11

Applications

What is covered in this chapter:

- The diverse areas of robot applications where human–robot interaction (HRI) is an important component.
- Applications beyond robots that are studied in a research context.
- Possible future applications.
- Potential problems that would need to be solved when HRI has a larger role in our society.

Human–robot interaction (HRI) has numerous applications expected to make a positive difference in people's lives. HRI is increasingly getting traction in the technology market, and although most applications are still being developed in the academic sphere, adventurous start-ups have popped up that are developing and selling HRI applications, and established information technology (IT) industries are keen to understand and develop technologies that allow robots or robot technology to interact successfully with people. Not all of these enterprises turn out to be successful. Sony, for example, was one of the pioneers of commercial robotics with its Aibo (see Figure 11.1) and Qrio (see Figure 11.2) robots, only to stop its efforts in the field in 2006. However, Sony's efforts were recently rekindled, with a new Aibo appearing in 2018 (see Figure 2.10). After Softbank Robotics released Pepper in 2014, the robot showed up in retail and entertainment roles across the world. Production of new Peppers was paused in 2020. Another example is the Bosch company, which initially supported Mayfield Robotics in developing the Kuri home robot but stopped the project before the official product launch.

A successful HRI application means something different depending on the perspective one takes: the notion of what constitutes success is very different for a researcher compared to an entrepreneur. Whereas a researcher will be interested in measurable outcomes of the robot's use and usability, an entrepreneur might be less concerned about the effectiveness of the robot and will be happy with a "good enough" technical solution that can be brought to market, thus preferring sales figures over scientific figures. Some may even develop unsuccessful applications on purpose for the entertainment value

Figure 11.1 The Sony Aibo ERS-7 (2003–2005) with the Nao (2008–present) robot.

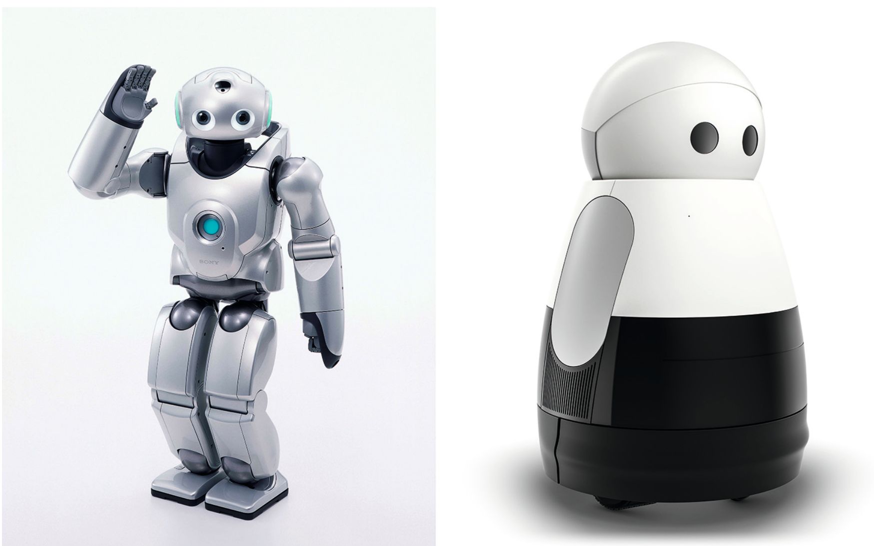

Figure 11.2 Sony's Qrio robot (left) (2003–2006) and Mayfield Robotics' Kuri (right) (2016–2018)—two robots that never made it to the consumer market. (Source: Qrio, Sony; Kuri, Mayfield Robotics)

or to inspire people to think more critically about the uses and design of robotic technology (see the accompanying text box for examples). Similarly, people may evaluate robots differently when they consider them as a research prototype and when they judge them as products they may or may not want to purchase (Randall et al., 2022).

