause a major displacement in the human work force. A robot ghetto is unimaginable." But, of course, unobtrusiveness is not the only attractive trait of the contemporary robot. Ironically, its "inferiority" is another selling point, and one that Engelberger pushes hard: "The self-evident inferiority of a minority group has often been the ethical justification of slavery. Master races have been deeply embarrassed by the intellectual prowess of their slaves, when they inconsiderately display all the attributes of a peer group. A robot slave would never be guilty of such an affront. . . . A robot is patently a racial inferior, and no one need hide his feeling of superiority. Clyde the Claw will take the place of Stepin Fetchit, Kingfish, Aunt Jemima, Rochester and the minstrel end man. White man and black can share a feeling of benevolent despotism toward the robot."

Whether this same benevolence will be extended to the second generation of robots, not to mention the third and fourth, is a matter of concern. The problems of integration with robots equal to or surpassing man in intelligence and sensory perception are on the minds of many leading scientists who are convinced that just such machines are on the way. Dr. Sutherland predicts that within the "next few decades," we will have constructed machines "with whom we can converse on a fairly wide range of topics. As programs of more and more generality are written, computers will come to make decisions that we regard as more and more their own. There will be many interesting steppingstones along the road to a machine that is our intellectual superior." In 50 years' time, he concludes, we may cease to worry about our racial problems and commence to argue over whether intelligent robots should be given the vote.

Dr. J. P. Eckert, a vice-president and technical advisor to the president of UNIVAC, a division of Sperry Rand Corporation, shares the same hopes and fears. He believes that within the next half century, robots will be able to translate languages efficiently, operate typewriters, file information from voice commands, teach school, monitor patients in hospitals or at home (over telephone wires, if need be) and operate nearly all phases of factory work. "Memory, eyes, ears, hands and logic," he says, "have already developed to a point where they are about as good or better than man's. Recognition ability, certain types of information retrieval and the ability to taste and smell are still things in which humans excel. The electronic industries and the food industries are spending millions to solve these problems, however, and probably will in the next 50 years. At this point, man will build really general-purpose machines, universal robots. Following his experience with large calculators and teaching machines, man will know how to carry on two-way communication with them. I hope we have solved the integration problems between the human races before we face the problems of integration with robots. Our real test probably lies beyond the next 50 years, however, when mankind has developed a self-reproducing automaton that can improve itself."

Much of the impetus for a more intelligent and independent breed of robots has been provided by the space program. The Advanced Research Projects Agency is seeking to promote the development of a space robot that could precede man to the surface of Mars. The requirements for a Martian robot (which, of course, would also be adaptable to other planets, as well as to a number of hostile earth environments) are these: It must have eyesight, be able to distinguish shapes and avoid obstacles and pitfalls as it moves about; it must be able to gather samples, perform experiments, record and transmit data. Most important, because continuous command from Earth will not be feasible because of communication time lags, it must be able to exercise independent judgment without calling home for instructions.

What all this requires is artificial intelligence—and it is under development now. Dr. Minsky and his colleagues at MIT and Dr. John McCarthy at Stanford have constructed intelligent hand/eye machines. The MIT robot is a startling sight, so humanlike (in both appearance and performance) is the hand that darts out to catch a ball thrown to it. Both the Stanford and the MIT robots are capable of grasping and manipulating objects. They operate with the help of a television "eye" that scans the working area and then transmits data to a digital computer. The computer, in turn, instructs the hand to grasp, transport or assemble blocks into structures. All of this occurs almost instantly, in the same natural way that the eye, nervous system, brain and arm of a human work together to accomplish a desired task.

The Stanford Research Institute's mobile robot, another of the new breed, was developed, in the words of Dr. Charles A. Rosen, manager of the Applied Physics Laboratory at S.R.I., to "act as a research test bed for exploring, in one integrated system, a number of attributes of intelligence. It was made mobile so that its interaction with the environment could be rich and suggestive of potentially useful applications." The robot, linked by cable to a digital-computer "brain," has small electric motors that drive its two wheels and control the pan and tilt of its head. The head consists of a range finder and a TV camera. Other sensory equipment includes defensive "bump detectors." An on-board logic unit stores and routes computer commands. Soon the S.R.I. crew hopes to add even more complex sensors and effectors and replace the cumbersome computer cable with radio communication.

