On June 18, 1987, The Computer Museum opened a 4000 square foot exhibit entitled Smart Machines. It is the largest single exhibit the Museum has undertaken in its five year history.

Birth

The idea of a Computer Museum exhibit on artificial intelligence (A.I.) and robotics goes back to January 1985. The Museum had just re-opened in its downtown Boston site. The initial set of exhibits consisted of four galleries that were primarily historical and one gallery that dealt with a particular aspect of current technology: computer imagery. The public’s positive response to the Image Gallery encouraged us to plan another thematic exhibit. After meetings with several subgroups of the Museum’s Board of Directors and other interested people, the combination of artificial intelligence and robotics rose to the top of the list.

Why combine A.I. and robots? When deciding what should be included in the exhibit, we followed a definition of A.I. that was formulated by Marvin Minsky. In doing so, we opted in favor of exhibiting machines that performed tasks that, if carried out by humans, would have required some intelligence. Thus, our exhibit demonstrates the idea that A.I. encompasses the mental aspects of solving a problem or fulfilling a task while robots perform the physical motions required to carry out that task.

Of course, a major research goal is to merge A.I. and robotics, creating an intelligent autonomous agent. Shakeny, one of our prize robots, epitomizes this effort. It was driven by A.I. – the problem-solving program STRIPS – but was itself a robot, complete with drive mechanisms and a range of sensors.

In addition, an exhibit on A.I. and robotics serves both of the key aspects of the Museum’s mission – education and preservation – while offering a unique and entertaining experience for the visitor. The educational challenge was to demonstrate and explain a rapidly evolving subject. Furthermore, we were anxious to preserve many one-of-a-kind robots that were neglected and in danger of being lost. Within the span of a few months we assembled the world’s most comprehensive collection of research robots. Finally, we aimed to make the exhibit popular by selecting entertaining interactive A.I. programs, including several on music, art and games, and by exploiting the intimately appealing nature of robots.

Taking Off

The exhibit went through a lengthy gestation period - from January 1985 to June 1986.
at the Museum to hear a presenta
tion given by Gwen Bell and me on the new project. They subsequently announced their intention to fund the exhibit. Gordon Bell, Museum Trustee and Associate Director for Computing and Information Science at The National Science Foundation, also made a major gift towards the exhibit. By September the project’s funding was secure and a nine month countdown to the opening began.

The first task was to build up the exhibit team. Leah Hutton joined the Museum as exhibit developer for the robot section, while I concentrated primarily on the A.I. exhibits. Michael Bergman came aboard as our technical coordinator to manage the wide assortment of computers and working robots that would power the exhibits. Gwen Bell agreed to develop the historical timeline of A.I. and robots and to help catalyze the exhibit’s development. Marc Leblanc, a high school student intern, became the team’s resident hacker. Meanwhile, Tom Merrill readied the Museum workshop in preparation for actual construction of the exhibit.

We hired the office of Michael Sand, Inc., to design the exhibit. They transformed our ideas into a floorplan and a physical display system and also provided ideas for making the exhibit more inviting. WITCOM Associates was hired to create seven video programs from 24 different sources selected from over 70 original tapes that we had collected. The video program for the Smart Machines Theater was a particularly complex job because of the need to relate the video to the artifacts on display. DEC provided their studio for final editing where we created a master tape that was used to make a videodisk containing the video for the entire gallery. Michael Callahan was engaged to provide the audiovisual and electronic systems, Steve Cummings came on board to compose sound tracks, and Ripman Lighting Consultants took on the lighting and special effects for the Theater.

Formulating the Exhibit

The topics to be covered by the exhibit fell into six sections spanning A.I. and robotics and are described later in this Report.

Tom Merrill adjusting the "Frankenstein Set," based on a Maxell advertisement.

Since we believe that the core elements in our educational exhibits on computing are the engaging working displays, we put most of our effort into developing non-static exhibits. We were extremely fortunate in finding a very skilled group of volunteers to help script and program unique and dynamic exhibits for us. Joe Bates, on his way to a faculty position at Carnegie-Mellon University, offered to help us create an exhibit that would address the problem of knowledge representation in A.I. After discussing many fascinating but unworkable ideas, we came up with the plan to base a demonstration on a conversation with the intelligent computer HAL in the movie 2001: A Space Odyssey. Joe wrote the script, and Marc LeBlanc programmed it onto an interactive videodisk system provided by DEC. Another successful match was made by Randy Davis of the MIT A.I. Laboratory who brought us together with Mitchel Resnick and Franklyn Turbak. Their goal was to find a way to build a rule-based expert system that would demonstrate in an entertaining way the strengths and weaknesses of rule-based techniques. They designed Haymarket, a trio of rule-based storekeepers, each of which has its own strategy for making innocent customers pay far too much money for a box of strawberries.

