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What Is Human–Robot Interaction?

What is covered in this chapter:

- the academic disciplines that come together in the field of human–robot interaction (HRI);
- the barriers created by the disciplines' different paradigms, and how to work around this;
- the history and evolution of HRI as a science;
- landmark robots in HRI history.

Human–robot interaction, or HRI, is commonly referred to as a new and emerging field, but the notion of human interaction with robots has been around as long as the notion of robots themselves. Isaac Asimov, who coined the term *robotics* in the 1940s, wrote his stories around questions that take the relationship between humans and robots as the main unit of analysis: "How much will people trust robots?"; "What kind of relationship can a person have with a robot?"; "How do our ideas of what is human change when we have machines doing humanlike things in our midst?" (see page 193 for more on Asimov). Decades ago, these ideas were science fiction, but nowadays, many of these issues have become a reality in contemporary societies and have become core research questions in the field of HRI.

Distinguishing physical and social interaction: One way to understand some key differences between the fields of HRI and robotics is that whereas robotics is concerned with the creation of physical robots and the ways in which these robots manipulate the physical world, HRI is concerned with the ways in which robots interact with people in the social world. For example, when the humanoid ASIMO (see Figure 2.1) goes up the stairs in a house or pushes a cart in an office, it is sensing and acting in the physical world alone and dealing with the physics of its own body and its environment. When ASIMO delivers coffee to a group of office workers or chases children around in a courtyard, it is dealing with the physical motions needed for those actions, but it must also address the

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social aspects of the environment: where the children or the office workers are, how to approach in a way that is safe and that they consider appropriate, and the social rules of the interaction. Such social rules might be obvious to humans, such as acknowledging the other actors, knowing who is "it" in a game of tag, and saying "you're welcome" when someone says "thank you." But for a robot, all these social rules and norms are unknown and require the attention of the robot designer. These concerns make HRI questions different from those pursued in robotics alone.

As a discipline, HRI is related to human–computer interaction (HCI), robotics, artificial intelligence, the philosophy of technology, and design. Scholars trained in these disciplines have worked together to develop HRI, bringing in methods and frameworks from their home disciplines but also developing new concepts, research questions, and HRI-specific ways of studying and building the world.

What makes HRI unique? Clearly, the interaction of humans with social robots is at the core of this research field. These interactions usually include physically embodied robots, and their embodiment makes them inherently different from other computing technologies. Moreover, social robots are perceived as social actors bearing cultural meaning and having a strong impact on contemporary and future societies. Saying that a robot is embodied does not mean that it is simply a computer on legs or wheels. Instead, we have to understand how to design that embodiment, both in terms of software and hardware, as is commonplace in robotics, and in terms of its effects on people and the kinds of interactions they can have with such a robot.

A robot's embodiment sets physical constraints on the ways in which it can sense and act in the world, but it also represents an affordance for interaction with people. The robot's physical makeup elicits people to respond in a way similar to that in which they interact with other people. The robots' human-likeness enables humans to use their existing experience of human–human interaction in human–robot interaction. These experiences can be very useful to frame an interaction, but they can also lead to frustration if the robot cannot live up to the users' expectations.

HRI focuses on developing robots that can interact with people in various everyday environments. This opens up technical challenges resulting from the dynamics and complexities of humans and the social environment. This also opens up design challenges—related to robotic appearance, behavior, and sensing capabilities—to inspire and guide interaction. From a psychological perspective, HRI offers the unique opportunity to study human affect, cognition, and behavior when confronted with social agents other than humans. Social robots, in this

Figure 2.1 Honda developed the Asimo robot from 2000 through 2018. (Source: Honda)

context, can serve as research tools to study psychological mechanisms and theories.

When robots are not just a tool but, rather, collaborators, companions, guides, tutors, and all kinds of social interaction partners, HRI research considers many different relationships with the development of society, both in the present and in the future. HRI research includes issues related to the social and physical design of technologies, as well as

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societal and organizational implementation and cultural sense-making, in ways that are distinct from related disciplines.

2.1 The focus of this book

HRI is a large, multidisciplinary field, and this book provides an introduction to the problems, processes, and solutions involved. This book enables the reader to gain an overview of the field without becoming overwhelmed with the complexities of all the challenges that we are facing, although we do provide references to the most relevant literature, which interested readers might want to investigate at their leisure. This book provides a much-needed introduction to the field so that students, academics, practitioners, and policy makers can become familiar with the future of how humans will interact with technology.

