1

Introduction

1.1 About this book

Since the 1950s, an everyday life with robots has always been about 10–20 years away. This is probably true at the moment in which you are reading this book. In the early 2020s, as we are writing, there's a lot of talk about robots in the news, on the movie screen, and of course, in science-fiction literature. We now even see robots in our daily lives, on city streets and in classrooms, cafés and restaurants, and hotels. Have you ever interacted with a robot? A vacuum-cleaning robot? A robotic toy, pet, or companion? Chances are that if you haven't, you will soon. Technology companies are eyeing the potential of personal robots, with start-ups as well as large multinationals readying themselves to create the kind of robot that everyone wants to own. But you may still not get a chance to be served breakfast in bed by your trusty robotic butler anytime soon. One of the reasons for this is that designing robots to participate in dynamically unfolding interactions with diverse users over long periods of time has turned out to be more difficult than anyone initially thought. Robust human–robot interaction—HRI—is difficult to design and implement.

So where is the field of robotics headed? What will, and should, our future with robots look like? How will robots find a place in our lives? These are still very open questions. A range of unknown but exciting futures awaits, in all of which robots support us, collaborate with us, transport us, or entertain us. If you've opened this book, you must be interested in seeing how this future might unfold. Perhaps you even want to get involved in shaping our future interactions with robots.

To get you started on this path, first of all, it is all about you: What kind of educational background do you have? Did you become interested in robots through your interest in engineering, psychology, art, or design? Or did you pick up this book because it rekindled a childhood fascination with robots? HRI is an endeavor that brings together ideas from a wide range of disciplines. Engineering, computer science, robotics, psychology, linguistics, sociology, and design all have something to contribute to how we interact with robots. HRI lies at the confluence of these disciplines. As a computer scientist, it pays to know about social psychology; as a designer, there's value in dipping your toes in sociology.

If you have an engineering background, do you think you can build a robot that interacts with people, working only with other engineers? We,

unfortunately, think that you will not be able to do so. To design robots that people want to interact with, you need a good understanding of human social interaction. To reach such understanding, you need insight from people trained in the social sciences and humanities.

Are you a designer? Do you think you can design a socially interactive robot without working with engineers and psychologists? People's expectations about robots and their roles in everyday life are not just high, but they also vary a lot from person to person. Some people may tell you they want robots that will cook for them; others wish for a robot to do their homework, then have an intellectual conversation about the latest *Star Wars* movie. The prowess of robots as assistants, however, is still rather limited. Moravec's paradox, decades after being first expressed, still holds: anything that seems hard to people is relatively easy for machines, and anything a young child can do is almost impossible for a machine. As a designer, you would therefore need a good understanding of technological capabilities and of human psychology and sociology to create a design that is viable and realistic.

And last but not least, those of you who have training in psychology and sociology, do you want to just wait around for such robots to appear in our society? Wouldn't it be too late to start studying these technologies after they appear in our environment? Don't you want to have an impact on what they look like and how they interact? One thing you can do is start talking to friendly engineers and computer scientists, or have lunch with a designer. They will give your social science ideas some grounding in what is technically possible and help you find the areas in which your knowledge can have the most impact.

Just like the six of us writing this book, you will all need to work together. To do so in an effective way, you will need to understand the perspectives of HRI practitioners from different disciplines and be aware of the different kinds of expertise needed for developing successful HRI projects. In this book, we want to provide you with a broad overview of HRI topics central to the field and get you started on thinking about how you can contribute to them. We would like you to join us in expanding the boundaries of what is known and possible. Technology has progressed to a degree to which it is possible to build and program your own robot at little cost. Robots will be part of our future, so seize your chance to shape it. Go read (this book!), create, test, and learn!

We assembled a team of leading experts from the wide spectrum of disciplines that contribute to HRI. All of our hearts beat for improving how humans and robots interact and for ensuring that robots are used in ways that benefit our societies and the lives of individuals who use and are affected by them.