Still other volunteer help was provided by several of Michael Bergman’s programmer friends: Tom Courtney programmed the object recognition demonstration, Sterling Barrett helped with the natural language interface demonstration and Steve Kuklich tailored a demonstration of how computers play games for Museum use. In addition, Bob Lee ruggedized the game West for us while Steve Foster, Warren Adam and Brian Sandberg, students from the Wentworth Institute, examined our historic robots and restored every possible degree of freedom. Finally, Curt Crittendon and Gunnell More built and programmed a sensing mobile robot.

To support the many working displays we planned, we sought the participation of numerous computer companies. We received full support from almost every company we approached. The matching of applications with available hardware proceeded step-by-step as each gift of equipment was confirmed. The 70 companies and 12 universities who contributed are listed on page 11.

Lastly, we put a great deal of effort and exhibit technology into the Smart Machines Theater with 25 historic robots on display. Each artifact comes to life on video with additional sound, light and motion effects that create an entertaining and instructive show.
The Final Push

The construction of the exhibit took place in the Museum's own workshop. Initially consisting of Tom Merrill and Joslin Fields, the workshop staff expanded in the final few weeks to include museum interpreters Wautier Habraken and George Khoure and several other staff members. Indeed, almost every member of the Museum staff and Michael Sand's office joined in the construction effort. Several groups worked right through the night in preparation for the opening. Alan Symonds (Ripman Lighting), officially in charge of the exhibit's lighting, also installed the robots from the Maxwell advertisement in between the cueing of the lighting and sound effects for the Theater. Together with his team from the American Repertory Theater, Alan lent his able hand to almost every aspect of fabrication. Many of the alchemical props used for the fantastic Frankenstein Set were provided by Boston University's chemistry department and Al Rifkin, the "mad scientist" owner of Able, the robot. Among the Museum staff, Michael Olekswagen, Linda Hinkle, Mark Hunt, Kathy Keough, Kurt Levitan, Greg Schroeder and Bonnie Turrentine volunteered many late hours assembling panels, painting, and helping in innumerable ways. Lynn Hall became the site manager, channeling all the available manpower into maximum productivity. Gwen Bell extended the number of available man-hours by providing abundant Chinese food every evening. Gordon Bell pioneered a new system for assembling the exhibit panels and installed the air conditioner in the machine room. Andre and Judith LeBlanc, Roger Glovsky, Patti Hilsis, and Laura and Victor Gregg also joined in.

The gallery was threaded with an Ethernet local area network, connecting up the MicroVAXs, Suns, Hewlett-Packard Bobcats and the Sequent computers. With so many new machines being installed and the extension of the network, we called our friends at the MIT Media Lab for help. Their resident system wizard, Henry Holtzman, obliged and in the final 48 hours up to the opening overcame seemingly insurmountable hurdles to make all the computers work in harmony.

In parallel with the concentrated effort in the gallery, our programmer friends were distributed around the building, busily adding the finishing touches: Tom Courtney (vision), Sterling Barrett (natural language frontend), Bob Lee (West), Steve Kukolich (tac-tac-toe), Jim Meahan (TALE-SPIN), Jonathan Press (grammar-checker), Mitchell Resnick and Franklyn Turbak (Haymarket), Harold Cohen (AARON), and the students from the University of Lowell (boatbuilder and log-cabin builder). Marc Raibert successfully coaxed a PDP-11/40E into life to drive his one-legged hopper. Henry Holtzman, attempting to get FranzLISP (needed to run our version of ELIZA) running on the Sequent computer in the small hours of the morning, came to a standstill because of an incompatible tape format. In desperation, we called up Thinking Machines hoping someone would be around. Sure enough, Steve Strassman was there and invited Henry over to fix the problem.

To the outside eye, the days before the opening were a scene of hopeless chaos. But to those involved in the project, there was a great sense of purpose and team spirit. Hidden skills emerged among staff, contractors and volunteers, and many friendships were established.

Barely one hour before the ribbon-cutting, Shigeo Hirose's long-awaited quadruped and snake-like Oblix arrived from Tokyo. In a final burst of activity, the crate was torn open, and these unique objects took their allotted positions in the robot theater. The sounds of the vacuum cleaners had barely retreated at the far end of the gallery as the opening speeches ended, and the ribbon was cut. Six hundred contributors and museum members swarmed into the gallery. About 400,000 lines of application code, running under 4 types of LISP, C, Basic, and Pascal, 50 robots weighing 6 tons, 25 computers, and 7 video programs came to life.

Smart Machines was open!
The unifying theme of the Smart Machines gallery is to demonstrate how machines do things that have hitherto been the province of intelligent human activity. We were determined to convey to our visitors the tremendous sophistication of the human mind and body, as well as some of the difficulties scientists face in their attempts to replicate even the simplest of human activities. The combination of A.I. and robotics was straightforward enough: we wanted to demonstrate both the mental capabilities and the physical dexterity of today's machines. This article attempts to explain how the various live exhibits selected for Smart Machines exemplify past and present trends in A.I. and robotics.

The exhibit is grouped into six sections: language understanding, knowledge-based systems, game-playing, robot sensing, mobile robots and robot arms. The historical time-line and robot theater are described in the next article.