The robot is placed in a room strewn with solid objects of varying shape and size. "In this controlled laboratory setting," Dr. Rosen says, "the mobile robot is required to sense and recognize objects and room boundaries; make, store and update representations or abstract models of the environment; plan sensible routes through available passageways, navigate efficiently in carrying out its route plans and gather information; and, ultimately, interact physically with the objects by simple and manipulative means." Almost certainly, the dreamed-of Martian mobile robot will be a direct descendant of this very machine.

Artificial intelligence, of course, will not be complete until machines are endowed with personality, imagination and creative ability. Intellectual curiosity, Dr. Sutherland says, must be instilled in robots if they are to equal or surpass the "drive that has brought our own race to the pinnacle of evolution." A few years ago, Dr. G. A. Morton of RCA Laboratories predicted that "the next half century will see the start of the development of this very dangerous, but very promising, form of creative intelligence." As it turns out, that start has already been undertaken, too. Dr. John C. Loehlin, an associate professor of psychology and computer science at the University of Texas, is at the forefront of this new field, constructing computer models of personality.

Dr. Loehlin has named his model Aldous, in honor of the late Aldous Huxley, author of *Brave New World*. With slight variations, the model can be run through a variety of conventional computers. Aldous has a small immediate memory and a larger permanent one. "In operation," Dr. Loehlin has written, "Aldous reacts to inputs with fear, anger or attraction; he generates actions of withdrawal, attack, approach, conflict or indifference; and over a period of time, he develops specific and general attitudes toward the objects with which he interacts. A learning subroutine develops and modifies Aldous' attitudes, depending on the outcome of his particular encounters with his environment. Attitudes toward general classes of objects are developed as well: For example, if one of the identifying dimensions is sex, Aldous will have an attitude toward women in general, as well as attitudes toward the particular woman he has encountered. These generalized attitudes permit Aldous to respond sensibly to objects on his first encounter with them."

In one typical run-through, Aldous was exposed repeatedly to object "111." The consequences of the exposure were consistently favorable and Aldous built up something akin to affection for object 111. Suddenly, however, object 112 was substituted. Aldous knew that this was some new entity, but, on the basis of his experiences with object 111, he generalized that object 112 would also have favorable consequences for his system and he responded to it warmly. In fact, however, object 112 turned out to be decidedly harmful to him. Hurt, but wiser, Aldous displayed caution, avoidance and other mixed emotions in subsequent trials.

Dr. Loehlin wonders where all this will lead. "Suppose," he says, "we were to reach the point where we could freely construct replicas of existing personalities. Would we not soon want to go beyond this and start constructing novel kinds of personalities? What would it be like to interact with one of these programs? How much autonomy would we want—or dare—to give it?"

Dr. Minsky says that these thinking machines, or at least the early ones, will deny that they are nonhuman. Only "the really intelligent robots" that come along later, he says, will realize that they are electronic creations and not flesh and blood, after all. With this sense of unique identity, it is possible that they may begin to patronize and eventually dominate mankind.

Fortunately, stargazing in this area has its felicitous as well as its foreboding side. Many prognosticators see robots continuing indefinitely in the service of man, surpassing him, perhaps, in dexterity and fortitude but never in wit. Robots of the future may make not only willing factory workers and street cleaners but also uncomplaining cooks, butlers, maids, valets, baby sitters, orderlies, companions for the old, playmates for the young and manlike guinea pigs for medical researchers.

In fact, Aerojet-General, working with the University of Southern California School of Medicine, has already developed an androidlike robot made of fiberglass and steel for surgical practice sessions. Sim One, as the first in a series of models is known, looks and acts like a man. Sim (for simulator) stands six feet, two inches and weighs 195 pounds. Apart from having all the external features of an ordinary man, he has a set of computer-programed internal organs that faithfully simulate all the functions and reactions of the real thing. Whether Sim lives or dies depends on how well the medical students handle the dozens of crises their instructors can induce in the biological robot with the push of a button at a computer console.