This book is an introduction, and as such, it does not require extensive knowledge in any of the related fields. It only requires the reader's curiosity about how robots and humans can and should interact with each other.

After introducing the field of HRI and how a robot works in principle, we focus on the robots' designs. Next, we address the different interaction modalities through which humans can interact with robots, such as through speech or gestures. The processing and communication of emotions is the next challenge we introduce before reflecting on the role that robots play in the media. The research methods chapter introduces the unique issues that researchers face when conducting empirical studies of humans interacting with robots. Next, we cover the application areas of social robots and their specific challenges before discussing ethical issues around the use of social robots. The book closes with a look into the future of HRI.

2.2 HRI as an interdisciplinary endeavor

HRI is multidisciplinary and problem-based field by nature and by necessity. HRI brings together scholars and practitioners from various domains: engineers, psychologists, designers, anthropologists, sociologists, and philosophers, along with scholars from other application and research domains. Creating a successful human–robot interaction requires collaboration from a variety of fields to develop the robotics hardware and software, analyze the behavior of humans when interacting with robots in different social contexts, and create the aesthetics of the embodiment and behavior of the robot, as well as the required domain knowledge for particular applications. This collaboration can be difficult due to the different disciplinary jargon and practices. The common interest in HRI among this wide variety of participants, how-

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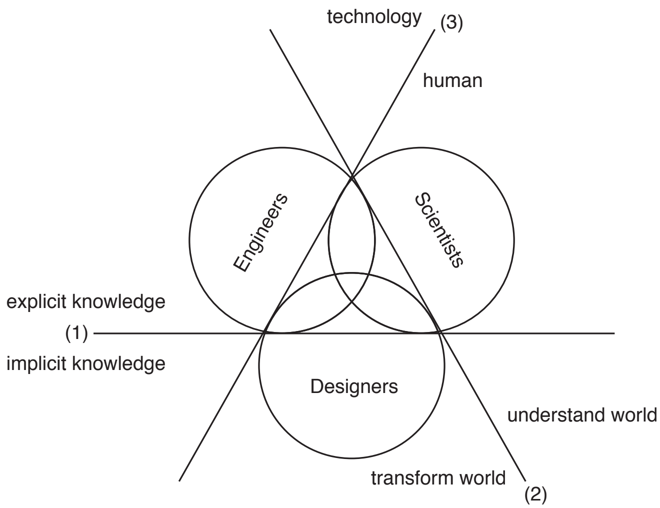

Figure 2.2 Barriers between the disciplines.

ever, is a strong motivation for familiarizing oneself with and respecting the diverse ways of acquiring knowledge.

HRI is, in this multidisciplinary sense, similar to the field of human–computer interaction (HCI), although dealing with embodied interactions with social agents differentiates HRI from HCI.

The various disciplines differ from each other in terms of their shared beliefs, values, models, and exemplars (Bartneck and Rauterberg, 2007). These aspects form a "paradigm" that guides their community of theorists and practitioners (Kuhn, 1970). Researchers within a paradigm share beliefs, values, and exemplars. The difficulties of working together on a shared project find their base in three barriers (see Figure 2.2) between designers [D], engineers [E] and scientists (in particular social scientists) [S]:

1. knowledge representation (explicit [S, E] versus implicit [D]);
2. view on reality (understanding [S] versus transforming reality [D, E]); and
3. main focus (technology [E] versus human [D, S]).

Barrier 1: Engineers [E] and scientists [S] make their results explicit by publishing in journals, books, and conference proceedings or by acquiring patents. Their body of knowledge is externalized and described to other engineers or scientists. These two communities revise their published results through discussion and control tests among peers. On the other hand, designers' [D] results are mainly represented by their concrete designs. The design knowledge necessary to create these designs lies within the individual designer, mainly as implicit knowledge, often referred to as intuition.

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Barrier 2: Engineers [E] and designers [D] transform the world into preferred states (Simon, 1996; Vincenti, 1990). They first identify a preferred state, such as the connection between two sides of a river, and then implement the transformation, which in our example would be a bridge. Scientists [S] mainly attempt to understand the world through the pursuit of knowledge covering general truths or the operation of general laws.