**Language Understanding**

One of the major conclusions of A.I. research during the 1970s was that knowledge and language could not be clearly separated. The early attempts to understand or translate language on a word-by-word basis failed. However, research has continued along several lines, and progress has resulted in commercially successful products.

A grammar correction system from Houghton-Mifflin shows how much a computer can do without any knowledge of the meanings of words. Visitors can watch the grammar checker find mistakes and correct them automatically.

Unlike a grammar checker, parsing is just the first stage of a program that actually tries to understand the meaning of a sentence. In a natural language interface program, the knowledge resides in the database. However, the questions stated in English must be translated into a machine language query to the database. Our exhibit features Datatalker, a natural language interface from Natural Language, Inc. It asks visitors to type in information about themselves, which it stores. It then invites questions in plain English about previous visitors. The program's task is eased because it expects a question about something in its database. After parsing a visitor's question stated in English, the program tries to extract the sentence's meaning, and, if appropriate, converts it into instructions to search through its database for information that will answer the question. The result of the search is translated back into an English reply. Other parts of the program keep track of the dialog, deciding when responses are adequate.

To go beyond a simple question and answer conversation, computers need a much wider and deeper knowledge. The exhibit addresses this enormous problem by demonstrating some of complexities of building a real computer like HAL in the film 2001: A Space Odyssey.
Haymarket Rules for Noah Budge

IF: the stage-of-game is greetings
SAY: "Welcome to my store. Just $6.00 for this box of strawberries."
CONCLUDE: the stage-of-game is bargaining

IF: the stage-of-game is not greetings
CONCLUDE: the number-of-interactions is increased by 1
IF: the number-of-interactions is greater-than 4
AND: the input-type is not number
OR: the customer-offer is less-than $6.00
CONCLUDE: the stage-of-game is finished
THINK: one-of "That's the last straw. This bargaining is going nowhere."
"This clown has tried my patience for too long."
SAY: one-of "You're wasting my time. Get out of my store and stay out!"
"I don't need troublemakers like you. Leave my store now!"

IF: the input-type is number
AND: the customer-offer is less-than $6.00
AND: the stage-of-game is not finished
THINK: one-of "Is this customer hard of hearing?"
"This person's a bozo!"
"Another customer trying to take advantage of me."
SAY: one-of "No. I told you my price is $5.00."
"You don't hear too well. I said $5.00."
"Look, I'm busy. $6.00 is my price. Take it or leave it."

IF: the input-type is complaint
AND: the stage-of-game is not finished
THINK: one-of "Why do I get stuck with all the complainers?"
"All I ever hear are complaints."
"Looks like I have a complainer on my hands."
SAY: one-of "Come on. I have other customers waiting. Make an offer."
"Quit your complaining and make me an offer."

IF: the input-type is compliment
AND: the stage-of-game is not finished
THINK: one-of "This customer's trying to butter me up. That won't work."
"I'm sick of customers trying to sweet-talk me."
SAY: one-of "Enough flattery. Make me an offer."
"I'd rather have $6.00 than your compliments."

The eight rules that drive Noah Budge, a simple-minded storekeeper.

Knowledge-Based Systems

The greatest number of useful applications in the field of A.I. have emerged from rule-based expert systems. Several hundred expert systems perform tasks ranging from diagnosing failures on gas turbines to suggesting which pesticides to use on a particular crop. In general, a Museum should exhibit genuine examples of its subject matter. However, expert systems are tools aimed at the technical user and would be totally incomprehensible to the majority of our visitors. As a compromise, we included one "real" expert system, somewhat modified for the Museum by its author, Randy Miller. The system is Quick Medical Reference (QMR), a medical diagnosis system that...
contains descriptions of nearly 600 diseases. Visitors can browse through the system, using it like an electronic textbook indexed either by disease or by symptom. Alternatively, visitors can retrieve a patient's case, make QMR diagnose it, and compare QMR's hypothesis with one of their own.

We assembled several highly instructive and entertaining "non-real" rule-based systems to demonstrate the capabilities and internal workings of expert systems. In the Haymarket exhibit, visitors haggle with up to three different rule-based storekeepers to buy a large box of strawberries. The simplest, Noah Budge, has only 8 rules and never budges on his price. Eventually, he will kick you out of the store if you don't give him what he's asking for. Visitors can choose Ho Nin with 30 rules and Nora Logical, the sophisticated storekeeper with over 100 rules. Another rule-based demonstration is a wine-advisor. This proceeds via a two-way spoken conversation. Visitors are asked questions about the type of food planned for the meal and what their tastes are in general. They respond by speaking into a microphone. After up to 10 questions, the computer makes a specific recommendation.

Several rule-based systems dealing with the arts are also on display, including a musical score follower (right) and a drawing expert (below). The goal is to demonstrate the application of rule-based programming techniques in non-technical domains. A computer composition system by Charles Ames generates rock and jazz pieces, which it performs

An exhibit based on Roger Dannenberg's ConcertCraft program can follow a score and accompany a visitor who performs a simple tune on a keyboard. The score follower has rules that enable it to keep pace with a human performer, even if the player changes tempo and makes mistakes.

