The Present and the Future of Cognitive Robotics

By Alessandra Sciutti, Michael Beetz, Tetsunari Inamura, Ayorkor Korsah, Jean Oh, Giulio Sandini, Shingo Shimoda, and David Vernon

There is an increasing demand for robots capable of safely interacting with individuals in everyday scenarios. This necessitates their ability to comprehend human behavior, predict future actions, and respond accordingly. This is precisely the focus of the field known as *cognitive robotics*. Cognitive robots can learn from experience and others, retain and retrieve relevant knowledge and skills, and employ this knowledge to make informed decisions while considering the consequences. They can reason about their actions and modify their behavior to improve their effectiveness. In short, cognitive robots are capable of flexible, context-sensitive action, knowing what they are doing and why they are doing it [1].

The potential application of cognitive robotics can be seen in all of the fields where effective interaction with the environment and natural human–robot collaboration are needed. The ability to learn from experience, anticipate the consequences of the robot's and the others' actions, and generalize already acquired concepts are, in fact, the basis of successful interaction with humans (Figure 1). Another potential application of cognitive robotics is robot manipulation in everyday activities (Figure 2), where cognition would, for instance, grant the possibility to assign a task to the robot in the same terms we would use for a human partner, conveying just the essence of the goal without having to specify exactly how that task is to be carried out.

Overall, cognitive robotics has the potential to revolutionize various industries and improve our daily lives by creating intelligent machines that can perceive, learn, reason, and interact with us in safe and helpful ways (Figure 3). This could lead to advances in health care by providing personalized assistance and enhancing manufacturing processes, search-and-rescue operations, and education.

TECHNICAL COMMITTEE ACTIVITIES

The IEEE Robotics and Automation Society (RAS) Technical Committee for Cognitive Robotics (TC-CoRo) was established in 2014 to advance the field of cognitive robotics and solidify its significance. This committee aims to bridge robotics, cognitive science, artificial intelligence (AI), medicine, and human sciences. It promotes methodologies and tools necessary for cognitive robotics, emphasizing industrial and social applicability.

TC-CoRo is currently cochaired by five researchers and three emeritus cochairs from different regions of the world, genders, and seniorities. The committee members engage in invited talks, journal editorial boards, and conference program committees to promote cognitive robotics and strengthen the community.

FIGURE 1. The robot understands the need of the human partner (i.e., finding her ringing mobile phone), anticipates her request for help, and selects the most appropriate way to support her by using intuitive communication to direct her attention to the desired object. (Source: Photo by Laura Taverna, IIT; used with permission.)

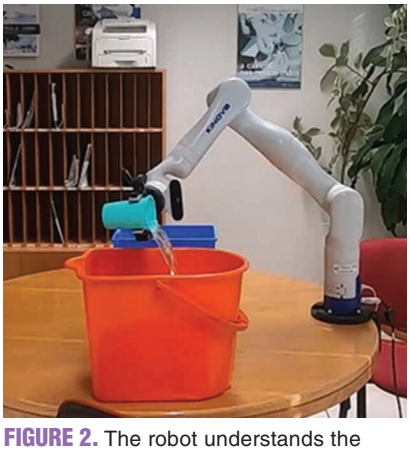

FIGURE 2. The robot understands the object's physical properties and selects the most appropriate kinematics and manipulation action. Details are provided in [5]. (Source: Photo by Linda Lastrico, IIT; used with permission.)

FIGURE 3. The robot safely coordinates with the partner in an interaction involving an exchange of forces and tool use. (Source: Photo by Laura Taverna, IIT; used with permission.)

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Furthermore, the committee organizes workshops and conferences to foster discussions on the challenges and opportunities in the field. These events facilitate knowledge exchange with researchers from various disciplines. TC-CoRo utilizes a moderated mailing list (all-coro-tc@ieee-coro.org) and a dedicated website (https://www.ieee-ras.org/cognitive-robotics) for sharing relevant announcements, resources, and links to notable events and publications. For these contributions to the field, TC-CoRo has received recognition, such as the RAS Most Active Technical Committee Award in 2017.

Recent activities include an online roundtable, organized by Shingo Shimoda, discussing the role of the next generation of cognitive robotics. The insights from the panelists led to a review article highlighting information generalization, active sensing, prediction, and language as essential functions for future cognitive robots [2]. Several events, such as workshops and panel discussions, have further stimulated the discourse, exploring foundational questions as in the TransAIR Virtual Workshop on Cognitive Architectures for Robot Agents (https://transair-bridge.org/workshop-2021) and the International Foundation for Robotics Research Colloquium on Cognitive Robotics (http://ifrr.org/cognitive-robotics). Also, the centrality of cognitive robotics in applications, like creativity in AI and robotics as well as autonomous driving, has been discussed in several events organized at various conferences (such as Robotics: Science and Systems 2021 and the International Joint Conference on AI 2022).

