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The AAAI 1999 Mobile Robot Competitions and Exhibition

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■ The Eighth Annual Mobile Robot Competition and Exhibition was held as part of the Sixteenth National Conference on Artificial Intelligence in Orlando, Florida, 18 to 22 July. The goals of these robot events are to foster the sharing of research and technology, allow research groups to showcase their achievements, encourage students to enter robotics and AI fields at both the undergraduate and graduate level, and increase awareness of the field. The 1999 events included two robot contests; a new, long-term robot challenge; an exhibition; and a National Botball Championship for high school teams sponsored by the KISS Institute. Each of these events is described in detail in this article.

The contests require entrants to tackle a set of established tasks in a competitive environment. Contests of this kind are an important forum for getting robots out of the controlled environment of the laboratory and testing their robustness. Unique this year was the lack of a "penned area" in which to hold the contests. All the contests were held in the open exhibit hall with spectators around and without any special marking of an "arena" or of the environment.

In the Scavenger Hunt, the entrants tried to locate a given list of items, just like the old party game. The objective of this contest was to create a forum for a wide variety of robotic skills to be displayed, such as object recognition, object manipulation, exploration, and mapping. University of North Dakota's RUSTY, built by Craig Eshenko, David Geise, Matt LaFary, and Mike Trosen, won first place. Second place went to Kansas State University's SLICK WILLY, done under the supervision of David Gustafson by Tim Beese, Frank Blecha, Jonathon Cameron, and Damon Kuntz. Third place was captured by University of Arkansas's ELECTRO, with Douglas Blank as the adviser and students Jared Hudson, Brian Mashburn, and Eric Roberts.

In Hors d'oeuvres, Anyone? the entrants served finger-food items at the large reception for conference attendees at the American Association for Artificial Intelligence festival. The objective was to unambiguously demonstrate interaction with the spectators. The teams' robots were encouraged to display distinctive personalities; allow two-way communication with the spectators; and, if necessary, physically nudge spectators out of the way to better serve a wide area of the room. The Hors d'oeuvres, Anyone? contest had the largest number of entrants, and each team adopted a different strategy.

Last year's winner, the team from the University of North Dakota, hoped to tightly integrate natural language processing, movement control, and vision. However, they encountered serious compatibility issues and had to revert to a less integrated method. Their success in the Scavenger Hunt provided some solace for their difficulties.

The University of South Florida team, directed by Robin Murphy with students Mark Eichenberg, Aaron Gage, Jeff Hyams, Mark Micire, Brian Minten, Min Shen, and Brian Sjoberg, collaborated with the school's theater department to create unique personalities for their pair of robots, pictured in figures 1 and 2. The dominant robot, called the BORG SHARK, was envisioned as a smarmy, aggressive character who served the food, while his helper, called the PUFFER FISH, was designed to be a shy,

Figure 1. BUTLER *the Borg Fish.*

reluctant partner who refilled the SHARK's tray when summoned. This team was the first to ever bring a sewing machine to the contest! The BORG SHARK and the PUFFER FISH received a Technical Innovation Award for conceptual and artistic design.

The University of Arkansas team, also entrants in the Scavenger Hunt, served colored candies; their goal was to learn to distinguish the spoken words *orange, brown,* and *yellow* during the competition. Their robot, ELEKTRO, asked a person to choose a color, offered the color it had heard, and then asked the person to give it appropriate feedback based on whether it had provided the correct color. Over the course of the two-hour competition, ELEKTRO's speech-recognition performance noticeably improved. ELEKTRO received a Technical Innovation Award for integrating machine learning.

The University of Southern California (USC) team, advised by Maja Mataric with students Brian Gerkey, Dani Goldberg, Monica Nicoleson, Stefan Weber, and Barry Werger, developed a human leg detector using a 180-degree laser sensor that proved to be a reliable way to locate people in the crowded conference environment. Their pair of robots, based on South Park characters, were highly mobile, audible above the din of conversation, and a favorite of the children in attendance. MR. HANKY and CARTMAN took home third place.

The Robotics Institute team from Carnegie Mellon University (CMU), directed by Illah Nourbashkh with student Chris Hardouin, located people by using pyroelectric sensors that registered changes in temperature caused by the motion of people walking nearby. This, too, proved to be a very reliable way to find people to serve. Their robot served cookies that were placed in a ring around the robot in front of its sonar sensors. As each cookie was removed, the robot could easily recognize that one had been taken. CMU's robot, called the TEXAS ALIEN WOMAN, was awarded second place.