AARON is a computer program that draws pictures. The program's knowledge is internally represented by several thousand rules of the form:

IF: something is the case
THEN: do the following... 

A picture develops as AARON threads a complicated path from rule to rule. Small variations in the picture are introduced early in the composition. Since the IF part of the rules depends on what has already been drawn, the same set of rules results in entirely different pictures each time.

Harold Cohen began work on AARON in 1972. In its early phases, the program knew how to build simple forms. It constructed drawings from these forms to produce pictures that evoked an impression of landscapes populated by creatures. In recent years, Cohen has given AARON explicit knowledge about the appearance of plants and human figures. The knowledge is in the form of hundreds of rules of the form:

IF: the arm is raised
THEN: the palm is facing forward.

To produce figures that look like people rather than stuffed dolls, AARON has rules that describe posture and balance. Cohen's ambition is to give AARON the knowledge to color its pictures. He says, "It took me 20 years to learn to teach the machine to draw, and I expect it will take me another 20 to teach it how to color."
Once upon a time.... Joe was in the cave. Irving was in the oak tree. Lucy was in the meadow. The water was in the river. The honey was in the elm tree. The worm was in the ground. The fish was in the river. The hay was in the barn. The berries were in the meadow. Joe was sad. He wanted to become happy. He thought that Lucy liked him. He wanted to persuade her to kiss him. He trusted her. He didn't like her. He decided that if he gives her the hay then she might kiss him. He wanted to ask her whether if he gives her the hay then she'll kiss him. He wanted to get near her. He went to the meadow. He asked her, "Will you kiss me if I give you the hay?" She knew that he didn't trust her. She decided that if he gives her the hay then she'll tell him that he was stupid. She told him, "If you give me the hay then I'll kiss you." He wanted to get the hay. He wanted to get near the hay. He went to the barn. He took the hay. He had the hay. He wanted to get near her. He went to the meadow. He gave her the hay. She had the hay. He didn't have the hay. She was hungry. She told him, "You're stupid." He didn't like her. She wanted to satisfy her hunger. She ate the hay. She wasn't hungry. She didn't kiss him. He didn't trust her. He was afraid of her. He couldn't persuade her to kiss him. He was still sad. The End.

Visitors can challenge computer opponents in four different games. The commercially available chess-playing program SARGON III offers a strong game, boasting a rating of nearly 2200 (approaching master level play) at its highest level of play.

A tale about Joe Bird and Lucy Lamb spun by Jim Meehan's program Micro TALE-SPIN.

through a Kurzweil 250 synthesizer. After selecting a musical style and a model, such as the twelve bar blues, the program selects instruments and then composes the rhythm, assigning each note a duration that depends in part on whether it is a basic, ornamental or cadence note. Finally, pitches are selected according to a set of about 20 rules. The rules make the notes conform to the harmony, create a melody and avoid repetition. The music is surprisingly convincing.

In contrast to all the systems described above, which represent knowledge as sets of rules, TALE-SPIN is based on scripts. This program came from the work of Roger Schank's group at Yale on language understanding. TALE-SPIN is a program that generates stories with a simple "point" somewhat reminiscent of the simpler Aesop's fables. The program simulates a world of characters who do things because they have problems to solve. These consist of fulfilling simple goals, such as satisfying hunger or thirst. Visitors select a main character -- Joe Bear, Irving Bird or Lucy Lamb -- and also determine the goals and character traits of the players. The program has a model of its characters and ensures that their behavior is rational. For example, if Joe Bear is thirsty and sees a river, he will try to get to the river.

In addition to rules, knowledge can be represented as frames, semantic nets and scripts. These are illustrated by panels in the exhibit.

Game-Playing

In addition to being fun, computer games are a valuable testing ground of ways to search through enormous numbers of alternative solutions to a given problem. Typically, when people play a game, they rely on knowledge of the opponent's ability and on an understanding of what it takes to win. Machines, on the other hand, rely on searching many possible moves to determine the best outcome. Research efforts have concentrated on optimizing the search for moves in chess. One approach is to perform the search in the proper order so that unpromising avenues can be eliminated early on. Another approach seeks to give the computer knowledge about chess,
increasing its ability to "size-up" a given position. Hans Berliner and his colleagues at Carnegie-Mellon University used both approaches to build the world's strongest computer chess player. Their program, called Hitech, has custom hardware to generate and evaluate up to 200,000 moves a second. This enables it to search about 11 half-moves ahead while playing in a tournament. In addition, Hitech's board knowledge is equivalent to a search of a further three half-moves.

Visitors can also play tic-tac-toe and five-in-a-row and choose the computer's strategy to be one of look-ahead search, voting or random. The program offers graphics that give an "X-ray" view of the program's deliberations.

A checker player by David Slate can beat all but the most serious players. Finally, in the game "How the West Was Won," the computer plays two roles: opponent and tutor. This is a numbers game, designed to help children gain familiarity with arithmetic. The computer tutor analyzes one's moves and suggests possible improvements. It never scolds or repeats itself and lets the player discover the game for him or herself. This coach was developed as a robust, friendly and intelligent tutor that could work well in the home and classroom.

