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Readying Robots for the Home

The evolution of human-robot interaction

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In 1997, a researcher at MIT, Cynthia Breazeal, had an astute observation that sparked the next two decades of human-robot interaction (HRI) research: "I am now a graduate student at MIT studying artificial intelligence, the year is 1997, and NASA has just landed the first robot on Mars. But robots are still not in our home, ironically" [1].

This question highlighted a key area of inquiry–what would it mean to have a robot interact with people in their homes? People are dynamic and it is not always easy to predict what they will do next. They engage with other people, organisms, and objects in their environments through complex social exchanges. Designing personal robots that live and work with humans involves interpreting these social signals and conveying their internal states back to people. This need has led to the development of social robots, or robots that are meant for interpersonal interactions, like communicating with humans, understanding them, and relating to them in a personal way [2]. This requires understanding human psychology, developments in engineering and computational advances in natural language processing, affective computing, and computer vision, to name a few.

Research has focused on both understanding humans' relationships with technology and designing robotic interactions to enrich human life. In this issue of *XRDS*, we hope to give you the current landscape of human-robot interaction (HRI) by pulling from HRI researchers with various backgrounds: design-oriented and system-oriented, industry and academia, contexts from education to healthcare, and various places around the world. This collection is meant to reflect the many types of research, applied to many walks of human life, that are required to make strides in the field.

As HRI researchers, we often get the question "why robots?" Early work in HRI established that embodiment and social interactions exhibited by embodied agents had a positive influence in people's engagement, trust, and empathy with technology when compared with other interfaces [3]. People were less likely to cheat embodied agents [4], be more engaged when they were expressive [5], and they started socially emulating their behaviors [6]. Social robots inspired creativity, curiosity, learning mindsets, and empathy in people and this made them useful across childhood learning, caregiving, entertainment, and work environments.

Many contexts, such as healthcare and education, rely on long-term engagement and rapport with social robots. While early research in the field utilized prototypes or Wizard of Oz experiences in lab settings, we now have robotic platforms that can be deployed long-term in real-world environments [7]. We can now understand what an everyday interaction with a robot will look like, opening up opportunities for more sophisticated data modeling, larger-scale research studies, and opportunities for iterative co-design practices with robot users. The latter, co-design, is especially important to address the equitable design and appropriate use of robots. It also aids in giving agency to users so that they can decide what role they want robots to have in their lives.

This issue covers the development and application of social robots and their interactions across these varying contexts. The curated articles delve into the role of robots in our daily lives, which is particularly relevant as humans are progressively forming partnerships with machines. Their social interfaces and ability to personalize interactions make social robots especially well-situated for learning companions. The issue begins with Prof. Anara Sandygulova and her team from Nazarbayev University who designed a reinforcement learning-based interactive robot system to

IBM recently unveiled their end-to-end quantum-safe technology, IBM Quantum Safe, to safeguard valuable data and address anticipated cryptographic standards and emerging vulnerabilities.

maximize children's knowledge of the Kazakh Latin alphabet and its handwriting over repeated interactions while adapting to each child's individual needs. Similarly, MIT Ph.D. student Xiajie Zhang uses reinforcement learning to personalize interactions between a learning companion robot and young children to support exploratory behavior and vocabulary learning. Next is Dr. Goren Gordon, the head of the Curiosity Lab at Tel-Aviv University; he applies robotic companions in the classroom beyond content learning to promote soft skills such as curiosity, growth mindset, and collaboration—all equally critical to children's growth.

Beyond education, social robots have found applications in healthcare and wellness. Adeyemi Federal University of Education's Dr. Iroju Olaronke reviews opportunities and challenges for child-robot interaction in healthcare. Her contribution highlights security, transparency, and privacy concerns around using robots in children's healthcare. Northwestern University assistant professor Dr. Sooyeon Jeong goes beyond thinking of robots as useful assistants and identifies social robots' ability to form long-term relationships with people. Her article describes how social robots can act as helpful at-home companions to improve people's psychological well-being. Long-Jing Hsu et al. focus on co-developing a robot for older adults that can support intangible aspects of older adults' well-being—their achievement of *ikigai*, or purpose in life.

HRI research often incorporates elements from other fields. Robot designers from Boston Dynamics, Leland Hepler and David Robert, reflect on how they learn from principles of transparent and predictable design to make their robots be truthful of their abilities and intentions. Similarly, Dr. Lindsay Sanneman describes how our understanding of human factors and explainable AI systems can help us design human-centered explanations that enable effective human–robot interaction across diverse contexts, and how to appropriately calibrate human trust in AI systems. Large language models enable robots to hold human-like dialogue, but the approach is still insufficient for natural human-robot conversation due to the lack of the agents' knowledge about the social and environmental context. Rafael Sousa Silva et al. take inspiration from cognitive science research and discuss the importance of memory systems in natural conversation and implement cognitively inspired models of long-term memory and working memory to keep track of what the robot knows and what knowledge the robot is currently attending to.

The invited articles discuss applications of HRI across learning, healthcare, and wellness; how to design transparent, explainable, and equitable robots; and future directions in designing for and with users. However, for responsible HRI design, we need to look inwards as HRI designers. Closing out the issue, Uppsala University's Dr. Katie Winkle calls upon HRI researchers, designers, and practitioners to reflect on the power structures that pervade the social contexts in which we design our robots for and in, and how that can inform equitable design. She discusses how participatory design practices can be leveraged to better distribute power between stakeholders by engaging users in research, design, and development processes.

Algorithmic advances in machine learning and affective computing now enable robots to perceive the world, express emotions, and hold natural conversations like humans. Robots can now learn people's preferences over long terms and personalize interaction to their needs. This opens up new possibilities for the applications of social robots, while also introducing new areas of studying why individuals tend to ascribe beliefs and intentions to social agents. We look back at the initial dream of putting robots in our home and reflect on how the field of HRI has progressed in designing personal robots that live, learn, and work with individuals. We envision future research about how people form relationships with these emotionally intelligent agents, and responsibly designing them while centering people's needs and rights.

Quoting Sanneman, "While there are still many unexplored directions and questions in the field... one thing that is clear is we should strive to keep humans at the center in our future research."

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