This year's winner, the team from Swarthmore College directed by Bruce Maxwell and Lisa Meeden with students Nii Addo, Laura Brown, Paul Dickson, Jane Ng, Seth Olshfski, Eli Silk, and Jordan Wales, designed a penguin named ALFRED that had the personality of a proper English butler. ALFRED, shown in figure 3, located people to serve using vision-based motion detection and face detection. After approaching a person, ALFRED checked a database of stored images to determine whether it might have interacted with the person before. If so, it referred to the person by a given nickname used previously; otherwise, it asked for an introduction. ALFRED expected the people it served to speak properly, using *please* and *thank you* when appropriate, and scolded them when they failed to do so. When ALFRED had been in one area of the room for too long, it used a floor-level nudging device to push through the crowd.

The robot contestants were evaluated by a panel of judges consisting of Ben Kuipers, Nils Nilsson, Alan Schultz, Chris Smith, and Ben Wegbreit. This year, in addition to certificates, the contestants were awarded mobile, research robots for several categories. In each of the contests, a robot was awarded to the first and second place teams' home institutions. In addition, the Ben Wegbreit Award for Integrative Technologies was given for the best integration across multiple AI techniques; this year, the award was won by the team from Swarthmore College. The awards consisted of PIONEER mobile robots from ActivMedia and ATRV-MINI and MAGELLAN mobile robots from Real-World Interface.

The Robot Challenge

This was the inaugural year of the Mobile Robot Challenge. Our goal in establishing the challenge was to "raise the bar" by presenting the robotics community with a task that drives ongoing research and provides an effective public venue for demonstrating significant new work.

The task for robots entering the robot challenge was, in short, to attend the National Conference on AI. Robots would be initialized at the front door of the conference. From there, they had to make their way (without a map) to the conference registration desk, wait in line, register, and then proceed to a designated presentation room. On reaching the presentation area, they were to give a short presentation about themselves and answer questions.

It was not expected that any robots entering in 1999 would complete the entire challenge task: it was our hope, rather, that the challenge would provide a focus for continuing research over the next 5 to 10 years.

In 1999, two robots were entered in the challenge: OFFICEBOY2000 (OB2K) from CMU and FOOF from USC. Both robot development teams focused on the first part of the task, namely, navigating from the front door to the registration desk without a map. The teams chose interactive methods to seek help from nearby humans in achieving their goal. Because the event was held in the conference hotel, hotel guests and conference attendees were able to interact with the robots during the trials.

USC's entry, FOOF, uses an interactive, behavior-based solution to the navigation task. Their robot carries a florescent orange-colored arrow that humans can use to point it in the right direction. When the arrow is lifted from the bracket that holds it, a sensor switch notifies the robot. It then looks for the arrow and uses a reactive strategy to align with it. Once the arrow is replaced in the carrying bracket, the robot proceeds on its way in the direction provided by the human. FOOF is an Activmedia PIONEER robot equipped with a pan-tilt color camera and a speech synthesizer.

Figure 2. LEGUIN the Puffer Fish.

Humans are an often-ignored source of information about the world that robots might use to accomplish their missions. The OB2K team sought to develop a system that could exploit this resource. Primary goals in develop-

Figure 3 (left). ALFRED *the Penguin Butler.*

Figure 4 (above). OFFICEBOY2000 *Wandering through the Hotel Lobby Asking for Directions to the Registration Desk.*

ing this robot included to (1) support a high level of human interaction to enable the robot to use humans as a source of task-oriented information; (2) implement an extensible mobile robot programming architecture that integrates existing AI and robotics techniques; and (3) simplify human-robot interactions by designing a useful, amusing character.

OB2K, pictured in figure 4, was assembled from commercial off-the-shelf components, including a Nomadic Technologies' SCOUT robot, a laptop computer, and computer speakers. The robot interacts with the environment around it to complete a task. With speech synthesis and a screen-based graphic user interface (GUI), OB2K takes advantage of human-computer–interaction methods that are already familiar to most people. If lost, OB2K yells and spins until someone helps it. If confused, it finds someone to ask for help and pesters that person (in an amusing way) until he/she does.

The OB2K software architecture is based on a three-tiered approach consisting of a parser, a sequencer, and a motion controller. All information the robot learns about the world is stored in a dynamic knowledge base that is updated and referenced while the robot attempts to complete its assigned task. The robot is programmed with several low-level skills that can be executed by the motion controller. These skills are associated with tasks and actions that the robot can complete and assembled into useful plans by the robot.

