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Overview of RoboCup-99

Silvia Coradeschi, Lars Karlsson, Peter Stone,
Tucker Balch, Gerhard Kraetzschmar, and Minoru Asada

■ RoboCup is an initiative designed to promote the full integration of AI and robotics research. Following the success of the first RoboCup in 1997 at Nagoya (Kitano 1998; Noda et al. 1998) and the second RoboCup in Paris in 1998 (Asada et al. 2000; Asada and Kitano 1999), the Third Robot World Cup Soccer Games and Conferences, RoboCup-99, were held in Stockholm from 27 July to 4 August 1999 in conjunction with the Sixteenth International Joint Conference on Artificial Intelligence (IJCAI-99). There were four different leagues: (1) the simulation league, (2) the small-size real robot league, (3) the middle-size real robot league, and (4) the Sony legged robot league. RoboCup-2000, the Fourth Robot World Cup Soccer Games and Conferences, will take place in Melbourne, Australia, in August 2000.

RoboCup-99, the Third Robot World Cup Soccer Games and Conferences, was held on 27 July to 4 August 1999 in Stockholm, Sweden. It was organized by Linköping University with the cooperation of Stockholm University, and it was sponsored by Sony Corporation, Sun Microsystems, Futurniture, First Hotel, The Foundation for Knowledge and Competence Development, The Swedish Council for Planning and Coordination of Research, The Swedish Foundation for Strategic Research, the Swedish National Board for Industrial and Technical Development, and the Wallenberg Laboratory for Research on Information Technology and Autonomous Systems.

The purpose of RoboCup is to provide a common task for evaluating different algorithms and their performance, theories, and robot architectures (Kitano et al. 1997). In this article, we focus on the scientific and technical progress made at RoboCup-99. However, because the game of soccer is quite accessible to both experts and nonexperts, RoboCup also provides an excellent opportunity for informing about, and popularizing research in, AI and robotics. About 7000 spectators are estimated to have visited RoboCup-99, and the event was covered by numerous media. A number of events helped to popularize RoboCup-99, including commented finals, an exhibition, information leaflets distributed to visitors, and the RoboCup Jr. event for children. For the benefit of an international audience, the games were web cast by the internet edition of the German magazine Der Spiegel.[1]

In the rest of this article, we describe the different leagues: the winners, the advances, the trends, and the challenges. More details can be found on the RoboCup home page,[2] in the RoboCup workshop proceedings (Veloso, Pagello, and Kitano 2000), and in the online team descriptions.[3]

In general, a significant improvement in the quality of the games could be observed in all leagues as well as a growing number of participants. No less important, the games were played in an atmosphere of great enthusiasm and sportsmanship. Figure 1 shows the award ceremony conducted on the intensive final day of the competition.

RoboCup-99 had four different leagues, each one with its specific architectural constraints and challenges. During the preliminary round, each league was divided into a number of round-robin groups of four to seven teams. The top teams in each group qualified for the elimination round, in which the ultimate winners were decided. The different leagues and several other activities of RoboCup-99 are presented here; the award winners are listed in table 1.

The Awards

Scientific Challenge Award: The Scientific Challenge Award is given each year to people or groups that have made significant scientific contributions to RoboCup. This year, three research groups—(1) University of Southern California/Information Sciences Institute (see

Figure 1. The Award Ceremony, with Some of the Winning Teams in the Center.

The Scientific Challenge Award

For automated and statistical game analysis systems and methodologies:	Information Sciences Institute, University of Southern California (ISI/USC), USA Electrotechnical Laboratory (ETL), Japan Chubu University, Japan
	Simulation League
First Place	CMUNITED-99, Carnegie Mellon University
Second Place	MAGMAFREIBURG, Albert-Ludwigs-Universität, Freiburg
Third Place	ESSEX WIZARDS, University of Essex
	Small-Size League
First Place	BIG RED, Cornell University
Second Place	FU-FIGHTERS, Free University of Berlin
Third Place	LUCKY STAR, Ngee Ann Polytechnic
	Middle-Size League
First Place	SHARIF CE, Sharif University of Technology, Teheran
Second Place	AZZURRA Robot Team, RoboCup Italia.
Third Place	CS FREIBURG, Albert-Ludwigs-Universität, Freiburg
	Legged Robot League
First Place	LES 3 MOUSQUETAIRES (LRP), Laboratoire de Robotique de PARIS
Second Place	UNSW-UNITED, University of New South Wales
Third Place	CMTRIO-99, Carnegie Mellon University