The computer direction assistant holds a road map of 11 square miles of Boston and Cambridge and can find the quickest route between any two points on its map. Visitors communicate directly with the computer via a touch-tone telephone. The assistant is very forgiving of mistakes and provides instructions in good, clearly-spoken English.

**Robot Sensing**

Giving robots sensory capabilities is an important part of the effort to endow robots with intelligence. A smart robot must find its way independently and cope with the unexpected. It can only begin to do this if it can sense the distance to any surrounding obstacles, feel if it is touching something, or analyze pictures taken with an onboard camera. Many of the historic robots acquired by the Museum and on display in the exhibit's Smart Machines Theater were built as experiments, allowing researchers to explore how a robot can gather and make good use of sensory data.

The Museum visitor can experiment with four robot senses: vision, hearing, touch and sonar. Human vision is so sophisticated that we hardly appreciate its complexity. For example, just consider how we can instantly recognize everyday objects, such as a tree or car, even though no two examples look alike in detail. Our vision relies on a great deal of knowledge about the world and about what we expect to see. By contrast, machines rely...
While wheels work well on roads, legs are needed to cross rough terrain. Perhaps the most spectacular demonstration in the exhibit is Marc Raibert's one-legged hopper. This robot balances itself on the move, rather like a person balancing a broom on a fingertip. A computer keeps track of its speed and position, adjusting the angle of the leg to keep the robot upright. An accompanying video shows one-legged, two-legged and four-legged running machines, as well as a series of legged walking robots.

Photo: Dan McCoy/Realtime

Ken Salisbury's three-fingered hand is featured in a video on robot hands. Built at M.I.T. in 1982, it can be instructed to hold an object with a constant force, thereby achieving a delicate but secure grasp. Feedback is obtained by means of a pressure-sensitive rubber layer that covers the fingertips.

Photo: Dan McCoy/Realtime

mainly on the details of the actual image, analyzing it first to find edges, and identifying objects by their outlines. This approach makes machines better at matching complicated abstract patterns, such as fingerprints. Part of a fingerprint recognition system used by police departments all over the world is on display. Visitors try to match a fingerprint on the screen with one of several prints displayed on the wall from famous criminals. The computer then shows how it would make the match, using the points where ridges start or fork to classify the pattern accurately.

Speech recognition systems can give computers a reasonable sense of hearing, particularly if the machine has been trained by the speaker. Visitors can use several systems, including one that can be trained to respond to the visitor's voice. Even after training, computer speech recognition is limited to a few thousand words at most and generally requires the speaker to pause briefly between each word. In both speech recognition and vision, computers have yet to match the ability of a two-year old child.

A sense of touch is needed by a robot hand when it tries to grasp a delicate object. A pressure sensitive pad mounted on the robot gripper can gauge the amount of pressure being applied. Visitors see the pressure of their fingers on a pad displayed as an array of colors on a screen.

Finally, visitors can try out a sense that humans do not have - sonar. Robots use sonar to gauge the distance to surrounding walls and obstacles. The sensor emits pulses of extremely high-pitched sound, which reflect off an object and are picked up by the detector. The sound's round trip travel time indicates the distance to the object. In the exhibit, a ceiling mounted sensor measures a visitor's height by bouncing a signal off the top of the head.

Mobile Robots

In addition to its sensing ability, an intelligent, independent robot must have a suitable drive system and be able to form and achieve goals. All the mobile robots on display in the exhibit are equipped with a drive system. Most have some form of sensing, but only Shockey seriously attempted the last and hardest requirement of forming plans and reasoning.

A mobile robot from Real World Interfaces roams around a cage, using sonar to sense and map the walls and obstacles. Visitors can try to override the robot's good sense by controlling its movement with a joystick, but it will never let itself collide with a wall. In addition, about 25 robot toys are on display and can be tried out by visitors. Most have wheels, but several can walk; some have bump sensors, or respond to claps or squeezing.
Robot Arms

Robot arms and hands attempt to replicate aspects of human manual dexterity. Arms are by far the most common type of robot. They perform a wide range of industrial tasks, from the tiny movements for assembling a wristwatch to the large powerful movements required to stack heavy cartons. In the exhibit, the real industrial arms are shown on video, and smaller, educational arms are operated by visitors.

Two robot hands are on display: the five-fingered Tomovic hand attached to the tentacle arm pictured on the front cover, and a three-fingered soft gripper from Shigeo Hirose at the Tokyo Institute of Technology.

An ingenious way to achieve responsive compliance was invented at the Draper Laboratories. Their system uses an arrangement of springs that greatly eases tasks such as putting a peg into a tightly fitting hole. With a stiff wrist, a robot would jam the peg and only make it worse by pushing harder. With the compliant wrist, however, the peg finds its way into the hole smoothly. Visitors can use a compliant wrist to try this out for themselves.