The self-crowned "Queen of Shitty Robots," Simone Giertz is a robot enthusiast who designs service robots that usually perform poorly in their intended application. Her videos on the testing of her different creations not only have entertainment value but also demonstrate how designing robots for seemingly simple tasks can prove to be quite challenging. White's "Helpless Robot," on the other hand, is a machine with a passive personality that asks people to move it around the room, opening up questions about the meaning of machine autonomy and whether our machines serve us or whether it is the other way around.[a]

[a] See www.youtube.com/channel/UC3KEoMzNz8eYnwBC34RaKCQ/

For now, most robot applications remain at the research stage, but this is expected to change rapidly. The first wave of commercial success in robotics took place in automating industrial production; the second wave of commercial success can be considered as robots with simple navigation capabilities, such as warehouse robots and delivery robots; the next wave of commercial success is expected to come from introducing robots in dynamic and open environments populated by people in customer service, companionship, and socially and physically assistive roles. It is here that HRI has its major role to play: a solid understanding of how robots should behave around people and how people respond to and benefit from robots is needed to make the next robot wave a success (Haegele, 2016). We also need to consider the question of robot cost and how consumers may evaluate it in relation to a robot's purported functions and benefits, as well as sources of potential funding to purchase robots for different consumers (e.g., health insurance), which are questions that academic studies of HRI have rarely considered as of yet.

This chapter discusses the more common applications of social robots. Section 11.1 covers the use of robots in customer service, ranging from tour guides to sales bots; Section 11.2 focuses on the use of robots in the educational system. In Section 11.3, robots from different forms of entertainment are introduced. Sections 11.4, 11.5, and 11.6 look at robots in more serious roles, such as healthcare, personal assistance, and services such as delivery and domestic cleaning. Robots fulfilling security tasks are covered in Section 11.7, whereas Section 11.8 briefly discusses collaborative robots. Finally, Section 11.9 considers autonomous vehicles (AVs).

11.1 Customer-facing robots

A novel robot often attracts people's attention; in public spaces like shopping malls and stores, visitors become interested and approach, and children crowd around it. This makes robots an ideal asset for customer service settings, at least during the initial "novelty" stage of a robot's use. Many such applications have already been successfully tested in field research and have been deployed in grocery stores or bank branches (e.g., Pepper providing service at HSBC in

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the United States). Robots have also been deployed in the context of hotels (Nakanishi et al., 2020) to promote "heartwarming interactions." In Japan, people can interact with robots in "robot cafés" in various ways: customers can hold and pet Lovots or Aibos at their tables, they can be served by people with disabilities logged into telepresence robots or by autonomous Pepper robots, and they can even bring their own robots to the café to interact with others (Kamino and Šabanović, 2023). During the COVID-19 pandemic, a Pepper robot was used in a hospital in Brussels to check whether visitors were wearing their masks correctly before entering the hospital.

11.1.1 Tour guide robots

One of the applications developed in the early years of HRI research is the tour guide robot (Burgard et al., 1998; Shiomi et al., 2006; Bose et al., 2022). Typically, a tour guide robot moves from one location to another while providing information about nearby entities; some of them take the user to a requested location. This robot application involves navigational interaction (e.g., the robot safely moving around in an environment it shares with humans) and face-to-face interaction with its users (see Figure 11.3). Along with providing a service to customers, tour guide robots also provide a way for researchers to explore people's open-ended interactions with robots and test out the effects of different interaction strategies on users' perceptions of robots in a somewhat more structured environment.

Figure 11.3 Care-O-bot robot as a museum guide (2023).

There are many instances of successful tour guide applications. One such application is in a museum setting, where a mobile robot is left to autonomously navigate around. Visitors are invited to use a user interface on the robot to indicate whether they want to have a tour guide. Once a tour is requested, the robot leads the visitors to several exhibits, providing a brief explanation at each (Burgard et al., 1998). HRI researchers experimenting with museum robots have found that giving the robot the ability to display emotions can enrich the educational experience and allow the robot to better manage its interactions with people, such as getting them to move out of its way by expressing frustration (Nourbakhsh et al., 1999). An alternative application concerns the retail context, when a customer may want to know where in the store a specific item is kept, and a robot takes the lead to show the customer the way to the appropriate shelf (Gross et al., 2009). A final example is the airport, where a robot can escort travelers to the gate for their next flight (Triebel et al., 2016; Hwang et al., 2022; Chen and VG, 2022).