Table 1. RoboCup-99 Award Winners.

article by Raines, Tambe, and Marsella, also in this issue), (2) Electrotechnical Laboratory (see article by Tanaka-Ishii, Frank, and Arai, also in this issue), and (3) Chubu University (see article by Takahashi, also in this issue)—were awarded for the development of automated and statistical game-analysis systems and methodologies.

The Simulation League: The game takes place on a software server, and the individual players are each controlled by separate programs. Thirty-seven teams participated in this year's tournament.

*The Small-Size Real Robot L*eague (F-180): Small (18 centimeters in diameter) robots play on a Ping-Pong-table–sized field using global vision. Sixteen teams participated.

*The Middle-Size Real Robot L*eague (F-2000): Larger (50 centimeters in diameter) robots, each with their own vision system, play on a 9-3 5-meter field. Twenty teams participated.

*The Legged Robot L*eague: The teams consist of legged robots provided by Sony. RoboCup-99 is the first time a full-scale Legged Robot League has been implemented (although RoboCup-98 in Paris featured a small exhibition league.). Nine teams participated.

*The RoboCup-99 W*orkshop: One of the central activities of the event, the workshop gives researchers the opportunity to present and discuss scientific results on issues pertaining to RoboCup. This year, 20 papers and 22 posters were presented (Veloso, Pagello, and Kitano 2000).

RoboCup Jr.: RoboCup Jr. is an activity that gives children hands-on experience with advanced robotic topics. There were three parts to RoboCup Jr.: First, an Israeli team showed the use of robot soccer in high school education with a penalty-shooting robot developed by high school students (ages approximately 16–17). Second, Bandai showed a remote-controlled soccer game with two robots (each with a holding and a shooting device) on each team. Third, the LEGO Lab from the University of Aarhus arranged open sessions for children (ages 7–14) to develop their own robot soccer players and participate in a daily tournament.

Simulation League

The Simulation League continues to be the most popular of the RoboCup leagues, with 37 teams participating in RoboCup-99, which is a slight increase over the number of participants at RoboCup-98. As with RoboCup-97 and RoboCup-98, teams were divided into leagues. In the preliminary round, teams played within leagues in a round-robin fashion; a double-elimination round followed (where a team has to lose twice to be eliminated) to determine the first three teams.

Research directions in the RoboCup Simulation League are quite varied (Veloso, Pagello, and Kitano 2000). Several contributions were made independently by teams that were entered in the competition. For example, onlookers were able to observe games by way of a variety of three-dimensional visualization systems. They were also able to listen to computer-generated, real-time game commentaries. The commentaries not only described the play-by-play action but also utilized statistical analysis techniques to evaluate the strengths and weaknesses of the participating teams. Statistical analysis techniques were also used to generate newspaper-style summaries of past games, complete with hyperlinks to the highlights of relevant plays, and to make predictions regarding the scores of future matches.

In past years, a majority of the teams were still wrestling with vision, localization, and control issues. This year, several teams seemed to have solved these problems entirely and were instead focusing on player skills and team coordination. One of the most interesting technical developments concerned ball-kicking technologies.

With respect to the competition entrants themselves, there is concrete evidence that the overall level improved significantly over the previous year. The defending champion team, the CMUnited-98 simulator team, was entered in the competition. Its code was left unaltered from that used for RoboCup-98 except for minor changes necessary to update from version 4 to version 5 of the soccer simulator. In 1998, this team won all its matches and suffered no goals against. However, this year, after advancing to the elimination round, it won only one game before being eliminated. One contributing factor to this result was that the CMUnited-98 team became publicly available after RoboCup-98,[4] thus allowing competitors to verify that their teams could beat it before this year's competition. The RoboCup Simulation League has been actively encouraging participants to release their software publicly after each year's competition.

