Socially Intelligent Robots

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WHAT IS A SOCIALLY INTELLIGENT ROBOT? It is a difficult concept to define, but science fiction offers many examples. There are the mechanical droids R2-D2 and C-3PO from *Star Wars*. There are many wonderful examples in the short stories of Isaac Asimov, such as *Robbie*. And more recently, there is *Teddy* from the movie *Artificial Intelligence*. Science fiction illustrates how these technologies could enhance our lives and benefit society, but it also warns us that this dream must be approached responsibly and ethically, as portrayed in *Blade Runner*.

For me, the ultimate vision of a socially intelligent robot is one that is able to communicate and interact with us, understand and even relate to us, in a personal way. Human social intelligence is certainly the most advanced example, but the level of social intelligence exhibited by companion animals would also find many pragmatic uses for robots. Robots today, however, treat us either as other objects in the environment, or at best they interact with us in a manner characteristic of socially impaired people. For instance, robots are not really aware of our goals and intentions. As a result, they don't know how to appropriately adjust their behavior to help us as our goals and needs change. They generally do not flexibly draw their attention to what we currently find of interest so that their behavior can be coordinated and information can be focused about the same thing. They do not realize that perceiving a given situation from different perspectives impacts what we know and believe to be true about it. Consequently, they do not bring important information to our attention that is not easily accessible to us when we need it.

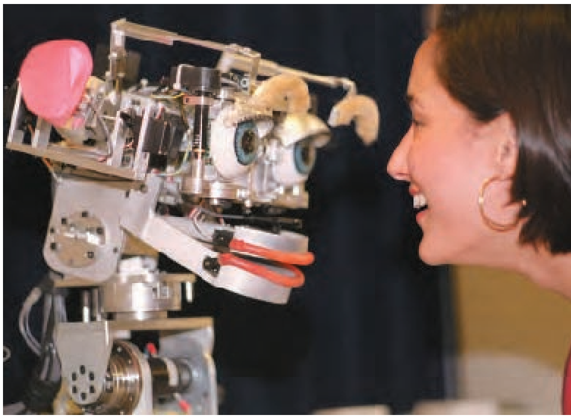
They are not deeply aware of our emotions, feelings, or attitudes. As a result they cannot prioritize what is the most important to do for us according to what pleases us or to what we find to be most urgent, relevant, or significant. They do not readily learn new skills and abilities from interacting with people. Although there have been initial and ongoing strides in these areas there remains significant shortcomings in the social intelligence of robots [1, 4, 6, 7]. As a result, robots cannot cooperate with us as capable partners. Consequently, human-robot interaction is often reduced to using social cues merely as a natural interface for operating (supervising) the robot as a sophisticated tool. This sort of master-slave arrangement does not capture the sense of partnership that we experience when communicating, working, or learning alongside other socially intelligent creatures. But steady progress is being made as interest grows in bringing robots into the human social environment.

As humans, we often develop technology to enhance our ability to work more effectively, or to perform tasks that are hazardous to people, etc. Traditionally, autonomous robots are viewed as sophisticated tools and have been targeted for applications that do not require social interaction with humans, such as sweeping minefields, inspecting oil wells, or exploring other planets. However, new applications are emerging where the ability for a robot to work alongside human teammates as a peer is an important part of the robot's functionality. For instance, NASA Johnson Space Center's humanoid robot *Robonaut* is an excellent example. Today, Robonaut is teleoperated by a highly trained specialist to work collaboratively with an adjacent human teammate, a cognitively demanding task. However, NASA JSC's future vision is to make Robonaut a completely autonomous teammate, ultimately able to work collaboratively with human astronauts on

extra-vehicular tasks, using the same tools and following the same task procedures as their human astronaut counterparts.

The emerging market of personal service robots requires robots to play a beneficial role in the daily lives of ordinary people. This application area, in particular, is driving research to develop autonomous robots that are natural and intuitive for the average consumer to interact with, communicate with, work with as partners, and teach new capabilities. In addition, this domain motivates new questions for robotics researchers, such as how to design for a successful relationship where the robot provides long-term appeal and benefit to the human over weeks, months, and even years. Note that the benefit that social robots could provide to people extends far beyond strict task-performing utility, to include educational, health, therapeutic, and social goals. To address these challenges, new areas of inquiry in the field of autonomous robotics are emerging, including Human-Robot Interaction (HRI) and Social Robotics.

Robotic Trends magazine defines personal service robots as "robots or robotic technology purchased by individual consumers that educate, entertain, or assist, or protect in the home." Although the service robot market is young, the few quantitative studies that do exist, such as recent research by the Japan Robotics Association (JRA), United Nations Economic Commission (UNEC), and the International Federation of Robotics (IFR), indicate that the service robot market will experience exceptional growth in the near term. The global demographic trend of rapidly aging societies, where a smaller working-age population is responsible for supporting a larger retired population, is one of the most urgently pressing application areas for bringing robots into the homes and human workplaces as capable assistants for people and for supplementing the workforce. The convergence of many technological developments in mobile computing, such as advances is microprocessor technology, wireless technology, image processing, speech recognition, motor sensor technology, and embedded systems development tools, make personal robot development increasingly feasible. In addition, personal robots of the future may very well leverage from the computational infrastructure of smart environments to help it to perceive, understand, and interact with people and its surroundings. Companies such as Toshiba and NEC are actively developing household interface robots that bear an amusing resemblance to the Star Wars droid R2-D2 and could someday serve as the persona of an intelligent home, interfacing with the electronic devices around the house (e.g., TV, computer, answering service, internet, security system, etc.).