To use OB2K, people type in a natural language command on a laptop-based GUI. Once the user provides enough information through the GUI to define a goal state, OB2K draws on its skill set to achieve it. OB2K parses the natural language input, then passes case frames to the sequencer to plan over. The sequencer plans the tasks it needs to complete and sends motion commands through the controller to the mobile robot platform. The architecture makes it easy to incorporate new skills so that more complex problems can be solved.

OB2K was tested on people ranging from Brazilian tourists to AI professionals during the days before the demonstration. During the challenge, the robot was able to navigate from the entrance to the registration desk. It successfully recruited humans in the area to point it in the right direction and tell it how far it was to the desk. OB2K is also able to use a map (if one is provided) to navigate to a room and carry out tasks such as delivery and monitoring of an assigned area.

OB2K was built and programmed by Rahul Bhargava, Christopher Quirk, and Daniel Robinson. Illah Nourbashkh of the CMU Robotics Institute advised the team.

The challenge contestants were evaluated by a panel of judges consisting of Henry Hexmoor, Ian Horswill, Leslie Kaelbling, Sven Koenig, and Ben Kuipers.

The Robot Exhibition

The Robot Exhibition gives researchers an opportunity to showcase current robotics and embodied-AI research that does not fit into the competition tasks. In an effort to increase awareness of the field, we hope to encourage a wide variety of robots and embodied-AI research. This year continued the trend toward novel hardware platforms and advanced high-level robotic capabilities, including human interaction.

There were three exhibits primarily showcasing novel hardware platforms: (1) SUBOT, (2) BABYCAKES, and (3) CYE.

SUBOT, by Jennifer Herron and John Spofford from Space Applications International Corporation, is a highly maneuverable spherical robot designed for indoor and outdoor reconnaissance in confined spaces (figure 5). Currently teleoperated, SUBOT will provide an excellent platform for future software development.

BABYCAKES, designed and built by undergraduates Michael Rosenblat and Morgan Simmons and graduate student Ercan Acar from CMU, is a platform to test complete coverage algorithms, with applications in land-mine recovery. BABYCAKES efficiently and completely explores unknown regions.

CYE is a new commercial robot from Probotics. CYE was designed for the household robotics market and, hence, is compact and easy to use with a GUI. Using extremely accurate dead-reckoning and calibration techniques, CYE navigates around its environment, vacuuming or pulling a wagon full of items.

On the theme of developing inexpensive high-performance robots, Tucker Balch, Jim Bruce, Anna Rillo, Sorin Achim, and Manuela Veloso from CMU showed MINNOW (figure 6). The mechanical platform is based on the commercially available CYE, controlled by the TEAMBOTS architecture (formerly called JAVABOTS). MINNOW will form the basis for research in robot teams operating in dynamic and uncertain environments.

Like TEAMBOTS, the web-based ROBOT SIMULATOR by Dan Stormont at the University of New Mexico, provides a strong foundation for developing and testing algorithmic approaches. The simulator uses VRML 2.0 and JAVA to simulate the operation of a mobile robot in a dynamic environment. The simulator allows the user to place and move objects in an office-like environment, select different robot chassis designs, and run various robot-navigation algorithms in the form of JAVA applets.

A new approach to robotics was demonstrated by Robin Murphy at the University of South Florida (USF): marsupials. Marsupial robotics research offers several unique research challenges, including control of high-mobility systems, data communications, charge docking, cooperative sensing, and cooperative motion. Murphy supervised a team of National Science Foundation–funded undergraduate women who demonstrated an urban search-and-rescue team, SILVER BULLET and BUJOLD, shown in figure 7. BUJOLD is a microrover designed for maneuverability in small spaces, carried for longer distances and over more challenging terrain inside SILVER BULLET.

IS Robotics, in collaboration with Murphy, also demonstrated a marsupial team. The team comprises an ATRV robot functioning as a mobile “base station” for an urban robot. The urban robot utilizes its unique stair-climbing locomotion mechanism to deploy from, and return to, the ATRV-mounted base station.

Figure 5. SUBOT, a Maneuverable, Indoor-Outdoor Robot.