One common research focus in the Simulator League is methods for generating action decisions under real-time constraints. For example, the eventual runner-up used an action-selection method based on extended behavior networks that generated decisions very quickly. This method was used primarily for times when an agent was in possession of the ball.

It is interesting to note that different techniques are generally used for agent control when the agents are not in possession of the ball. Many teams—among those this year's champion, CMUnited-99—use the concept of flexible formations in which agents adjust their positions based on the locations of the ball and the opponents (see the article by Stone, Riley, and Veloso, also in this issue). Some research focuses on using machine-learning or linear programming techniques to allow agents to adapt their positioning based on the locations of the opponent players during the course of a game.

An interesting improvement to the soccer simulator this year was the addition of an online coach. Each team was permitted to use a single agent with an overhead view of the field that could communicate with all teammates whenever play was stopped (that is, the ball was out of bounds). At least one team took advantage of this feature to have the coach give advice to the team regarding the overall formation of the team, which could range from offensive to defensive and "narrow" (concentrated near the middle of the field) to wide.

Small-Size Real Robot League

The F-180, or Small-Size Real Robot, RoboCup League features five players on each team in matches on a field the size of a Ping-Pong table (figure 2). Each robot can extend to 18 centimeters along any diagonal and occupy as much as 180 square centimeters of the pitch. Coloring of the field, the robots, and the ball help computerized vision systems locate team players, opponents, and the ball. The robots are often controlled remotely by a separate computer that processes an image of the field provided by an overhead camera. A number of teams, however, are moving toward fully autonomous robots with their own on-board vision.

This year saw a substantial increase in the capabilities of robot soccer teams. In past years, a majority of the teams were still wrestling with vision, localization, and control issues. This year, several teams seemed to have solved these problems entirely and were instead focusing on player skills and team coordination. One of the most interesting technical developments concerned ball-kicking technologies. Nearly half of the participating teams used some sort of kicking device. One team (the FU-FIGHTERS from Berlin) was able to propel the ball so fast that observers could barely track it. Another interesting development was a new spinning technique for removing stuck balls from along the wall or in corners. One team demonstrated this technique early in the tournament, and several others quickly adopted it.