It is easy to imagine similar scenarios where robots would be helpful. For example, it is common for people to escort other people in daily interactions, either because they need physical assistance or because they want to be accompanied. Robots could be used in this context in the future. One such application being developed by HRI researchers is a guide robot for individuals with visual impairments (Feng et al., 2015). Although the current limitations in robotic hardware and HRI capabilities prevent such uses in the present, technical advancements and further HRI research should enable us to have robots with faster velocity and better navigation capability in human crowds that can be applied for accompanying users in a broader range of environments.

11.1.2 Receptionist robots

Figure 11.4
Receptionist robot.

Receptionist robots are placed at a reception desk and interact with visitors, typically offering information through spoken-language conversation. For instance, Gockley et al. (2005) studied people's interactions with a robot with a display for its head as a receptionist at a university (see Figure 11.4). The robot was able to provide directions and would share daily stories with people who came to chat with it. It turned out that people were sensitive to the robot's moods, and the length of their interactions with it changed based on whether the robot displayed a happy, sad, or neutral expression (Gockley et al., 2006). There is also work that includes multiparty interaction, an HRI constellation that still brings lots of challenges (Moujahid et al., 2022). Moreover, android robots have been used as receptionists in hotels. In this case, users use a graphical user interface to proceed through the check-in process, attended by an android robot and a small humanoid robot that offers greetings to the visitors.

11.1.3 Robots for sales promotion

Another straightforward application of service robots is product promotion in the retail context. In this setting, robots can function as proxies for store clerks, informing customers about the promotions offered by the store. Because people are naturally curious about robots, these robots can easily attract the attention of potential visitors, who will stop to listen and then look around. In Japan, Pepper is already used for this purpose. In the typical use case, robots are not necessarily proactive but instead wait for visitors to initiate interaction. In the research context, researchers study robots that proactively approach customers to offer promotions (Satake et al., 2009). For instance, the famous Geminoid android robot has been deployed in shopping malls in Japan to boost sales (Watanabe et al., 2015; Chen et al., 2022).

11.2 Robots for learning

Social robots have been shown to be particularly effective in assisting in learning and education through social interaction (Belpaeme et al., 2018). This should not be confused with the use of robot building as an educational tool to teach mathematics, programming, or engineering, such as LEGO Mindstorms. Robots can take on various roles in the process of learning: The robot can act as a teacher, taking the students through the curriculum and offering testing opportunities to assess knowledge. As a tutor, a robot would support the teacher in his or her teaching (Kanda et al., 2004). This role is

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actually preferred by teachers and students (Reich-Stiebert and Eyssel, 2016). However, the robot is also often presented as a peer. The peer-like robot has a similar level of knowledge as the learner, and the learner and robot take a learning journey together, with the robot adapting its performance to that of the learner. Robots as peers can also encourage learners to adopt a "growth mindset," which leads to higher achievement (Park et al., 2017b). At the far extreme is the robot that needs to be completely taught by the student. This approach, known as a *care-receiving robot* or *teachable agent*, is effective for two reasons. First, teaching a subject often leads to mastery of that subject, and second, having a less knowledgeable peer can boost the learner's confidence (Hood et al., 2015; Tanaka and Kimura, 2010). Finally, robots could also be used as a sidekick for teachers. In this role, the robot spices up the lesson and makes the learning more entertaining, thus capturing student interest (Alemi et al., 2014).