A major thrust of industrial development is to tighten the link between the design and manufacture of a product. Using a computer-aided design system, an industrial designer can create a product and then send instructions for making that product directly to a numerically controlled tool or to a robot. Visitors can experiment with this process by designing a log cabin made of Lincoln logs. When the design is complete, the cabin is constructed automatically by a pair of simulated robots on a screen. Real robots would need to be guided by a vision system to ensure that the logs were positioned accurately. This is demonstrated in an adjacent display in which a vision system guides a robot arm that assembles a toy boat from its parts. Both these displays were provided by the University of Lowell's Center for Productivity Enhancement.

The Future

The exhibit can be readily updated as new items become available. A large industrial arm has already been offered to us by Cincinnati Milacron, and we hope to be able to demonstrate an industrial application. We welcome suggestions from our members and visitors!
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Thank You!

The Computer Museum Report
The Smart Machines exhibition has two historical components. A timeline, on display at the entrance to the exhibit, chronicles the major milestones to 1979. The Robot Theatre displays a collection of historic robots through the early 1980s. This article is intended as a synthesis of these two exhibits.

Precursors

1738
Jacques de Vaucanson builds a mechanical duck to tour and raise money for the inventor's experiments for creating life artificially. The copper duck quacks, bathes, drinks water, eats grain, digests it, and voids.

1818
The book, Frankenstein, by Mary Shelley includes the first description of creating a man-made being, who becomes a fearful monster.

1900
At the Paris World's Fair, Torres y Quevedo demonstrates an electro-mechanical machine that can play selected chess end games.

1920
Karel Capek writes the play R.U.R. (Rossum's Universal Robots) in which robots are produced by an Englishman named Rossum. The name, Rossum, is derived from the Czech word for reason, while robot is a Czech word for worker. The popularity of the play led to the widespread adoption of the word robot.

1942
Isaac Asimov publishes "Runaround" in the March issue of Astounding, in which he introduces the Three Laws of Robotics.

1943
Warren McCulloch and Walter Pitts propose that the behavior of the brain can be treated as a network of neurons that behave like on-off switches.

1947
Only a year after the completion of ENIAC, the first electronic computer, Arthur Samuel proposes to build a computer to play checkers.

1948
Norbert Wiener coins the term cybernetics, a philosophical perspective for describing interacting systems in terms of exchange of information.

1949
The Debate Begins: Can Machines Think?

On June 9, at Manchester University's Lister Oration. British brain surgeon Sir Geoffrey Jefferson states, "Not until a machine can write a sonnet or compose a concerto because of thoughts and emotions felt, and not by the chance fall of symbols, could we agree that machine equals brain — that is, not only write it but know that it had written it. No mechanism could feel (and not merely artificially signal, an easy contivance) pleasure at its successes, grief when its waves fuse, be warmed by flattery, be made miserable by its mistakes, be charmed by sex, be angry or miserable when it cannot get what it wants."

On June 11, The London Times quotes the mathematician Alan Turing, "I do not see why it (the machine) should not enter any one of the fields normally covered by the human intellect, and eventually compete on equal terms. I do not think you can even draw the line about sonnets, though the comparison is perhaps a little bit unfair because a sonnet written by a machine will be better appreciated by another machine."

The Debate Begins: Can Machines Think?

The Computer Museum Report
In New York, Claude Shannon's paper to the Institute of Radio Engineers proposes two computer chess strategies that are still in use. The first is to look at all the choices up to a fixed depth and the second is to look at a selected few to greater depth.

In the 1950s robots and artificial intelligence (A.I.) started evolving along separate tracks.

1951
Turing creates a standard test to answer: "Can machines think?" If a computer on the basis of written replies to question, could not be distinguished from a human respondent, then it must be "thinking."

1954
George C. Devol, Jr., applies for the first US patent for an industrial robot. He calls it "unimation" for short.

1956
John McCarthy of Dartmouth convenes the Dartmouth Summer Research Project on Artificial Intelligence, marking the birth of the field.

1959
McCarthy creates LISP. Unlike other current programming languages, LISP is designed to work with English words and phrases. A key feature is that the data and programs are simply lists in parentheses, allowing a program to treat another program—or itself—as data. This characteristic greatly eases the kind of programming that attempts to model human thought. Frank Rosenblatt invents an ingenious evidence-weighing machine called a "Perceptron." It is supposed to recognize patterns by their parts without regard to their relationships.

In the 1960s, the Department of Defense Advanced Research Project Agency (DARPA) provides large-scale funds for artificial intelligence research at Carnegie-Mellon University, Massachusetts Institute of Technology and Stanford University.

1963
McCarthy leaves M.I.T. and founds Stanford University's artificial intelligence laboratory.

At Ramcho Los Amigos Hospital an orthotic arm is designed to aid a paralyzed person.

1961
James Skelge writes a Symbolic Automatic Integrator (SAINT) to solve elementary symbolic integration problems at the level of a good college freshman.

SAD-SAM (Syntactic Appraiser and Diagrammer—Semantic Analyzing Machine) is programmed by Robert Lindley at Carnegie Institute of Technology. The program accepts English sentences and answers questions about the facts it has stored.