The committee actively supports conferences, workshops, and journals related to cognitive robotics. In particular, TC-CoRo participates in the Steering Committee of *IEEE Transactions on Cognitive and Developmental Systems* after contributing to its launch in collaboration with the IEEE Computational Intelligence Society. The members of the TC have also been active in the organization and technical support of several editions of the IEEE International Conference on Development and Learning and Epigenetic Robotics, a multidisciplinary conference targeting researchers in robotics, psychology, and human science. The different communities are united by the joint goal of further understanding human development and learning systems and creating robots inspired by the human cognitive system.

The committee's efforts extend to education and dissemination. The members develop educational materials and courses such as the course "Design and Implementation of Cognition-Enabled Robotic Systems" by Michael Beetz, David Vernon, and Joern Syrbe (available on the German open KI Campus platform: https://ki-campus.org/courses/cognitionrobot-ub2021) and the introductory course "Cognitive Robotics" by David Vernon (developed with the support of the IEEE RAS Program for Creation of Educational Material in Robotics and Automation and freely accessible at http://www.cognitiverobotics.net/). Additionally, the committee members have created multiple materials for dissemination aiming to broaden knowledge and interest in the field.

> "COGNITIVE ROBOTS ARE IN THE PROCESS OF BEING BETTER EQUIPPED TO COMPREHEND AND INTERPRET HUMAN LANGUAGE, ENABLING EFFECTIVE COMMUNICATION AND INTERACTION IN DIVERSE CONTEXTS."

The TC continues to actively promote education on cognitive robotics. For example, to communicate with policymakers and the public on the recent progress of robotics technologies and their impacts on future education, the committee members joined in a panel discussion with education specialists of the Organisation for Economic Cooperation and Development in a special meeting co-located with this year's IEEE International Conference on Robotics and Automation conference. They provided input to help assess current AI and robotics technologies.

TC-CoRo cochairs and members also organize periodic events dedicated to education, such as the Everyday Activity Science & Engineering (EASE) Fall School for cognition-enabled robot manipulation, held yearly in Bremen. Important books and book chapters on cognitive robotics have been published by the members of the TC and by the cochairs as, for example, the book *Cognitive Robotics* [3]. In addition, the cochairs appointed two Distinguished Lecturers, Friederike Eyssel (Bielefeld University) and Yukie Nagai (University of Tokyo).

The committee has also been proactive in engaging the wider public, particularly children and girls, through participation in public events and the creation of dedicated educational materials (e.g., free downloadable educational children's books on cognitive robotics, such as the book series *Finja Finds It Out Again!* and the title *The Mysterious Robot* for school pupils in grades 3–6, designed by the collaborative research center EASE) or virtual interactive online experiences providing insights on the actual capabilities of current cognitive robots e.g., "Trip in the Mind of a Robot" (in Italian, with English subtitles), first presented at the Genoa Science Festival by the Italian Institute of Technology (IIT): https://short.iit.it/contact. TC cochairs also organize enrichment programs (https://ashe.si/aix) and workshops for high school students to promote robotics and attract more women to science, technology, engineering, and mathematics fields.

In addition, in recent years, the committee members have been utilizing robotics competitions (Figure 4) to integrate student education to broaden the cognitive robotics research community. The TC members have been continuously participating in the @Home League of RoboCup (https://athome.robocup.org/) and World Robot Summit competition [4], which test the interactive intelligence performance of robots designed to assist with everyday life tasks. Through these competitions,

research is conducted on standard setting for evaluating interactive intelligence between robots and users. These discussions are advancing toward standardizing performance assessment guidelines in cognitive robotics. Moreover, the barriers to research participation are lowered by making openly available the hardware (Toyota HSR): http://humansupportrobot.org/ and software for the cyberphysical system: https://github.com/SIGVerse/sigverse_unity_project/wiki needed to participate in these competitions.

CHALLENGES AND FUTURE DIRECTIONS

Cognitive robotics has witnessed remarkable advancements in recent years, with three notable innovations setting the base for future developments. First, there is an increasing emphasis on *adopting an architectural approach* to facilitate human–robot interactions, enabling robots to operate autonomously and sustain long-term engagements. This approach focuses on creating frameworks that support effective interaction with the environment and seamless and meaningful exchanges between humans and robots. Second, significant progress in *integrating machine learning techniques with model-based approaches* in cognitive robots is being made. This amalgamation can lead to enhanced perception, decision making, and learning capabilities, empowering robots to adapt and respond intelligently to dynamic environments. Finally, there has been notable headway in *language understanding and acquisition* within real-world settings. Cognitive