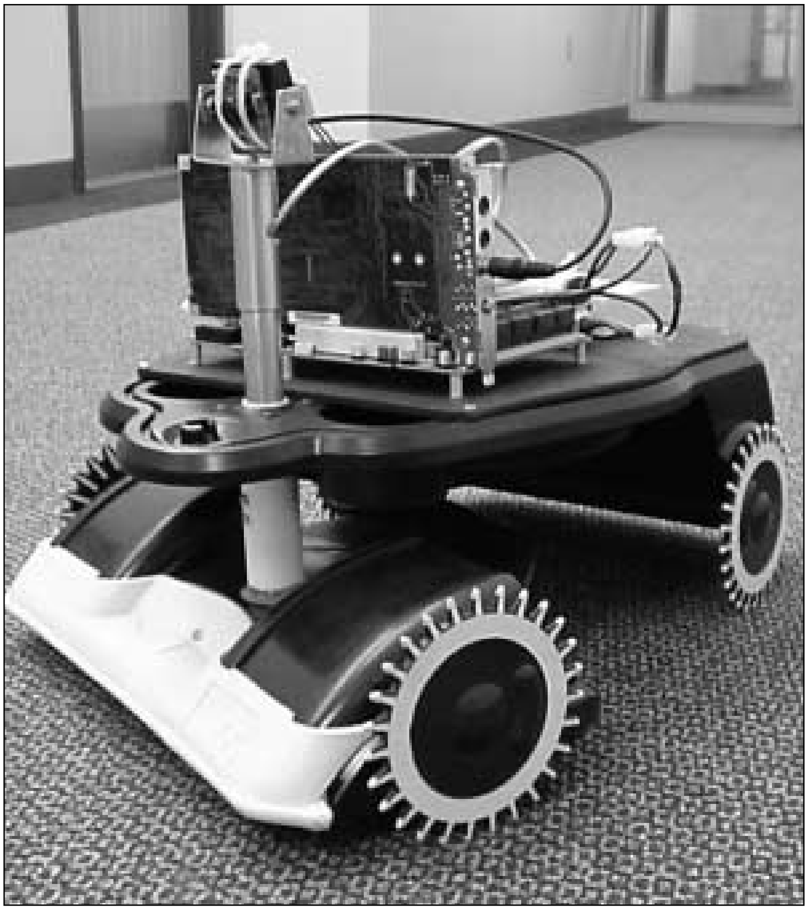

Figure 6. MINNOW, Based on CYE.

One major theme evidenced in this exhibit was an increased trend toward robot-human interactions. In the 1998 exhibit, several robots showed human-centered capabilities, and this year continued and expanded this theme.

One step toward increasingly autonomous systems was demonstrated by Darrin Bentivegna from the Georgia Institute of Technology. Bentivegna is exploring the task of learning by observation to effectively reduce system training time. He demonstrated the techniques in two domains: (1) a virtual air-hockey player and (2) a three-dimensional labyrinth game. In the labyrinth game, a player controls the movement of a marble by tilting the platform using two knobs. The object of the game is to move the marble through a maze that contains holes that the marble can fall into. After observing a particular human player, the learner will exhibit some of the human's characteristics, often exceeding his/her capabilities.

Alan C. Schultz and his team from the Navy Center for Applied Research in AI brought ROAD RUNNER, which explores adjustable autonomy. Using a PALM PILOT, the human can use different levels of control in a series of navigation tasks. ROAD RUNNER integrates research in navigation, continuous localization, exploration, map building, and path planning. The robot can move into unknown areas, build a map while it stays localized, plan paths, and adapt to rapid changes in the environment. Schultz also