1.2 Christoph Bartneck

Christoph Bartneck is an associate professor in the Department of Computer Science and Software Engineering at the University of Canterbury. He has

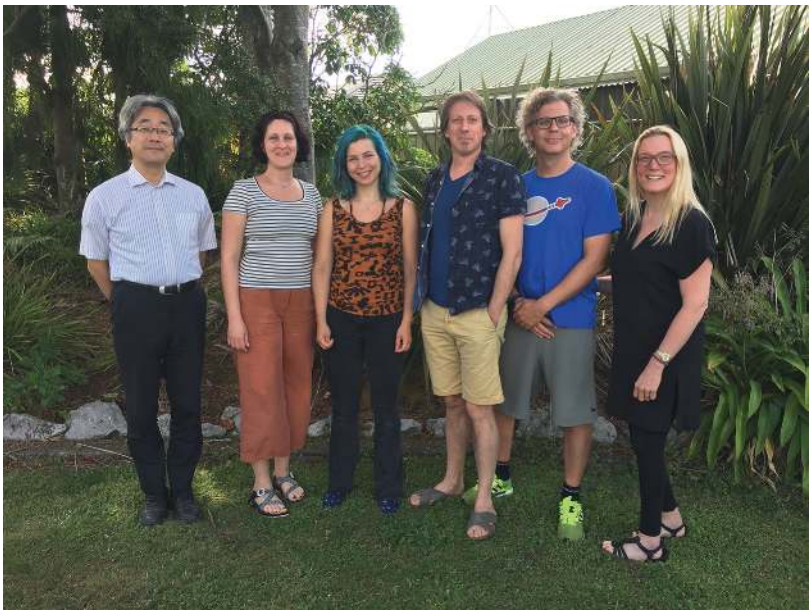

Figure 1.1 The authors of this book got together in Westport, New Zealand, in January 2018 to start the manuscript during a weeklong "Book Sprint." Writing and editing continued throughout the following year and a half through remote collaboration—many long Skype calls and emails.

a background in industrial design and human–computer interaction, and his projects and studies have been published in leading journals, newspapers, and conferences. His interests lie in the fields of human–computer interaction, science and technology studies, and visual design. More specifically, he focuses on the effect of anthropomorphism on HRI. As a secondary research interest, he works on projects in the area of sports technology and the critical review of scientific processes and policies. In the field of design, Christoph investigates the history of product design, tessellations, and photography.

1.3 Tony Belpaeme

Tony Belpaeme is a professor at Ghent University, Belgium, and prior to that was a professor of robotics and cognitive systems at Plymouth University, United Kingdom. He received his PhD in artificial intelligence from the Vrije Universiteit Brussel (VUB). Starting from the premise that intelligence is rooted in social interaction, Tony and his research team try to further the artificial intelligence of social robots. This approach leads to a spectrum of results, from theoretical insights to practical applications. He is involved in large-scale projects studying how robots can be used to support children in education, and he studies how brief interactions with robots can become long-term interactions and how robots can be used in therapy.

1.4 Friederike Eyssel

Friederike Eyssel is a professor of applied social psychology and gender research at the Center for Cognitive Interaction Technology at Bielefeld

University, Germany. Friederike is interested in various research topics ranging from social robotics, social agents, and ambient intelligence to attitude change, prejudice reduction, and the sexual objectification of women. Crossing disciplines, Friederike has published vastly in the fields of social psychology, HAI, and social robotics.

1.5 Takayuki Kanda

Takayuki Kanda is a professor in informatics at Kyoto University, Japan. He is also the visiting group leader at Advanced Telecommunications Research (ATR) Interaction Science Laboratories, Kyoto, Japan. He received his bachelor's degree in engineering, his master's degree in engineering, and his PhD in computer science from Kyoto University, Kyoto, Japan, in 1998, 2000, and 2003, respectively. He is one of the starting members of the Communication Robots project at the ATR in Kyoto. He has developed a communication robot, Robovie, and applied it in daily situations, such as peer tutoring at an elementary school and as a museum exhibit guide. His research interests include HAI, interactive humanoid robots, and field trials.