Barrier 3: Scientists [S] and designers [D] are predominantly interested in humans in their role as possible users. Designers are interested in human values, which they transform into requirements and, eventually, solutions. Scientists in the HCI community are typically associated with the social or cognitive sciences. They are interested in the users' abilities and behaviors such as perception, cognition, and action, as well as the way these factors are affected by the different contexts in which they occur. Engineers [E] are mainly interested in technology, which includes software for interactive systems. They investigate the structure and operational principles of these technical systems to solve certain problems.

Not every HRI project can afford to have dedicated specialists from all these disciplines. HRI researchers often need to wear several hats, trying to gain expertise in a variety of topics and domains. Although this approach may reduce the problems of finding common ground, it is quite limiting. We often do not know what we do not know. It is therefore important to either engage with all or many of the involved disciplines directly or at least communicate with experts in the respective fields. As the field of HRI grows and matures, it has also been expanding to include more and more different disciplines, frameworks, and methods (e.g., historians, philosophers), which can require an even more expansive set of knowledge requirements. In this case, we suggest also getting used to reading broadly, not just in your own discipline or subdomain of HRI but also in related fields, to understand how your own work fits into the bigger picture. When developing specific HRI applications, it is also crucial to collaborate with domain experts, including potential users and stakeholders, in the design–from the beginning of the project–to make sure to ask relevant questions, use appropriate methods, and be aware of the potential broader consequences of the research to the application domain.

2.3 The evolution of HRI

The concept of "robot" has a long and rich history in the cultural imagination of many different societies, going back thousands of years to tales of humanlike machines, the later development of automata that reproduce certain human capabilities, and more recent science-fiction narratives about robots in society. Although these cultural notions of

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robots may not always be technically realistic, they color people's expectations of and reactions to robots.

The first mention of "social robot" in print was in 1935, when it was used as a derogatory term for a person having a cold and distant personality.

> Toadying and bootlicking his autocratic superiors, he is advanced to preferment. He is a business success. But he has sacrificed all that was individual. He has become a social robot, a business cog. (Sargent, 2013)

In 1978, the first mention of "social robot" was made in the context of robotics. An article in *Interface Age* magazine described how a service robot, in addition to skills such as obstacle avoidance, balancing, and walking, would also need social skills to operate in a domestic setting. The article calls this robot a "social robot."

Ever since the concept of "robot" emerged, first in fiction and later as real machines, we have pondered the relationship between robots and people and how they could interact with each other. Every new technological or conceptual development in robotics has forced us to reconsider our relationship with and perception of robots.

When the first industrial robot, the Unimate, was installed at General Motors' Inland Fisher Guide Plant in Ewing Township, New Jersey, in 1961, people did consider how they would interact with the robot, but they were more concerned about the place robots would take among human workers. People who saw behavior-based robots for the first time could not help but marvel at the lifelike nature of the robot. Simple reactive behaviors (Braitenberg, 1986) implemented on small mobile robots produced machines that seemed injected with the very essence of life. Scurrying and fidgeting around the research labs of the 1990s, these robots evoked humanlike character traits and fundamentally changed our idea of how intelligence, or at least the appearance of intelligence, could be created (Brooks, 1991; Steels, 1993). This led to the creation of robots that used fast, reactive behavior to create a sense of social presence.

An early example of a social robot is Kismet (see Figure 2.3). Developed at the Massachusetts Institute of Technology in 1997, Kismet was a robot head-and-neck combination mounted on a tabletop box. Kismet could animate its eyes, eyebrows, lips, and neck, allowing it to pan, tilt, and crane its head. Based on visual and auditory input, it reacted to objects and people appearing in its visual field. It extracted information on visual motion, visual looming, sound amplitude, and emotion from speech prosody, and it responded by animating its facial expressions, ears, and neck and by babbling in a nonhuman language