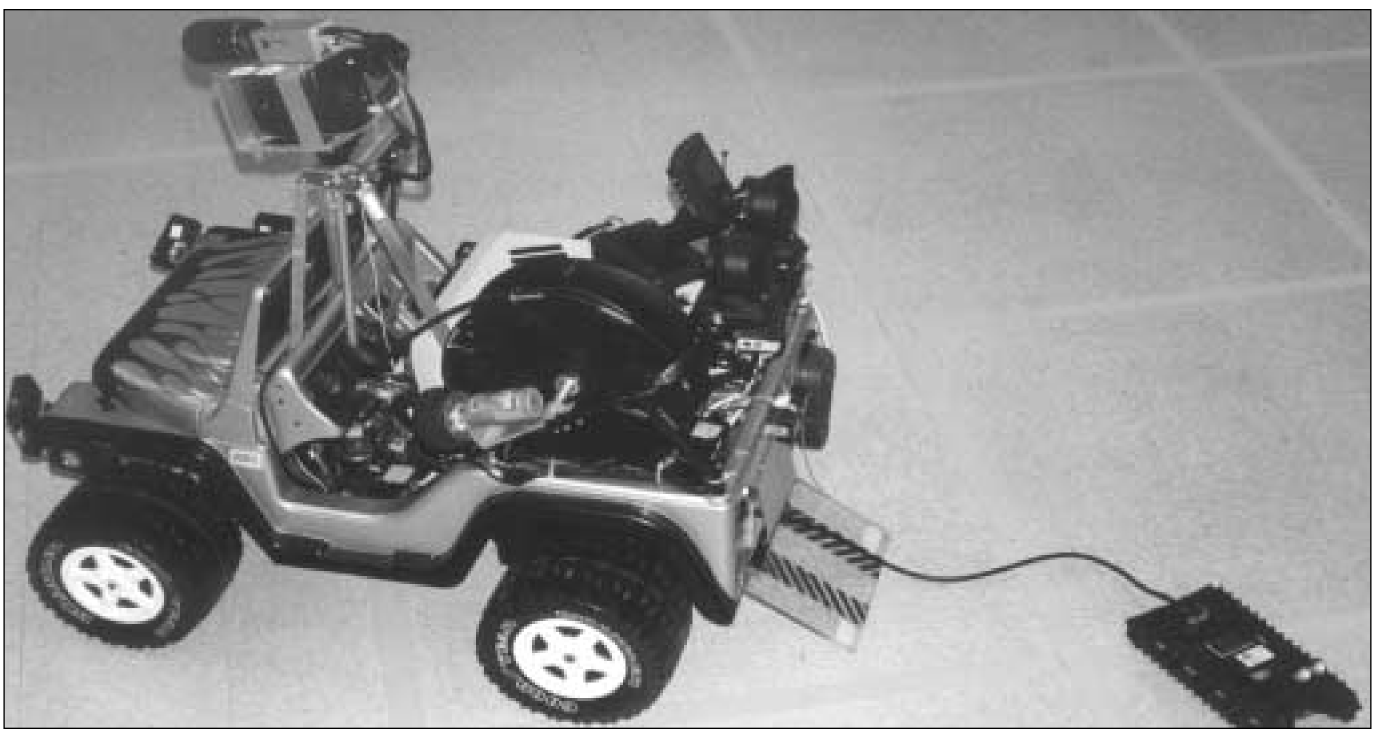

Figure 7. The Marsupial Team: SILVER BULLET and BUJOLD.

demonstrated COYOTE, a robotics research project dealing with multimodal communication. COYOTE combines a natural language–understanding component with a gesture-recognition system to allow freer human-robot interaction. COYOTE, shown in figure 8, is an important step toward full-fledged, natural communication.

Human-centered communication was also the focus of a second project from Murphy. BUTLER and LEGUIN, shown in figures 1 and 2, are a pair of highly colorful cooperating heterogeneous robots (that also entered the competition). Along with advances in the use of computer vision, sensor fusion, and dynamic sensor allocation, BUTLER and LEGUIN attempt to engage and interact with the audience. This exhibit focused on how the University of South Florida Art Department helped create "delightful" robots using interactive media and how AI constrained art and vice versa.

The final exhibit was also artistically inclined. ROBOT IMPROV, developed by Allison Leigh Bruce, Brian Magerko, and Sam Listopad under Illah Nourbakhsh's supervision at CMU, is a pair of robots that do improvisational acting. There is no predetermined script, only sets of available actions and dialog for the actors to choose from. Each play is improvised at run time. The actors use believable behavior and a high level of communication to act out dramatic plays.

The Robot Exhibit has traditionally been a place for demonstrating unusual and state-of-the-art robotic capabilities, and 1999 was no exception. The exhibits demonstrated a wide variety of embodied AI technologies, and in the years to come, we expect to see robotics making inroads into almost every aspect of day-to-day life.

Figure 8. COYOTE Recognizing Gestures.

The Botball Tournament

University students and AI professionals were not the only participants in the Robot Exhibition Hall. Seventeen high school and middle school student teams from across the country brought small, autonomous mobile robots, made from specialized robot kits, to compete in the first annual National Botball Tournament (figure 9).

