RoboCup: A Treasure Trove of Rich Diversity for Research Issues and Interdisciplinary Connections

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RoboCup has been a vehicle for promoting robotics and artificial intelligence (AI) research by offering a publicly appealing but formidable challenge. One effective way to promote science and engineering research is to set a challenging long-term goal. RoboCup was founded with such a goal: "By 2050, have a team of soccer robots defeat the team of World Cup champions." Our challenging goal has been

expanded to include teams of rescue robots, those that service humans at home or in manufacturing tasks, and robotics soccer, rescue, and dancing motion challenges for educating children. Building teams of robots for environments with great uncertainty (e.g., soccer, rescue) will have significant social and economic impact, and reaching the specific soccer 2050 goal will certainly be considered a major achievement for the fields of AI and robotics.

Figure 1 shows how we have expanded the competition in terms of

leagues since 1997. We started the soccer domain with three leagues, then added Rescue, Junior, @Home, and Industry. The participating teams increased rapidly during the first 10 years, but, due to space and time limitations, the number of teams in the international global event is now limited to approximately 350–450 (see Figure 2). The main purpose of the Technical Committee (TC)-RoboCup is to share the challenges pursued by RoboCup researchers with the IEEE Robotics and Automation Society (RAS). To accomplish this, the TC-RoboCup functions

Leagues/Years	1997	1998	1999	2000	2001	2002	~2006	2007	2008	2009	~2012	~2016	2017	~2019
RoboCupSoccer														
Simulation (Sim)	Official													
Small-Size League (SSL)	Official													
Middle-Size League (MSL)	Official													
Four Legged		Exhibit.	Official							Stop				
SPL									Exhibit.	Official				
Humanoid				Exhibit.	Exhibit.	Official								
RoboCupRescue														
Simulation (Rescue-Sim)				Official										
Real Robot (Rescue-Rob)				Exhibit.	Official									
Rapidly Manufactured Robot													Official	
RoboCupJunior														
Soccer			Exhibit.	Official										
Rescue									Exhibit.	Official				
OnStage									Official					
RoboCup at home (@HOME)														
Open Platform							Exhibit.	Official						
Domestic SPL													Official	
Social SPL													Official	
RoboCup Industrial														
RoboCup Work (AtWork)											Official			
Logistics (Festo)											Official			

SPL: Standard Platform League; Exhibit.: Exhibition

Figure 1. The expansion of RoboCup leagues. (Note: The skipped years had no changes.)

as two bridges: one that connects AI and robotics communities and another that connects all TCs related to the TC-RoboCup (see Figure 3). The TC promotes soccer, rescue, and @Home competitions to show how AI and robotics technologies are working toward a society that is symbiotic with robots. This is accomplished through scientific and engineering discussions at the workshops or the organized sessions held at robotics conferences, such as the IEEE International Conference on Robotics and Automation (ICRA) and IEEE/RSJ International Conference on Intelligent Robots and the Systems (IROS), and also at AI conferences, such as the International Joint Conference on Artificial Intelligence (IJCAI) and the American Association for Artificial Intelligence (AAAI).