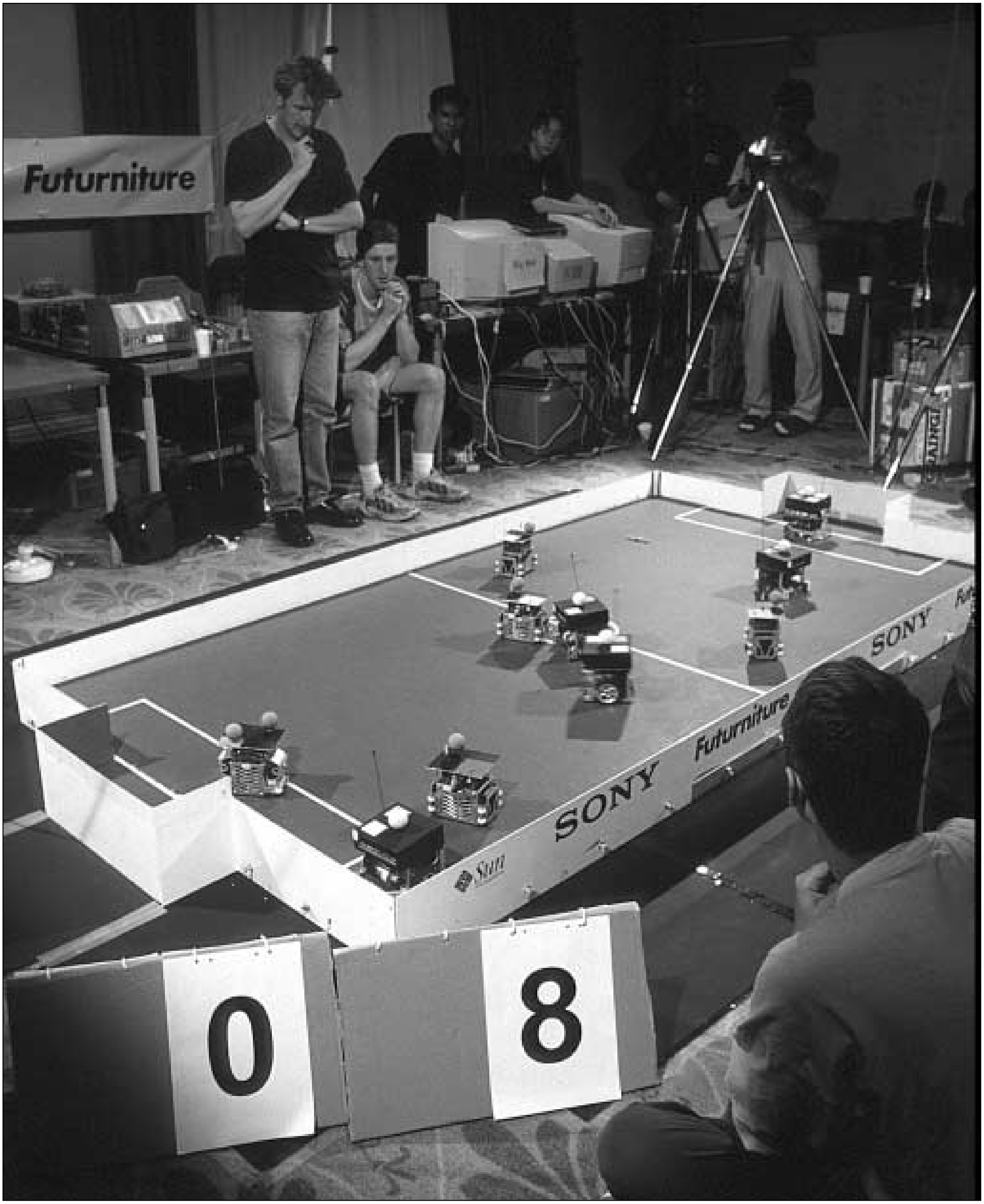

Figure 2. A Match from the Small-Size League.

The core research issues faced by RoboCup F-180 researchers include the development of individual robot skills; reliability in dynamic, uncertain, and adversarial environments; and, importantly, cooperative team coordination (Veloso, Pagello, and Kitano 2000; D'Andrea and Lee article, also in this issue). In the F-180 league, these capabilities depend significantly on engineering challenges such as reliable real-time vision and high-performance feedback control of small robots. Several teams demonstrated a mastery of the engineering challenges, but much remains to be accomplished in team coordination.

Rules for F-180 league robotic soccer continue to evolve. Of course, the long-term vision for RoboCup is participation in the real human World Cup; so, our robots must eventually be capable of play according to the Fédération Internationale de Football Association (FIFA, the World Cup rule-making body) regulations. For now, however, we adjust FIFA's rules to accommodate our robots. Examples of RoboCup adjustments to the rules include special markings to help with vision issues and walls around the pitch to keep the ball from departing the playing surface.

Overall, systems that manage to exhibit relatively few behaviors in a very robust and reliable manner seem to be more successful than more complex but less reliable systems.

Middle-Size Real Robot League

The middle-size (F-2000) tournament went very smoothly. Twenty teams participated and played 62 games, giving all teams ample opportunity to gain practical playing experience. The new rule structure for the Middle-Size Real Robot League, which is based on the official FIFA rules, proved to be successful and helped to focus on real research issues instead of rule discussions.