Botball is a national program of the KISS Institute for Practical Robotics. It is designed to get middle and high school students excited about science, math, and technology and help them develop skills and learn more about engineering, AI, and computer science. Botball also offers a vision of a rewarding career path in technology that students might not have considered previously.

In Botball, student teams have about six weeks to design, build, and program (in c) an autonomous mobile robot about the size of a toaster. The robots must be able to play the Botball game (which changes every year) in a head-to-head, double-elimination tournament. The robots must start by themselves, play for 90 seconds, then stop by themselves. Botball also contains a separate robot design and web site creation competition.

This 1999 tournament was played on a 4- × 8-foot arena and involved each team trying to move its color Ping-Pong balls into the opponent's goal area: one point for each ball over the goal line and five points for each ball in the corner pocket. In addition to offense, many teams had their robots set up barriers to try to block their opponents from scoring.

The crowds cheered wildly at this year's National Botball Tournament, as FEMBOT, a robot created by the all-girls team from Oak Ridge High School in California boldly flung itself across the arena, Lego arms extended, shoving its Ping-Pong balls across the arena into the opponent's goal. The team from Oak Ridge gave their robot both brains and brawn (but mostly brawn), not to mention an impressive speed that helped it achieve its goals.

FEMBOT was not the only star of the show. Menlo-Atherton High School's robotics team

Figure 9. The Botball Tournament.

produced MINOTAURUS, a remarkable robot that played the game brilliantly, scooping up Ping-Pong balls in its rotating combinelike collector on one end; passing the balls into a holding chamber; seeking the goal zone; then depositing only the correctly colored balls into the high scoring position, ejecting its opponent's balls from the playing field. During the seeding rounds, MINOTAURUS achieved the maximum score all three times (no other team got the maximum even once).

What made MINOTAURUS unique among all the Botball robots was its amazing ability to play in any of several personality modes, which could be chosen at the last minute by the team members. Demonstrating a sportsmanship rarely found in the world today, MINOTAURUS could either play nicely by attempting to score points while ignoring its opponent, or it could play an aggressive game, in which it placed the wrong colored balls in its opponent's goal, causing them to have a negative score. The Menlo-Atherton team would make the appropriate attitude adjustment just before the round based on earlier observations of each opponent's strategy displayed in previous or seeding rounds.

"This has been by far my best experience in high school. By far!" exclaimed one member of the Menlo-Atherton team. The team from Menlo-Atherton, California, won the overall National Botball Championship for 1999, winning the highest combined score from seeding and head-to-head rounds. AGITATOR, from Allen D. Nease High School in Jacksonville, Florida, took second place in the overall tournament, and FEMBOT from Oak Ridge High School took third place in the overall scoring, although it came in first in the head-to-head competition.

Over 100 high school and middle school roboticists attended the Sixteenth National Conference on Artificial Intelligence (AAAI-99), participating in the national Botball Tournament. These students enjoyed mingling with the university students and professionals who were displaying their own robots. After watching these professionals, the reactions from the students varied from "Wow!" to a blasé "I can do that." For almost all the students, AAAI-99 was the first technical conference they had ever attended, and all were impressed by the experience.

Competitors	
ALFRED	www.palantir.swarthmore.edu/~jane/
BORG SHARK and PUFFER FISH	www.csee.usf.edu/robotics/
ELEKTRO	brainstem.uark.edu/mrrg/
MR. HANKY and CARTMAN	www-robotics.usc.edu/main.html
SLICK WILLY	www.cis.ksu.edu/~dag/robotics/home.shtml
Exhibitors	
BABYCAKES	www.andrew.cmu.edu/user/mr4/minesweeper.html
CYE	www.personalrobots.com/
LEARNING BY OBSERVATION	www.cc.gatech.edu/projects/Learning_Research/
MINNOW	www.cs.cmu.edu/~coral/minnow/
ROAD RUNNER and COYOTE	www.aic.nrl.navy.mil/~schultz/research/
ROBOT IMPROV	www.cs.cmu.edu/afs/andrew/scs/ri/robotimprov/www/
SILVER BULLET and BUJOLD	www.csee.usf.edu/robotics/USAR/
SUBOT	www.cis.saic.com/projects/subot/
TEAMBOTS	www.cs.cmu.edu/~trb/TeamBots/
URBIE and ATRV	www.rwii.com/rwi/
WEB-BASED SIMULATOR	www.usu.edu/~afrotc/cadre/stormont/vrml.html
Botball	
KISS Institute	www.kipr.org
General	
AAAI 2000 Competition and Exhibition	www.alc.nrl.navy.mil/~schulz/aaai2000/

Table 1. Pointers to Further Information.