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Today we see social robotic technology applied to diverse entertainment purposes. We are very familiar with animatronics in theme parks, and the use of sophisticated robotic puppets for special effects in films. The development of graphically rendered synthetic actors in films is being paralleled in university research labs by the development of socially skilled animatronic characters that can perform live and face-to-face with human actors [3]. Recent advances in low-cost electronics has enabled a new generation of robotic "pets"—many are inexpensive, such as Hasboro's *Furby* and its successors, and others are more expensive and rather sophisticated such as Sony's robotic dog, *Aibo*. Location-based entertainment applications such as museum tour guide robots offer not only entertainment value but also provide educational value by providing visitors with information of interest. In the past, simple interactive robotic characters have been applied to learning contexts, such as Actimates. Research labs continue to focus on the application of socially interactive robotic characters in the form of learning companions that interact with the human learner as a supportive peer or as a tutor [5].

Health-related and eldercare applications are being widely explored. Several universities are developing robots that lend assistance to the elderly in an eldercare facility, such as socially interactive robotic walkers that escort patients to appointments with the nurse or care provider. Doctor's have begun to explore robotic telepresense technologies—remotely operating a mobile robot equipped with video conferencing technology to allow them to visit their patients at different hospitals. In addition, researchers are developing robotic pet therapy surrogates that are intended to provide the same health benefits of their living counterparts. Another article in this section outlines a number of different uses of robots for therapeutic applications.

Socially intelligent robots are interesting from a scientific perspective as well. Our evolution, our development from infancy to adulthood, our culture from generation to generation, and our day-to-day existence in society are all profoundly shaped by social factors. Understanding our sociality is critical to understanding our humanity. Toward this goal, robotics researchers use robots as experimental testbeds for scientific inquiry [8]. For instance, several efforts are under way to use robots in treatment of autistic children and to try to understand this social impairment by modeling it on robots [2]. In this work, computational models of social abilities are implemented, tested, and analyzed on robots as they participate in controlled social experiments to understand human social behavior and social development. The parameters of these models can be systematically varied to understand their effects on social behavior, to refine these models, and to generate new models and theories. By doing so, such models are applied to better understand social behavior disorders, which in turn aid in the development of effective treatments. Robot data could be compared with human performance under similar conditions. Differences between the two could be used to refine the models and inspire new experiments.

The field of social robotics is in its infancy. I have outlined a wide variety of applications for such robots—past, present, and future. Several of these applications require the robot to be socially interactive. The deeper scientific questions and far more sophisticated applications shall require such robots to be socially intelligent as well. Here, examining the social cognition of humans and animals shall be an extremely useful guide as we strive to address several "grand challenge" problems of social robotics. These grand challenge problems include the development of robots that can work collaboratively alongside humans as peers; engage in rich forms of social learning such as imitation and tutelage to learn new skills, knowledge, and tasks while on the job from ordinary people who will want to teach

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them; participate in successful relationships with people that provide benefit over the long term; understand people as people—in social-psychological terms to appreciate our goals, beliefs, feelings, etc.; and communicate with us in human-centered terms.

Given that robots have been exploring other planets for years, it's ironic to think of your home as the "final frontier" for robots. But the complexity of human society raises many new challenges for them. However, with every advance in these "grand challenge" areas, R2-D2 and C-3PO are coming closer to a home near you.

ABOUT THE AUTHOR *A pioneer in the areas of human-robot interaction and sociable robotics, Cynthia Breazeal is an assistant professor of Media Arts and Sciences at the MIT Media Lab where she is director of the Robotic Life Group and holds the LG Group career development chair. Her research interests focus on the scientific pursuit and technological innovation necessary to create machines that understand and engage people in social and affective terms. Her first book,* Designing Sociable Robots, *is published by The MIT Press (2002).*

Towards Collaboration with Robots in Shared Space: Spatial Perspective and Frames of Reference

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IMAGINE MOBILE ROBOTS OF THE FUTURE, working side by side with humans, collaborating in a shared workspace. For this to become a reality, robots must be able to do something that humans do constantly: understand how others perceive space and the relative positions of objects around them—they need the ability to see things from another person's point of view. Our research group and others are building computational, cognitive, and linguistic models that can deal with frames of reference. Issues include dealing with constantly changing frames of reference, changes in spatial perspective, understanding what actions to take, the use of new words and common ground.

Our approach is an implementation informed by cognitive and computational theories. It is based on developing computational cognitive models (CCMs) of certain high-level cognitive skills humans possess and that are relevant for collaborative tasks. We then use these models as reasoning mechanisms for our robots. Why do we propose using CCMs as opposed to more traditional programming paradigms for robots? We believe that by giving the robots similar representations and reasoning mechanisms to those used by humans, we will build robots that act in a way that is more compatible with humans.

Hide and Seek. Our foray into this area started when we were developing computation cognitive models of how young children learn the game of hide and seek [1]. The purpose was to enable our robots to use human-level cognitive skills to make the decisions about where to look for people or things hidden by people. The research resulted in a hybrid architecture with a reactive/probabilistic system for robot mobility [5], and a high-level cognitive system based on ACT-R [6] that made the high-level decisions for where to hide or seek (depending on which role the robot was playing). Videos of the robot playing a game of hide and seek can be seen at www.nrl.navy.mil/aic/iss/aas.

While this work was interesting in its own right, the system led us to the realization that the ability to do perspective-taking is a critical cognitive ability for humans, particularly when they want to collaborate.

Spatial Perspective in Space. To determine just how important perspective and