Research Issues

The main research topic is robot teamwork in adversarial and highly uncertain environments, a topic that has not been addressed by existing TCs. To
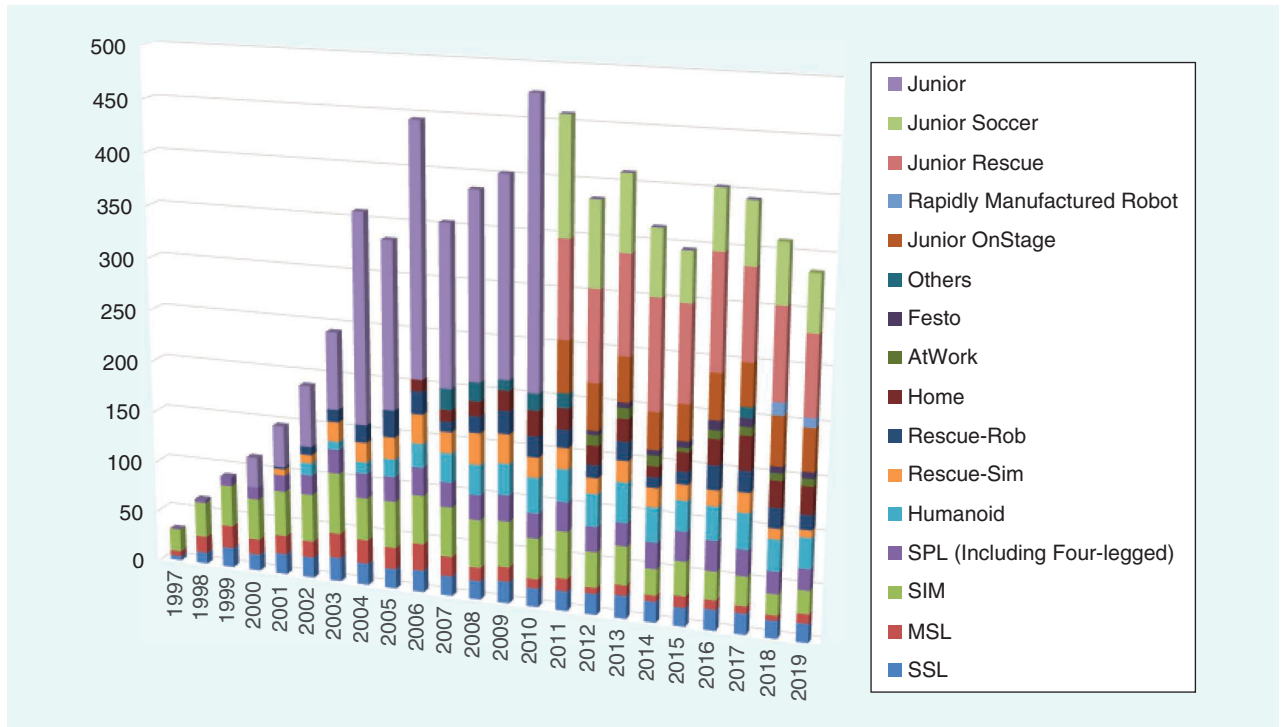

Figure 2. The rapid progress of team numbers in terms of leagues.
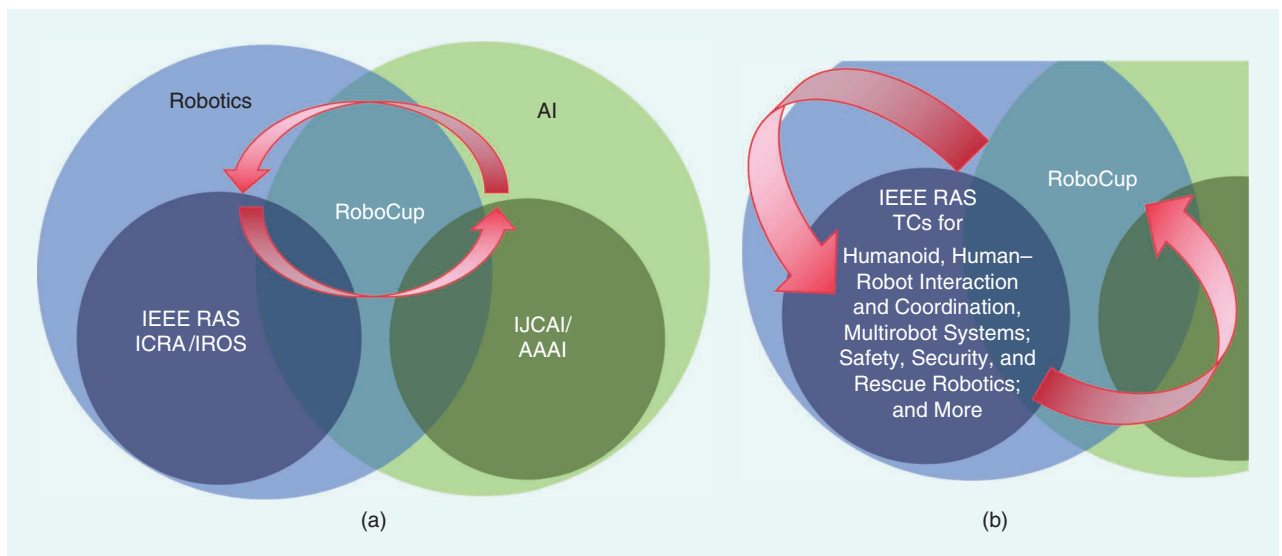