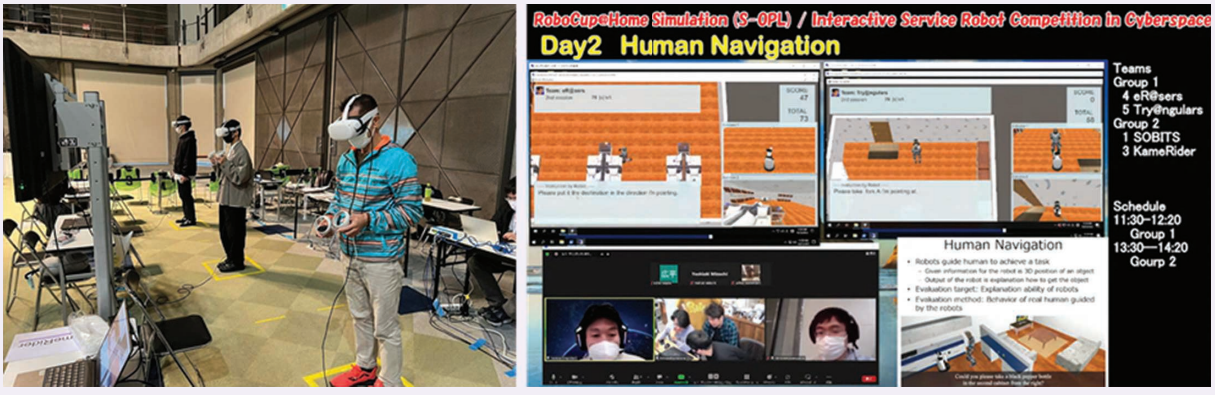

FIGURE 4. The Robot Competition held at IROS 2022 in Kyoto (the Interactive Server Robot Competition in Cyberspace). Humans can interact with virtual robots in cyberspace via an immersive virtual reality interface. The evaluation target is the ability of explainable AI in a daily life environment.

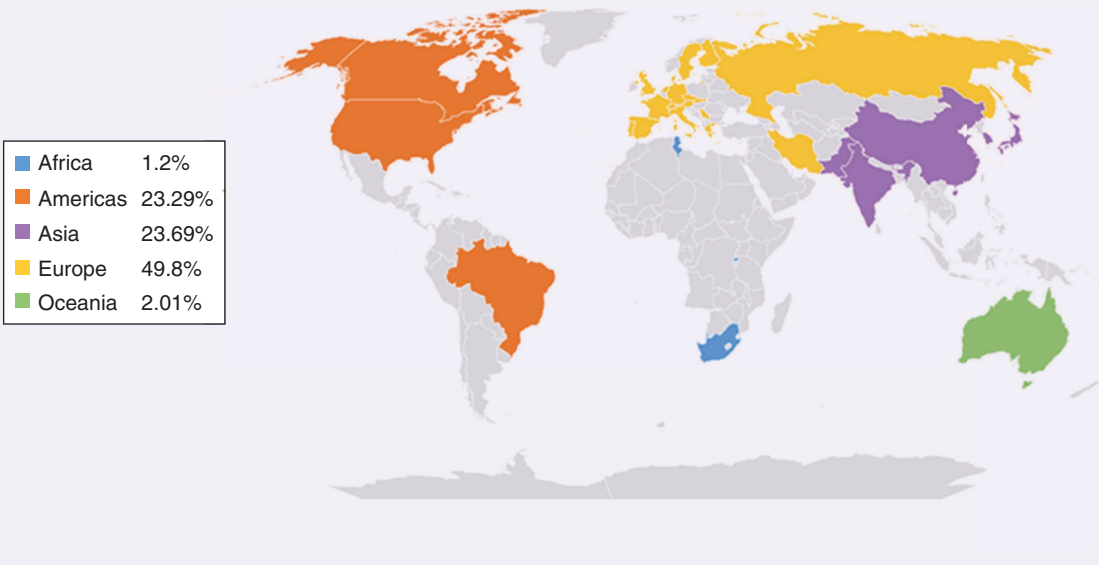

FIGURE 5. The geographical distribution of the TC-CoRo members. (Source: Graph by Linda Lastrico, IIT; used with permission.)

robots are in the process of being better equipped to comprehend and interpret human language, enabling effective communication and interaction in diverse contexts.

These three noteworthy innovations demonstrate the evolving landscape of cognitive robotics as researchers strive to develop robots that can meaningfully engage with humans, leverage advanced learning techniques, and grasp the nuances of language in everyday scenarios. Looking ahead, the challenges in cognitive robotics involve *demonstrating the generalizability of robot skills, their adaptivity, and their ability to exhibit long-term learning in interactions.* This requires a balanced approach to exploration–exploitation, enabling prospection and internal simulation, leveraging a correct combination of language and nonverbal communication, and developing a robust memory system. An architectural view of robot cognition will be crucial in achieving continuous and adaptive collaboration. It might also support addressing the challenge of enabling robots to handle dyadic interactions and more complex group scenarios, such as autonomous driving in populated areas or collaborative robotics in industry.

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With its growing membership of 249 in 2023 (Figure 5), TC-CoRo aims to disseminate the topics of cognitive robotics further and maintain an active discussion across disciplines. The committee offers numerous resources, an active member mailing list, and support for organizing events related to cognitive robotics, contributing to the advancement and awareness of this exciting field.

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