Just as in real soccer, robotic soccer is good for lots of surprises! Already the preliminaries presented several of them: Teams such as ATTEMPTO! (University of Tübingen, second in RoboCup-98), TRACKIES (Osaka University, third in RoboCup-98 and co-champion in RoboCup-97), or USC DREAMTEAM (USC, co-champion in RoboCup-97) suffered unexpected losses, often against surprisingly strong newcomers such as SHARIF CE (University of Teheran), CoPS Stuttgart, ALPHA++ (Ngee Ann Polytechnic, Singapore), or WISELY (Singapore Polytechnic), and did not survive the preliminary rounds. Four teams from Europe and four teams from the Middle and Far East, three of which were new entries, made it to the playoffs. Another big surprise occurred in one of the semifinal rounds, when the Italian team (ART) won over the then-undefeated champion of RoboCup-98, CS FREIBURG, in a match that required a penalty shootout and two technical challenge rounds to come up with a decision. In an exciting final game, a crowd of several hundred spectators watched how the team from the University of Teheran, SHARIF CE, defeated ART by 3 to 1.

One thing you can learn from the tournament is that hardware alone does not buy you success. Both in 1998 and 1999, the team from GMD Robots in Bonn had interesting robots, but its performance did not yet benefit from its technical capabilities. Also, the 1998 runner-up ATTEMPTO! this year had the probably most complete robot design, including both directional and omnidirectional cameras but did not get past the preliminaries. Complex hardware requires substantial time to develop adequate software that can actually exploit the hardware features. However, hardware innovation can be the foundation for success. The 1999 champion, SHARIF CE (see the article by Jamzad et al., also in this issue), benefited substantially from the agility of its robots, which arose from a combination of clever drive design and speed. Overall, systems that manage to exhibit relatively few behaviors in a very robust and reliable manner seem to be more successful than more complex but less reliable systems.

The research efforts of teams in the Middle-Size Real Robot League clearly indicate several focal points: vision, localization, and behavior engineering (Veloso et al. 2000). In the vision area, methods for fast color image segmentation have been developed. Several groups use omnidirectional cameras and developed methods for processing the respective images, in particular for self-localization and object recognition. Another interesting direction investigates approaches to vision-based self-localization, which usually extend model-based methods developed for use with other sensor modalities (laser range finders, sonars) to work with features extracted from camera images.

Perceiving the relevant objects and knowing your location are important prerequisites for generating successful soccer-playing behavior, which makes up the other major thread of research. Several teams presented methods for designing behaviors for a single player, without giving particular attention to cooperative play. A few teams started to seriously investigate methods for generating cooperative playing skills, and some already began to apply reinforcement learning techniques to this problem.

Overall, the league is in good shape. Worldwide, well over 20 teams are working on building and improving a middle-size robot team. Provided that the rules and the playing field