Figure 3. RoboCup as (a) a bridge between robotics and AI and (b) another bridge between other TCs.

address this, we have to solve several issues and subissues that we can share with other TCs.

- *Perception*: Vision is the main source for object recognition and tracking (a ball, goal, opponents, or common players) and self-localization. At the beginning, we used colored objects and markers to simplify the environment, but we gradually removed these constraints to create more realistic environments. The recent progress of deep learning contributed to this process [1]. Filtering the perception and integrating it with other information is crucial to analyzing the game situation. Omnidirectional vision systems have been common in the Middle-Size League (MSL) (with omnidirectional vehicles) and the early Humanoid League, too. Later, the Humanoid League prohibited the omnidirectional vision system because it has a different optic projection than that of humans.

- *Action*: In the case of wheel-based locomotion, several types of omnidirectional vehicle systems have been used in the MSL and Small-Size League, although nonholonomic vehicles (the differential gear type) were used in the early period. In these wheel-based leagues, the kicking devices, based on pneumatic or other mechanisms, have been used to shoot or pass the ball. In the case of legged locomotion, before the start of the Humanoid League, four-legged robots (such as the Sony AIBO) were used in the Standard Platform League (SPL), and heading behavior was used for the first time in RoboCup with the Sony AIBO's head. Bipedal walking is still a big challenge, and stable, but quick, motion is needed in the game. Running, jumping, and heading have not been addressed in the leagues so far. For these dynamic motions, other kinds of actuators, such as pneumatic ones rather than electric motors, should be explored. Soft robotics seems to be an area with big potential.

- *Integration and coordination*: Perception and action are not separable but should be considered together, especially in the case of robot learning. Reinforcement learning has been used from the beginning of RoboCup [2]–[4]. The optimal (fastest) gait for Sony AIBOs, obtained by a sort of reinforcement learning in real robot environments [5], [6], was used by many teams in the former SPL. Probably, deep learning will be applied to generate more sophisticated behaviors, like those of human players. Teamwork needs more cognitive reasoning, such as predicting other players' moves and communicating with teammates, which are essential for a smart team strategy.

Both online and offline learning methods are helpful.

These issues are only some of those experienced in RoboCup. All achievements in RoboCup have been published as part of Springer's "Lecture Notes in Artificial Intelligence" series every year: the first one was [7]. The latest information can be found at https://www.robocup.org. Many RAS TCs may have common issues. Therefore, we would like to push for more collaborations with other TCs.

RoboCup 2019

RoboCup 2019 was held in the Exhibition Centre at the International Convention Centre, Sydney, Australia, on 2–9 July 2019. The total number of participants was approximately 3,000, and the number of teams was 335. Figure 4 shows the venue and the competition site.