Tutoring robots may take over specific tasks from the teacher. Because teachers typically deal with class sizes of more than 20 students, they are required to teach to the mean of the class using a broad rather than a personalized style. It has been shown that tutoring has a strong impact on learning. Bloom (1984, p. 4) found that one-to-one tutoring resulted in a two-standard-deviation improvement against a control group, concluding that "the average tutored student was above 98% of the students in the control class." Although research has since shown that the effects are not as large as first observed, there is nonetheless a distinct advantage to the one-to-one tutoring approach (VanLehn, 2011). Social robots in education capitalize on this by offering a one-to-one, personalized tutoring experience.

Robots have been used to teach a wide range of topics, from mathematics to languages and even mindfulness and social skills, both to adults and children. The main contribution of the robot seems to be that its physical presence promotes learning. Although computer-based tutoring programs, also known as *intelligent tutoring systems* (ITSs), are effective (VanLehn, 2011), the social robot adds to this through its social and physical presence. Studies have shown that robots offer a distinct advantage over on-screen social agents or ITSs, and the students learn faster and learn more when tutored by a robot as compared to alternative technologies (e.g., Kennedy et al. 2015; Leyzberg et al. 2012). The reasons for this are still unclear: it might be that the social and physical presence of the robot engages the learner more than just on-screen delivery and feedback, or it might be that the learning experience is more multimodal, thus resulting in a richer and embodied pedagogical exchange (Mayer and DaPra, 2012)—of course, a combination of these two is also possible. It may come as no surprise that socially supportive robots perform much better (Saerbeck et al., 2010). Some socially interactive behaviors can also backfire in learning contexts, leading the student to interpret the robot as a peer rather than a teacher and to engage with it socially rather than focusing on achieving certain learning goals (Kennedy et al., 2015). HRI research is therefore necessary to guide the development of robots that can effectively support learning.

11.3 Robots for entertainment

11.3.1 Pet and toy robots

Robotic pets and toys were among the first commercial robot applications for personal use. After the first doglike robot, Aibo (Fujita, 2001), appeared on the market in 1999 (see Figure 11.1), the development of many other entertainment robots soon followed. Compared with other robotic applications, entertainment robots have been easier to get to market because the functions they perform do not have to be as advanced, and they often use preprogrammed capabilities, such as dancing, talking, burping, and even seeming to develop their knowledge by simply starting to use more advanced preprogrammed skills after a period of time. Some of the most popular robotic toys over the years have been Furby, Sony's Aibo robot dog, and more recently, Cosmo. LEGO Mindstorms was a market leader in the educational toy robot niche but has recently been discontinued; it is followed by a slew of robots that allow children to learn how to code and think computationally, such as Dash and Dot and Ozobot, among many others. The WowWee company is another market leader, with many different robots, including the humanoid robots Robosapiens and Femisapiens and a mobile home robot. The company Sphero developed a robotic ball that could be remote-controlled; following the release of the new series of Star Wars films in 2015, the company amended the design to represent the BB-8 droid, which became one of the most popular holiday toys of that season.

Although most entertainment robots target children and adolescents, many are also enjoyed by adults. The Aibo in particular was very popular with adults, who even started a "black market" of Aibo parts when the robot was discontinued by Sony in 2006. As mentioned earlier, Sony introduced a brand-new version of Aibo in 2018.

Pleo (see Figure 11.5), a *Camarasaurus rex* robot platform, provides a similar complexity of interaction, with various modes of personality and behavior that adapt and change across time and users. These examples show that many robot toys are not necessarily social or humanlike in appearance,

Figure 11.5 Pleo robot (2006–present). (Source: Max Braun)

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but they still elicit strong social responses in children and adult consumers alike.

Considering the variety of ways in which robots can provide entertainment and the popularity of robots among the public in general, it is not surprising that the market for toy robots has been and is expected to stay one of the largest for personal robots (Haegele, 2016).