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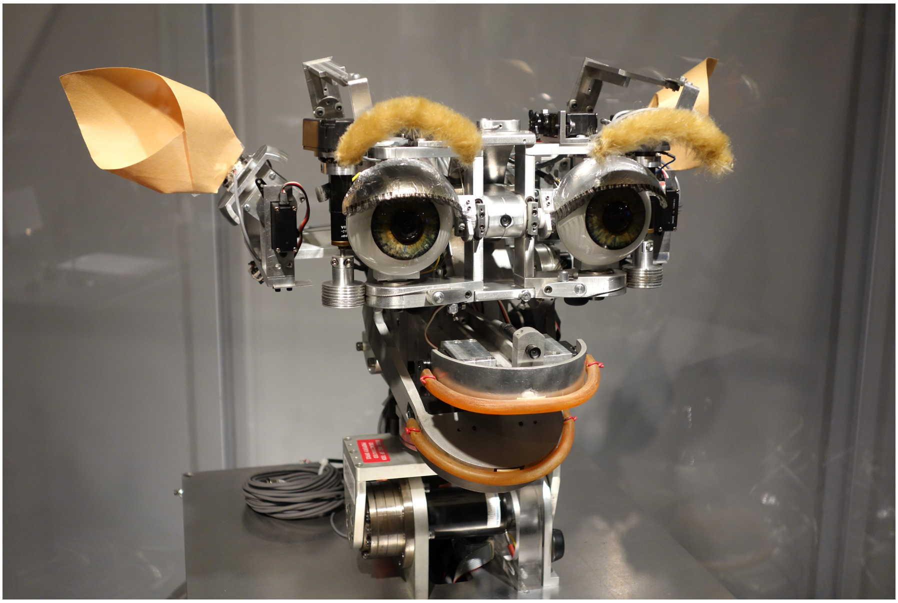

Figure 2.3 Kismet (1997–2004), an early example of social human–robot interaction research from the Massachusetts Institute of Technology. (Source: Daderot)

(Breazeal, 2003). Kismet was surprisingly effective at presenting a social presence, even though the control software only contained a small selection of social drives. It did so not only with its hardware and software architectures but also by taking advantage of human psychology, including what is known as the "baby schema," a predisposition to treat things with big eyes and exaggerated features in social ways despite their lack of fully functional social skills.

Like many robots in the early days of social robotics and HRI, Kismet was a bespoke robot, available to researchers in only one laboratory and requiring constant effort by students, postdocs, and other researchers to keep up and build up the robot's capabilities. These limitations understandably constrained the number of people and the range of disciplines that could participate in HRI in the field's early days. More recently, HRI research has been bolstered by the availability of reasonably priced commercial platforms that can be readily purchased by laboratories. These have expanded both the replicability and comparability of HRI research across labs, as well as the range of people who can engage in the discipline.

A number of robots have had a significant influence on the field. The Nao robot, developed by Aldebaran Robotics (now Softbank Robotics Europe), is perhaps the most influential robot in the study of social robotics (see Figure 2.4). First sold in 2006, the small humanoid robot, due to its affordability, robustness, and ease of programming, became a widespread robot platform for studying HRI. The robot, because of its size, is also highly portable, allowing for studies to be run outside the lab.

Figure 2.4 Nao (2006–present), a 58-cm-tall humanoid robot, currently the most popular research platform in social robotics.

The Keepon robot, developed by Hideki Kozima, is a minimal robot consisting of two soft yellow spheres to which a nose and two eyes are added. The robot can swivel, bend, and bop, using motors worked into the base of the robot (Kozima et al., 2009); see Figure 2.5. Keepon was later commercialized as an affordable toy, and through some moderate hacking, it can be used as a research tool for HRI. Studies with the Keepon robot convincingly demonstrated that a social robot does not need to appear humanlike; the simple form of the robot is sufficient to achieve interaction outcomes where one might assume the need for more complex and humanlike robots.

Figure 2.5 Keepon (2003–present), a minimal social robot developed by Hideki Kozima. The robot was later commercialized as an affordable toy. (Source: Hideki Kozima, Tohoku University)

The Paro companion and therapy robot (see Figure 2.6), shaped like a baby seal, has been particularly popular in the study of socially assistive robots in eldercare, as well as other scenarios. Paro has been commercially available in Japan since 2006 and in the United States and Europe since 2009 and is a robust platform that requires almost no technical competence to operate. Paro has therefore been used by various psychologists, anthropologists, and health researchers, both to study the potential psychological and physiological effects on people and to explore ways in which robots might be adopted in healthcare organizations. The simplicity of the robot's operation and its robustness enable its use in many different contexts, including in long-term and naturalistic studies. At the same time, the fact that it is a closed platform—which does not allow robot logs or sensor data to be extracted from the robot or allow the robot's behaviors to be changed—poses some limitations for HRI research.