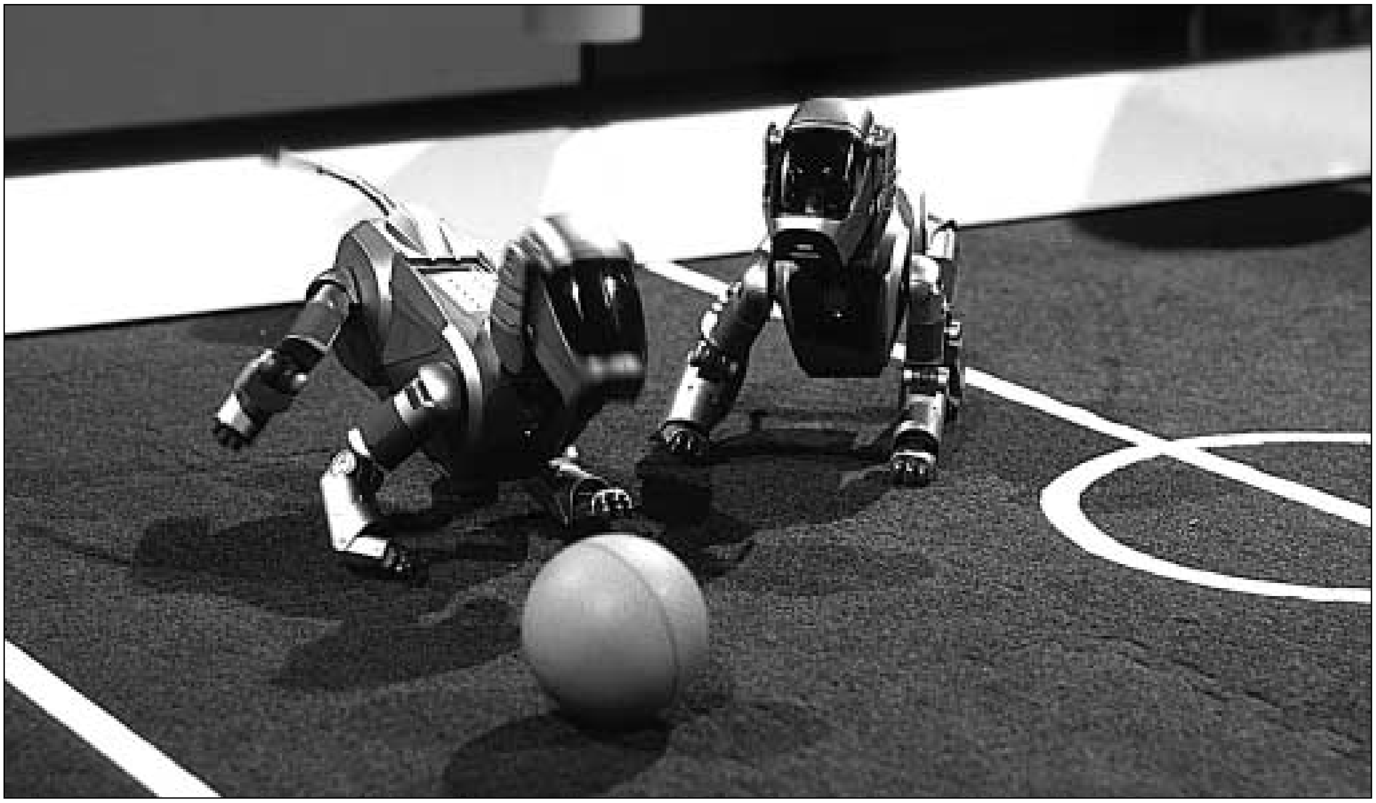

Figure 3. The Legged Robot League.

remain reasonably stable for the near future, we can expect significantly enhanced vision capabilities, much improved ball control, smoother individual behaviors, and increasingly more cooperative playing behaviors. It will be a lot of fun to watch the RoboCup-2000 and -2001 tournaments!

Sony Legged Robot League

The Sony Legged Robot League is a new official RoboCup league. Four-legged autonomous robots compete in three-on-three soccer matches (figure 3). The robot platform used is almost the same as for the famous Sony AIBO entertainment robot that was introduced into the general consumer market in July 1999, and the 5000 sets were immediately sold out (3000 sets in Japan in 20 minutes, and 2000 sets in the United States in 4 days). The main difference from the commercial version is that RoboCup teams can develop their own programs to control the robots. Because hardware modifications are not allowed, the outcomes of the games depend on whoever has developed the best software.

Exhibition games were played at RoboCup-98 in Paris, where the prototype of AIBO was used by three teams, Osaka University's BABYTIGERS, Carnegie-Mellon University's CM-TRIO98, and Laboratoire de Robotique de PARIS's (LRP) LES 3 MOUSQUETAIRES. In addition to these three seeded teams, we had six more teams competing this year, from Sweden (Stockholm, Örebro, Ronneby, and others), Humboldt University, University of Tokyo, University of New South Wales (UNSW), University of Pennsylvania, and McGill University.

There were three groups in the round-robin turn, each of which consisted of three teams, including one seeded team. All three seeded teams advanced to the final league as expected because new teams had only two months to develop and debug their programs. In addition, a wild-card spot in the final league was given to one of the teams that failed to advance in the round robin. This spot was awarded to the winner of the RoboCup Challenge. Each team had one try in three different situations to score a goal. Although none of the teams actually scored, UNSW secured the wild-card spot with its steady performance.

Because the robots easily lose sight of the ball because of the limited visual angle of the charge-coupled–device camera attached at the nose, they spend most of their time looking for the ball. Therefore, the winning teams were those that had developed image-processing programs for more robust color detection.