11.3.2 Robots for exhibitions

Robots are often used in exhibitions and theme parks to entertain audiences. These often-animatronic devices are very robust; they must play the same animation script sometimes hundreds of times per day, with only a brief moment for maintenance between performances. Some robots intentionally look like robots, but others resemble animals, for example, dinosaurs (see Figure 11.6), or people. In these cases, the robot has flexible latex skin, which has been carefully painted to reflect realistic skin coloration and patterns. Most of these animatronic robots have no autonomy: they play a prerecorded script of animation timed to a soundtrack. In rare cases, the robot may have limited autonomy, such as the ability to focus on members of the audience while speaking. A popular example of the use of animatronic robots is the Hall of Presidents located in the Walt Disney World Resort.

11.3.3 Robots in the performing arts

Robots are also sometimes used in the performing arts. One of the first robot performance art pieces was Senster, created in 1970 for Philips' Evoluon in Eindhoven, the Netherlands (Reichardt, 1978). Senster was an electro-hydraulic structure shaped after a lobster's claw, with six hinged joints.

Figure 11.6
Animatronic robot.

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It registered and responded to sound and movement from the environment. It was on display until 1974, when it was dismantled. More recently, 20 Nao robots performed a synchronized dance recital for France Pavilion Day (June 21) at the Shanghai 2010 Expo.

Not all art applications have to be for a broader public. Home theater systems might soon become what their name promises. Imagine a future in which you download the theater script of *Romeo and Juliet* into your robots. You can then either watch the robots perform the play or join in yourself. It is important to note that a major use of robotics—both in the past and currently—is to automate tasks that we do not want to perform ourselves. Industrial robots, for example, were introduced to relieve us of difficult and repetitive manual labor. There is little use in automating tasks that we actually enjoy doing. This does not mean that there is no place for robots in the theater—plays that actually deal with robots should, of course, be cast with robots (Chikaraishi et al., 2017).

Furthermore, there are many ways in which robots can interact with people in art performances, to which the future social robots could contribute as a human counterpart. For example, Hoffman and Weinberg (2010) developed a marimba-playing robot that joins a jazz-like session with a human player. Kahn et al. (2014) revealed that a robot can partner with a human to enhance human creativity in the art-creation context. Nishiguchi et al. (2017) suggest that developing robots that can perform as actors in a play alongside humans can also be a way to develop more humanlike behaviors for robots.

11.3.4 Sex robots

Along with toy robots aimed at the child market, there are also embodied robots and virtual reality (VR) interfaces for the fulfillment of adult entertainment needs. Colloquially known as "sex robots," diverse robotic platforms offer varying levels of humanlike appearance and behavioral response. The RealDoll company, which develops hyperrealistic sex dolls (see Figure 11.7), is working on adding robotic capabilities, including an emotive face and responses, to its base models. Several other producers have developed prototypes of sex robots, although none has yet come to market. It is envisioned that the sex robot industry will continue to grow over the coming years. Devlin (2020) discusses current developments in sexual companion robots, along with the psychological and social implications of these technologies.

11.4 Robots in healthcare and therapy

Healthcare and therapy represent prominent domains of application for robotics (Riek, 2017). In these domains, social robots are used to offer support, education, and diversion to patients, with an eye toward improving healthcare and therapy outcomes. The practice of using social robots in healthcare is referred to as *socially assistive robotics* (SAR) (Tapus et al., 2007; Feil-Seifer and Matarić, 2011). Healthcare robots are targeted for

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Figure 11.7 The Harmony X sex robot by RealDoll exhibited in a museum (2023).

diverse populations, very often older adults (Broadbent et al., 2009; Broekens et al., 2009). The use of robots to support care raises many ethical issues and requires careful consideration of ethics in design (Van Wynsberghe, 2016; Stahl and Coeckelbergh, 2016), including those regarding the potential impacts of using robots for care on people's autonomy and independence (Sharkey and Sharkey, 2012; Sparrow and Sparrow, 2006), the authenticity of care relationships with robots (Turkle, 2017), and concerns about overreliance on robots (Borenstein et al., 2017).