1.6 Merel Keijsers

Merel Keijsers is an assistant professor in psychology at John Cabot University in Rome, Italy. Her training is in social psychology and statistics, and she completed her PhD on the topic of robot bullying at the University of Canterbury, New Zealand. For her PhD, she studied what conscious and subconscious psychological processes drive people to abuse and bully robots; recently, she has gained an interest in how robots influence the way humans view themselves. More generally, having a background in social psychology, she is mainly interested in the similarities and differences in how people deal with robots versus other humans.

1.7 Selma Šabanović

Selma Šabanović is a professor of informatics and cognitive science at Indiana University, Bloomington, where she founded and directs the R-House Human-Robot Interaction Lab. Her research combines studies of the design, use, and consequences of socially interactive and assistive robots in different social and cultural contexts, including healthcare institutions, user homes, and various countries. She also engages in the critical study of the societal meaning and potential effects of developing and implementing robots in everyday contexts. She received her PhD in science and technology studies from Rensselaer Polytechnic Institute in 2007, with a dissertation on the cross-cultural study of social robotics in Japan and the United States. She served as the editor in chief of the journal *ACM Transactions on Human-Robot Interaction* from 2017 to 2023.

1.8 Notes on second edition

The field of HRI, like many fields relating to emerging technology, changes and develops as new technological capabilities become available for the design and implementation of robots and the study of people who interact with them. To ensure that this text maintains its relevance, we updated it in 2023 to cover new technical capabilities as well as new theoretical and methodological developments in the field. We also wanted to add more discussion of conversations about inclusion, societal relevance and impact, and ethical considerations regarding HRI to the original text. Finally, we recognized that our first edition focused largely on social robotics as the main domain of HRI, obscuring human–robot interactions in domains like factories, where people and robots collaborate to work on different tasks; disaster assistance, where people interact with mobile and flying robots to put out fires or save human lives; and even in autonomous driving, where interactions between people and robots may not be focusing on social engagement. In this edition of the book, we reframe our understanding of the social nature of HRI to include HRI and collaboration whose social nature is more broadly construed—in some sense, all robots operating alongside and with humans can be understood as social, and all human–robot interactions can be the purview of HRI research. In late 2022/early 2023, we worked both in person and remotely to update the text and teaching activities provided in the book. We hope you enjoy the new materials!

2

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 these.
- 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 for 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 237 for more on Asimov). Decades ago, these ideas were science fiction, but nowadays, many of these issues are real and present in contemporary societies and have become core research questions in the field of HRI.

This chapter aims to set the table for the rest of the book. Because HRI is an incredibly diverse field, Section 2.1 highlights and explains the main themes included in this book. Section 2.2 covers the interdisciplinary nature of this field, and the consequences for research and robot design are explored. Finally, Section 2.3 provides a timeline of the development of (social) robots and gives an overview of the robots most commonly used in HRI.

Distinguishing physical and social interaction: Robotics at large has traditionally been concerned with the creation of physical robots and the ways in which these robots manipulate the physical world. HRI adds to this and is concerned with the ways in which robots interact with people as part of their social world and how people respond to the presence of robots. For example, when a robot picks up a box in an empty warehouse or cleans an office building after hours, it is sensing and acting in the physical world alone and dealing with the physics of its own body

and its environment. But when the robot takes the box to a warehouse worker who needs to fill it with appropriate materials, delivers coffee to a customer in a café, or chases children around in a courtyard, it is not only dealing with the physical motions needed for those actions, but it must also address the social aspects of the environment. For example, it needs to consider where the children, customers, or the office workers are; how to approach them in a way that is safe and that they consider appropriate; and how to follow the appropriate social rules of the interaction. Such social rules might be obvious to humans, such as acknowledging the presence of others, 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, psychology, and design. Scholars trained in these disciplines have worked together to develop HRI, bringing in methods and frameworks from their home disciplines and also developing new concepts, research questions, and HRI-specific ways of studying and building the robots that interact with people.