SAD-SAM INPUT:
John is Mary's son.

SAD-SAM OUTPUT:
Mary's brother is John's uncle. Mary's mother is John's grandmother, etc.

1962
Engelberg founds Unimation, the first industrial robot company. The Unimate Mark II robot welcomes visitors into the Museum's Smart Machines Gallery.

Samuel's checkers program, which has the ability to learn from its mistakes, plays at the masters level.

1965
Hubert Dreyfus' paper "Alchemy and Artificial Intelligence," is published by The Rand Corporation. His assertion that "Even though machines can perform intelligent tasks, the evidence against their ever becoming able to be really, humanly intelligent is overwhelming," leads to debates and research that continue into the 1980s.

McCarthy Creates LISP

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1967
Television cameras controlled by a remote computer are added to the Stanford Cart, permitting it to follow a white line on a road.

1968
Engelberger travels to Japan and grants Kawasaki the right to build Unimates in exchange for royalties. These are the first robots built in Japan.

Bruce Buchanan and Edward Feigenbaum.

for control and hydraulic fluids for power.

Seymour Papert writes "The Artificial Intelligence of Hubert L. Dreyfus: A Budget of Fallacies." In it, he states, "It is cowardice to assure us that the computer is barred by its finite number of states from encroaching further into areas of activity... (regarded) as 'uniquely human.'"

1969
Shakey, the first integrated robot system equipped with a TV camera and other sensors, slowly roams through the rooms of The Stanford Research Institute, guided by a remote radio control of an SDS-940 computer.

The Original Stanford Arm, the first successfully electrically-powered computer-controlled robot arm, is constructed by Victor Scheinman. It is used to develop industrial assembly techniques for robots.

In the 1970s, A.I. is recognized as a computer science discipline, and industrial robots are put to work in factories around the world.

1970
200 people attend the first meeting of the International Joint Conference on Artificial Intelligence (IJCAI).

Terry Winograd integrates natural language understanding and knowledge about a world of table top blocks in SHRDLU, written for his doctoral thesis at M.I.T.

1971
France installs its first industrial robot, a Unimate, at Renault's R-5 plant to build LeCar.

Stanford Research Institute gives Shakey the ability to reason about its actions. Shakey radios information from its sonar and bump sensors to a room-sized computer (DEC PDP-10 and PDP-15), which sends back commands to move Shakey. The computer spends about half an hour to move Shakey one meter.

DARPA funds a $15 million, five-year research program to achieve a breakthrough in speech understanding.

Orn, on loan from Stanford University, Stanford, Calif.

12-jointed Tentacle Arm, on loan from Massachusetts Institute of Technology, Cambridge, MA.

In the 1970s, A.I. is recognized as a computer science discipline, and industrial robots are put to work in factories around the world.

Stanford Arm, on loan from Stanford University, Stanford, CA.

Industrial robots are put to work in factories around the world.

1972
At the University of Aix-Marseille, Alain Colmerauer develops the use of formal logic as a programming language, PROLOG.

1973
Yvrick Wilks writes the first acceptable language translator program, which produces respectable French from small English paragraphs.

1974
The first commercially available mini-computer controlled robot, T3, is produced by Cincinnati Milacron.

1975
Margie (Meaning Analysis, Response Generation, and Inference in English) is developed by Roger Schank and his students at the Stanford A.I. Laboratory.

Minsky develops the concept of frames as a convenient way to represent specific objects or concepts. Each frame consists of a name and a series of slots that describe the object's or concept's attributes. Unimation has its first profitable year.

1976
The DARPA speech goals are met by the Hearsay speech program developed at Carnegie-Mellon University under the direction of Raj Reddy. It beats DARPA's goal of understanding 90% of ordinary continuous speech using a vocabulary of 1000 words.

1979
Seven years of research on the CM-1 were spent by Moravec's refined Stanford Cart successfully traverses, without human intervention, a room strewn with chairs.

The first World Computer Chess Tournament is held.

In the USA, Robert McGhee develops a hexapod walking machine controlled by a digital computer. In the USSR, scientists develop a hexapod walker controlled by a hybrid (analog and digital) computer.

EMYCIN developed by William Van Melle, Edward Shortliffe, Bruce Buchanan, and Edward Feigenbaum is the first expert system "shell." A shell is a program that provides the framework for developing an expert system. The user supplies his own rules to build an expert system in the subject of his choice.

The software prototype has both sensing ability and intelligence.

1978
The Mars Rover project is cancelled because NASA opts for a manned space program.

GM unveils its production line, which uses a programmable universal machine for assembly (PUMA) system based on the Scheinman arm.

Hans Berliner's backgammon program wins the world championship.

Consight-I, by Steven Holland, Lothar Rossol and Michelle Ward, is able to identify and sort randomly oriented parts on a moving conveyor belt. When the parts move under two converging light beams, the beams are split in two. This pattern is detected by a computer connected to a television camera. Consight-I consists of a Vivarrm robot arm controlled by a PDP 11/45 computer. Commercial versions use an arm by Cincinnati Milacron.
CONTEMPORARY ROBOTS
FROM THE MUSEUM'S
COLLECTION

1981
Avatar represents
a breed of per-
sonal home robots
that evolved
following the
microcomputer
revolution in the
early 1980s. This
robot can move
without bumping
into things, talk
and handle objects
with its arm.