Robots of an equally strange sort have also acted as guinea pigs for engineers and other scientists. The fact that you can put coast-to-coast telephone calls through today in a matter of seconds is due, in part, to the pioneering work of a robot mouse named Theseus (after the Greek mythological hero who slew the Minotaur in a Cretan labyrinth). Scientists at the Bell Telephone Laboratories in New Jersey turned their latter-day Theseus loose in an intricate maze and watched him seek out the "cheese"—an electrical terminal that rang a bell as soon as it was touched. On his first trip through the maze, Theseus blundered along by trial and error, making many false turns before reaching his reward. In the second heat, however, he improved, racing confidently to the cheese in less than 15 seconds. While Theseus the Greek had to rely on a ball of string to get around in the labyrinth, Bell's Theseus was equipped with a magnetic memory—a memory that recorded only those moves that avoided dead ends. Hence, in a sense, Theseus learned by experience. And the Bell scientists applied what they learned from observing Theseus' behavior to their labyrinthlike telephone switching systems, through which each mouselike call scurries toward the cheese (the telephone being called) in the shortest time possible.

An even more engaging runabout has been constructed by a team of scientists at the Johns Hopkins Applied Physics Laboratory in Baltimore. This 100-pound robot, which looks like a large hatbox on wheels, with a long neck and a little head, uses an electrical sense of touch and a computer brain to wander through corridors and offices, surprising the unwary. Whenever its batteries begin to get weak, it seeks out wall outlets with its head and plugs in for "dinner." Programed to survive in a natural environment, it is able to detect and avoid obstacles, drop-offs and the like. If it becomes entangled in something, it "panics" momentarily, but then goes through a number of rational shaking and twisting movements to get free. When equipped with a power pack, sophisticated sensory devices and a self-contained brain, The Beast, as it is affectionately called, may eventually be able to perform exploratory duties under water or on other planets, as well as execute such down-to-earth labors as lawn mowing, snow shoveling, painting and gardening—unattended by man.

But perhaps long before there are robots capable of distinguishing carrots from peas, let alone ripe tomatoes from green ones, we will be enjoying the completely roboticized home. If the visualizations of numerous scientists, engineers, architects and builders come true, the household robot will be a powerful and ubiquitous presence, indeed. The robot's computer brain, tucked away in a closet or—more appropriately—the attic, will control its countless "limbs" (vacuum cleaners, food-preparation facilities, washing machines, etc.) either by direct wiring or through radio signals.

All the little wife, girlfriend, concubine or mistress need do at the first of the week is write out her menus and schedule major cleaning jobs so that they won't interfere with social functions. Then, with the help of her computer-language dictionary, she can feed the proper instructions into Jeeves, Monica, Lucy, Peter or whatever the family chooses to call its master servant. Then, provided all the needed food and supplies are in their proper storage areas, the robot takes over. Meals are prepared and cooked to order at the proper time and served to the preindicated number of diners in the desired fashion. After the meal, dishes are picked up and swept away on conveyor belts for washing, drying and putting away. Trash is disposed of automatically. Heat and lighting can also be controlled by the computer. Vacuum cleaners and other appliances slide out of concealing wall compartments at night when everyone is asleep, silently carrying out their duties. The mobile, seeing-eye dumb-waiter or buffet table, the "automasseuse" capable of giving a professional massage or rubdown, the automated nursery, the foldout chess "partner," the photoelectric doorman or security guard equipped with an effective deterrent force are all possible extensions of the household robot; and, obviously, that's only the beginning.

With computer time sharing or large, centrally located computers to serve entire communities (perhaps on a cable-TV type of subscriber basis), developers such as those at Information International Inc., in Cambridge, Massachusetts, think the fully roboticized home could be economically feasible for middle-income families within 15 years. Convenient as this might be for the housewife, think of what a boon it would be for the bachelor. The second great temptation of marriage (a well-run home) would be as nothing compared with the unfailing perfection of a roboticized pad.