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 often 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, in terms of both 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. When a robot has eyes, people make the assumption that the robot can see them. When the robot has a mouth, people assume that the robot can talk. The robots' human-likeness enables humans to use their existing experience of human–human interaction to understand and participate in human–robot interaction. These experiences can be very useful in framing an interaction, but they can also lead to frustration if the robot cannot live up to the users' expectations (as discussed in more detail in Chapter 8).

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

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

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 individuals are confronted with social agents other than humans. Social robots, in this context, can serve as research tools to study psychological mechanisms and theories.

From the very first mention of the term *robot* in Karel Čapek's play *Rossum's Universal Robots*, our vision of the ideal robot has focused on mimicking humanlike capabilities, often represented by a humanoid form, either in a full body, as in Honda's ASIMO (see Figure 2.1), or in parts, such as by robot arms or their more anthropomorphic representation in Sawyer robots. When we look at the current state of the art in HRI, however, we see that robot embodiments are much more diverse—spherical robots can roll around and interact with children (e.g., Sphero, Roball); robots can fly in the air (e.g., drones) or go underwater (e.g., OceanOneK); robots can mimic animals so that

they can encourage petlike interactions with people (e.g., Paro) or even interact with their biological counterparts in nature (e.g., squirrel robot); and robots can look like objects (e.g., suitcases, trash cans, boxes) or common devices, such as buses and cars, and take many other forms. One of the exciting things about HRI is that it can expand our visions of what robots and our interactions with them could be like beyond the familiar anthropomorphic notions.

When robots are not just tools but also teammates, collaborators, companions, guides, tutors, and other types of social interaction partners, their study and design as part of HRI bring up many different questions about interpersonal relationships and societal development, both in the present and in the future. HRI research includes issues related to the social and physical design of technologies, as well as 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 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 policymakers 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 people and robots 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. We also consider how we can understand and study how people perceive robots. 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 broader societal and 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, however, 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 intelligent agents in diverse social contexts differentiates HRI from HCI.

The various disciplines that contribute to HRI 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. One way of understanding the difficulties of working together on a shared project can be based on three barriers (see Figure 2.2) that can occur between designers [D], engineers [E], and scientists (particularly 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 on (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

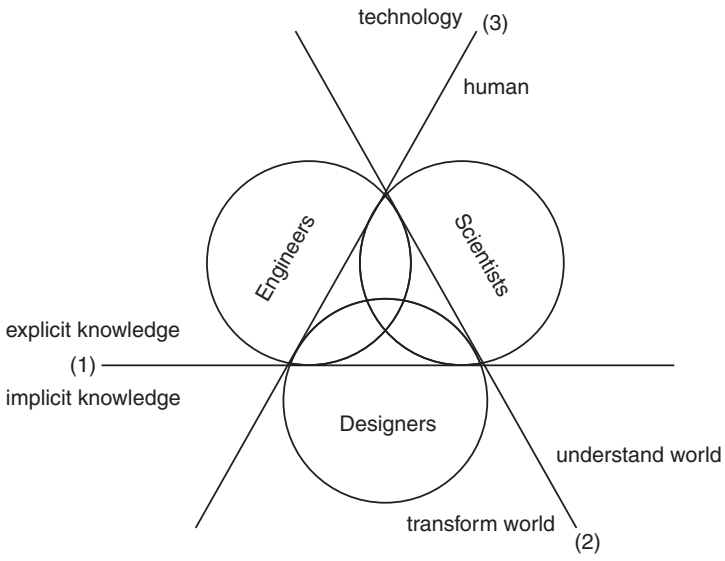

Figure 2.2 HRI taps into several disciplines, and barriers are often experienced between these.