1981
One of three of
Shigeo Hirose's
robots at the
museum, the
quadraped can
perform a compli-
cated task such as
“feeling its way” up
stairs of varying
heights. It has
contact sensors on
the sides and
bottom of its feet.
When these are
touched, the quad-
ruped responds
with animal-like
reflexes. Each leg
contains an
elegant mechani-
cal device that
translates small
motor movements
inside the body
into larger move-
ments of the legs.

1981
The first direct
drive (DD) arm by
Takeo Kanade
served as the
prototype for DD
arms used in
industry today.
The electric motors
housed inside the
joints eliminate the
need for chains or
tendons used in
earlier robots. DD
arms are fast and
accurate because
they minimize
friction and
backlash.

1983
Odex is the first
commercially
available walking
robot. It can work
in dangerous
places inaccessible
to vehicles with
wheels. These
include radioac-
tive zones in
nuclear power
stations, military
battlefields, and
underground
mines. Its legs can
also serve as arms
for lifting and
moving objects.

1985
Underwater rovers
explore the ocean
depths under
remote control. The
famous Titanic
wreck was ex-
ploring by a large
rover called Argo,
but most underwa-
ter rovers are used
for routine
inspection tasks.
The Sea Rover,
designed by
Christopher
Nicholson, can
dive to depths of
up to 120 meters
and travel at 1.5
knots while
transmitting color
video pictures from
under the sea.

Direct
Drive
Arm-1

Odex-1

1981

1983

1985

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Calendar Fall 1987

Oct 4  Sunday  3 PM
Britain's First Commercial Computer, The Leo 1
John M. M. Pinkerton, McLean Pinkerton Associates
The use and design of Leo 1 will be illustrated with a period film and a talk by its chief engineer.

Oct 11  Sunday  3 PM
The Society of the Mind: A Psychological Look at Artificial Intelligence
Professor Marvin Minsky, MIT

Oct 18  Sunday  2-4 PM
Whirlwind's Genesis and Descendants
A panel discussion by the pioneers that built the Whirlwind computer at MIT and subsequently carried on the research and development at the MIT Lincoln Laboratory.

Nov 1  Sunday  3 PM
Robots: A Recapitulation of Life
Professor Hans Moravec, Carnegie-Mellon University
An illustrated lecture by one of the field's innovators.

Nov 6-8  Saturday  25th Birthday Party of Interactive Computer Games
Panel Discussions: Computer Games, Past, Present and Future
Sunday  Second International Core Wars Competition
MicroMouse Demonstrations

New From The Computer Museum Store
The New Computer Museum Slide Rule Tie Bar
The perfect gift for every math-minded man. This tie bar is based on the real thing, complete with A, C, and D scales and a moveable cursor. Handsomely finished in antique gold. $22.50 post-paid (Members $20.25)

☐ YES! I want to become a Member of The Computer Museum.
☐ $20 Student  ☐ $45 Family  ☐ $250 Sponsor
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Members receive free admission for one full year, invitations to exhibit previews, advance notice of exhibitions and lectures, invitations to members-only events, a subscription to our exciting quarterly magazine, The Computer Museum Report, and a 10% discount in the Museum Store.

Enclosed is my check made payable to The Computer Museum for $__________
or charge to:  ☐ VISA  ☐ MasterCard  ☐ American Express

Card # ____________________________ Expiration Date ____________________________

Signature ____________________________

Name _______________________________________

Address _______________________________________

City ____________________________ State ______ Zip _______________

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The Computer Museum
The Computer Museum is a non-profit 501(c)(3) foundation that chronicles the evolution of information processing through exhibitions, archives, publications, research and programs.

Museum Hours: Summer: Open daily 10 - 5, Friday 10 - 9, Winter: Open Tuesday - Sunday 10 - 5, Friday 10 - 9. Open Mondays during Boston school vacation weeks, 10 - 5. Closed Thanksgiving, Christmas, and New Years Day. Hours are subject to change.

Membership All members receive a membership card, free subscription to The Computer Museum Report, a 10% discount on merchandise from The Computer Museum Store, free admission and invitations to Museum previews. For more information contact Membership Coordinator at The Computer Museum, 300 Congress Street, Boston, MA 02210. Telephone (617) 426-2800.

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**The End Bit**

BIPER-3, designed by Hirofumi Miura and Isao Shimoyama in 1981, was the first legged machine to balance itself dynamically. Like a person, its gait relies on its own forward momentum. It has stilt-like legs and uses its hips to pick up its feet. This gives the machine a pronounced shuffling gait like Charlie Chaplin's stiff-kneed walk.

BIPER-3 can walk forward, backward, or sideways.

*On loan from the University of Tokyo, Tokyo, Japan*