Y2K Robot Events

At AAAI-2000, held at the end of July in Austin, Texas, we continued the theme of realistic environments, replacing the Scavenger Hunt contest with an Urban Search-and-Rescue contest.

Once again, a day-long workshop was held for the robot contestants and exhibitors at the close of the conference. The purpose of this workshop is to allow team members to understand and benefit from each others' efforts. Each group presented the research behind their entries. Proceedings of the 1999 and 2000 workshops are available as AAAI technical reports.

We expect even more teams in the future, and we would particularly like to encourage more international interest. Previous years have had teams from around the world.

For more information about the robots and events mentioned in this article, see table 1.

Acknowledgments

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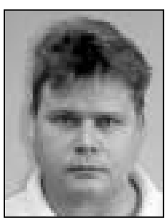
The KISS Institute conducts regional Botball Tournaments around the country, then invites all the teams to participate in the National Botball Tournament, which is hosted by AAAI, which also supplies travel grants for the top teams from each region. Other major sponsors of the 1999 Botball Program, in addition to AAAI, were NASA Goddard Space Flight Center, NASA Ames Research Center, the Education Foundation of Fairfax Virginia, and the University of Oklahoma College of Engineering.

Lisa Meeden received a B.A. in mathematics from Grinnell College in 1985 and a Ph.D. in computer science, with a minor in cognitive science, from Indiana University in 1994. She is currently an associate professor of computer science at Swarthmore College. Her primary research interests are evolutionary robotics and robot learning.

Alan C. Schultz is the head of the Intelligent Systems Section, Navy Center for Applied Research in Artificial Intelligence at the Naval Research Laboratory in Washington, D.C. His research is in the area of evolutionary computation, evolutionary robotics, learning in robotic systems, robot-human interfaces, and adaptive systems. He is the recipient of an Alan Berman Research Publication Award and has published over 40 articles on machine learning and robotics. Schultz earned his M.S. in computer science from George Mason University in 1988 and a B.A. in communications from American University in 1979. Schultz is a member of the American Association for Artificial Intelligence, the Institute of Electrical and Electronics Engineers (IEEE), IEEE Computer Society, and the Association of Computing Machinery.



Tucker Balch is a member of the faculty in the Robotics Institute at Carnegie Mellon University. He received a B.S. and a Ph.D. in computer science at the Georgia Institute of Technology. His research interests include communication and cooperation in multirobot teams. His e-mail address is trb@cs.cmu.edu.

Karen Zita Haigh is a senior research scientist at the Honeywell Technology Center in Minneapolis, Minnesota. She completed her Ph.D. in computer science at Carnegie Mellon University in the spring of 1998. For her thesis work, she built a robotic system that created symbolic task plans for asynchronous goal requests and learned from its experiences. Her current research interests include robotics, planning, and machine learning.

David P. Miller is professor of aerospace and mechanical engineering and computer science and Wilkonson Professor of Intelligent Systems at the University of Oklahoma. He is also the technical director of the KISS Institute for Practical Robotics, located in Norman, Oklahoma. He received a B.A. with honors in astronomy from Wesleyan University

and a Ph.D. in computer science from Yale University. Before joining the University of Oklahoma, he held research positions with a variety of organizations including the NASA Ames Research Center, the MITRE Corporation, the Massachusetts Institute of Technology, and the Jet Propulsion Laboratory. His general research interests are in automated planning, robotics, and communications with automated systems. For several years, he concentrated on creating control architectures that produce planful goal-directed behavior out of collections of real-time reflexive routines, and then applying this work to real-world problems. He led a team of researchers at JPL that applied these techniques to planetary rovers, which initiated a new class of low-cost planetary missions. The application area he is currently working with is assistive robotics for people who are mobility impaired. Although similar control techniques can be used, and the overarching architecture is the same, this application opens up issues of communications at the task and execution levels and management of the discourse at the different levels between the user and the robot. Through the KISS Institute, he works on outreach programs that promote computer science and engineering, especially to K–12 students.

Marc Böhlen is a graduate student in both the Robotics Institute and the School of Art at Carnegie Mellon University.

Rahul Bhargava is an assistant professor in the Department of Managerial Sciences at the University of Nevada.

Cathryne Stein is president and director of the KISS Institute for Practical Robotics.