Currently, one of the most exciting competitions is the MSL game, where two strong teams have performed competitively with each other for several years: Tech United (from the Technical University of Eindhoven) and Water (from Beijing Information Science and Technology University). Figure 5 shows a shooting scene by Water (in the blue uniform). A video clip showing several combinations of passing and shooting is available at https://www.youtube.com/watch?v=_Y5_iGxWFrQ.
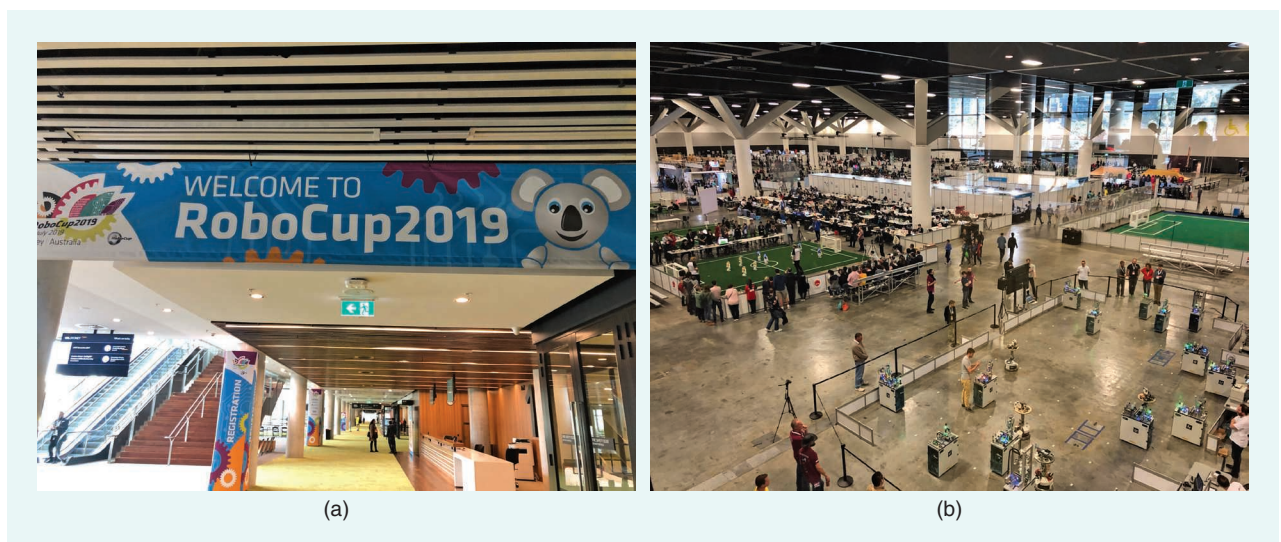

Figure 4. The RoboCup 2019 venue: (a) the RoboCup 2019 banner and (b) the competition site.

After the competitions, we exchanged information and planned for international collaboration. Figure 6 shows some younger participants of Robo Cup 2019.

RoboCup Visiting Fellows Program

Based on the beliefs that 1) RoboCup is a unique and special community and venue within the research community and 2) the only way to fully appreciate what it has to offer is to experience it firsthand, in 2019, the RoboCup Federation announced the new RoboCup Visiting Fellows Program. Successful applicants received travel support to attend the 2019 international RoboCup in Sydney. In addition, they received a promise of reimbursement for some start-up expenses needed to organize a new team for entry in 2020 and/or 2021 RoboCup events. While at RoboCup 2019, they received detailed, behind-the-scenes education about how the RoboCup community works including meetings with current organizers and participants.

Our call for applicants included university faculty and Ph.D. or post-doctoral students who had never participated in RoboCup and were interested in becoming involved in the community. We specifically encouraged applicants from underrepresented groups within the RoboCup community, with a focus on gender, ethnicity, or geography. We selected two pairs of applicants from more than 25 as our inaugural visiting fellows: one from the University of Washington, Seattle, and the other from Democritus University of Thrace, Greece. We anticipate issuing another

Figure 5. A shooting scene by the Water team.

Figure 6. The participants of the RoboCup 2019 @Home education event.

call for applicants to the Visiting Fellow Program for RoboCup 2020.

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INDUSTRY ACTIVITIES *(continued from page 98)*

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