Most teams used the walking programs provided by Sony because of the limited time available for walking program development and/or because they preferred to focus the tactics of the game plays. A few teams developed their own walking programs, for example, LRP (see the article by Hugel, Bonnin, and Blazevic, also in this issue), which developed a stable and robust walking program, and Osaka, which developed trot walking to increase the speed of walking. These two points are highly significant when it comes to showing a good performance during the match; therefore, the newcomers seem to have been at a disadvantage. Because all developed programs are planned to be publicly accessible, the teams attending next year might be able to use these resources and improve on them. Twelve teams are expected to attend in Melbourne, Australia, in 2000.

Conclusion

RoboCup is growing and expanding in many respects. The number of participants is increasing; so is the complexity of the arrangements. A new league was introduced in 1999. The performance of the teams is clearly increasing; in many cases, the progress made can only be described as very impressive. Once more, RoboCup has proved its capacity to attract the interest of the general public and the news media. Finally, and perhaps most important of all, RoboCup continues to stimulate and generate research of a high standard in AI and robotics. In 2000, RoboCup is being played in Melbourne, Australia, in connection with the Sixth Pacific Rim International Conference on Artificial Intelligence (PRICAI-2000). There is also a European competition, RoboCup Euro-2000, in Amsterdam, The Netherlands.

Notes

1. www.spiegel.de.
2. www.robocup.org.
3. www.ida.liu.se/ext/robocup/.
4. CMUnited-98 source code is accessible from www.cs.cmu.edu/~pstone/RoboCup/CMUnited98-sim.html.

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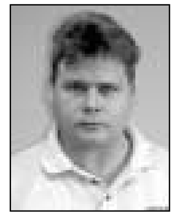
Silvia Coradeschi is an assistant professor at the Center for Applied Autonomous Sensor Systems at Örebro University, Sweden. Since 1996, she has been involved in RoboCup activities. She is a member of the board of trustees of the RoboCup Federation and was general chair of RoboCup-99. Her main research interest is in establishing the connection (anchoring) between the symbols used to perform abstract reasoning and the physical entities that these symbols refer to. She also works in multiagent systems and cooperative robotics. Her e-mail address is silvia.coradeschi@tech.oru.se.

Lars Karlsson is an assistant professor at the Center for Applied Autonomous Sensor Systems at Örebro University, Sweden. He was co-chair of RoboCup-99. His research interests include planning, agent architectures, and reasoning about actions. His e-mail address is lars.karlsson@tech.oru.se.

Peter Stone is a senior technical staff member in the Artificial Intelligence Principles Research Department at AT&T Labs Research. He received his Ph.D. in 1998 and his M.S. in 1995 from Carnegie Mellon University, both in computer science. He received his B.S. in mathematics from the University of Chicago in 1993. Stone's research interests include planning and machine learning, particularly in multiagent systems. His doctoral thesis research contributed a flexible multiagent team structure and multiagent machine-learning techniques for a team operating in real-time noisy environments in the presence of both teammates and adversaries. His e-mail address is pstone@research. att.com.



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

Gerhard K. Kraetzschmar is a senior research scientist and assistant professor in the Neural Information Processing Department at the University of Ulm. His research interests include a wide range of areas in robotics, neural and evolutionary computation, and (distributed) AI, including autonomous mobile robots, neurosymbolic integration, learning and memory, and robot control and agent architectures. His e-mail address is gkk@acm.org.

Minoru Asada received a B.E., an M.Sc., and a Ph.D. in control engineering from Osaka University, Osaka, Japan, in 1977, 1979, and 1982, respectively. In 1995, he became a professor of mechanical engineering for computer-controlled machinery at Osaka University, Suita, Osaka, Japan. Since April 1997, he has been a professor in the Department of Adaptive Machine Systems at Osaka University. He received the 1992 Best Paper Award at the IEEE/RSJ International Conference on Intelligent Robots and Systems and the 1996 Best Paper Award from the Robotics Society of Japan. He was a general chair of the IEEE/RSJ 1996 International Conference on Intelligent Robots and Systems. Since early 1990, he has been involved in RoboCup activities. His team was first place, with the University of Southern California, in the middle-size league at the first RoboCup. His e-mail address is asada@ams.eng.osaka-u.ac.jp.