The Baxter robot, sold by Rethink Robotics until 2018, is both an

Figure 2.6 Paro (2003–present), a social robot made to resemble a baby harp seal. Paro is provided as a social companion robot. (Source: National Institute of Advanced Industrial Science and Technology)

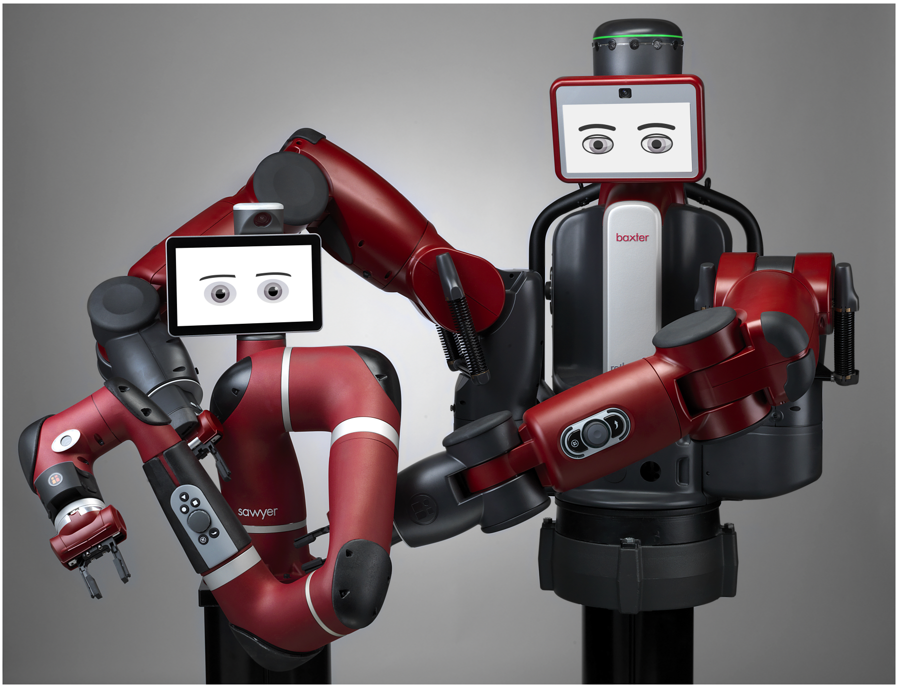

Figure 2.7 Baxter (2011–2018) and Sawyer (2015–2018), industrial robots with compliant arms by Rethink Robotics. Baxter was the first industrial robot to include social interaction features on an industrial manipulator. (Source: Rethink Robotics, Inc.)

industrial robot and a platform for HRI (Figure 2.7). The robot's two arms are actively compliant: in contrast to the stiff robot arms of typical industrial robots, Baxter's arms move in response to an externally applied force. In combination with other safety features, the Baxter robot is safe to work near, which makes it suitable for collaborative tasks. In addition, Baxter has a display screen mounted at head height on which the control software can display facial animations. Baxter's face can be used to communicate its internal state, and its eye fixations communicate a sense of attention to the human co-worker.

Although the availability of affordable commercial robots with open application interfaces caused a proliferation of HRI studies, a second development has allowed for in-house-built social robots. New develop-

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Figure 2.8 InMoov (2012–present) can be built using rapid-prototyping technology and readily available components. The InMoov robot is an open-source social robot.

Figure 2.9 Kaspar (2009–present) is a "minimally expressive" robot, built using brackets, servo motors, and a surgical silicon mask. Kaspar is used in autism therapy.

ments in mechatronic prototyping mean that robots can be modified, hacked, or built from scratch. Three-dimensional (3D) printing, laser cutting, and the availability of low-cost single-board computers have made it possible for researchers to build and modify robots in a short time and at minimal cost, for example, InMoov (see Figure 2.8) or Ono.

As you can see, the variety of robot hardware opens up endless research questions that can be addressed from a multidisciplinary perspective. Unlike other disciplines, HRI places particular emphasis on investigating the nature of social interactions between humans and robots, not only in dyads but also in groups, institutions, and sooner or later, in our societies. As will become clear in this book, technological advancements are a result of joint interdisciplinary efforts that have important societal and ethical implications. Keeping these in mind by doing human-centered research will hopefully lead to the development of robots that are widely accepted and that serve humans for the greater good.

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Questions for you to think about:

- The HRI field draws insights from many other fields, but what other fields could benefit from research in HRI?
- Are you a designer, engineer, or social scientist? Try to imagine a situation in which you are collaborating with others to construct a robot (e.g., if you are an engineer, you are now working with a designer and a social scientist on this endeavor). How is your way of working different from the approaches the other teammates might use?
- What is the main difference between the disciplines of HRI and HCI, and what makes HRI unique as a new field?

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