11.4.1 Robots for senior citizens

Robotic assistants could make a world of difference for senior citizens who wish to stay independent as long as possible. For example, the ElliQ robot (Figure 11.8) combines an artificial intelligence (AI) assistant-like function (e.g., providing news updates and weather forecasts) with basic social interaction (e.g., sharing inspirational quotes and simple daily small talk) and more personalized help (e.g., setting reminders, doing basic wellness checks, helping with messaging and calling loved ones). Thus, although unable to physically assist in daily tasks, robots like these could help people by reminding them to take their medications (Pineau et al., 2003) and can provide pre-clinic or tele-clinic support at home, thus reducing costs for medical services (Robinson et al., 2014).

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Figure 11.8 The ElliQ robot (2019–present) from Intuition Robotics is designed to interact with senior citizens. (Source: Intuition Robotics)

Although senior citizens and people with mild cognitive impairments are a key target audience for robot developers who want to offer technology-mediated social, emotional, and cognitive rehabilitation and diversion, there are other target groups that can benefit from social robots.

For example, the Paro robot is a seal-like robot equipped with sensors that allow it to detect when it is being picked up or stroked (see Figure 2.8). It can respond by wriggling and making seal-like noises. Paro has been used in a multitude of studies with elderly people, and positive psychological, physiological, and social effects of long-term interaction with the robot have been documented (Wada and Shibata, 2007). The robot is used as a companion in care homes and stimulates not only human–robot interactions but also interactions between the residents. It has been able to reduce feelings of loneliness and improve the residents' quality of life. Paro has been commercially available in Japan since 2006 and in the United States and Europe since 2009. It is interesting to note that although it is purchased by many individuals for home use in Japan, in Europe and the United States, the robot is almost exclusively purchased by healthcare institutions and companies. Furthermore, some robots, such as NEC's PaPeRo (see Figure 11.9), have only ever been released in Japan.

Figure 11.9 NEC's PaPeRo robot has been available in different versions, such as PaPeRo R-100, PaPeRo Mini, and PaPeRo i (1997–present).

11.4.2 Robots for people with autism spectrum disorder

Children and adults with autism spectrum disorder (ASD) are another group for which social robots are often developed and used. It has been shown that people with ASD generally respond well to robots, and there has been a large body of research looking into how robots can be effectively used to support ASD therapy (Diehl et al., 2012; Scassellati et al., 2012; Thill et al., 2012).

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Figure 11.10 A range of robots used in ASD therapy. From left to right, Nao (2008–present), Elvis (2018–present), Kaspar (2009–present). and Zeno (2012–present). (Source: Elvis, Brubotics–Vrije Universiteit Brussel; Kaspar, Kerstin Dautenhahn, Ben Robins, Adaptive Systems Research Group, University of Hertfordshire, UK)

Many types of robots have been used in a therapeutic context to support children with ASD (Robins et al., 2009; Pop et al., 2013). These include a wide range from humanoid robots, such as Kaspar and Nao, to zoomorphic robots, such as Elvis and Pleo (see Figures 11.10 and 11.11).

The predictable nature of robot behavior and the fact that robots are nonjudgmental have been credited as potential reasons why using them in interactions and therapeutic interventions with individuals with ASD is successful. The robots are either used as a focal point for the interaction between the therapist and the patient or are used to train and improve children's social competencies and their ability to regulate and interpret emotions.

11.4.3 Robots for rehabilitation

Robots are also used to support physical rehabilitation. This can be done by offering physiotherapy and providing encouragement and mental support. Social robots have been shown to be effective in cardiac-focused rehabilitation by providing encouragement and social facilitation during cardiac exercises (Kang et al., 2005; Lara et al., 2017). Robots can also be used to encourage users to adopt healthy practices or to change unhealthy habits. For example, Kidd and Breazeal (2007) describe a robot that acts as a weight-loss coach, and Belpaeme et al. (2012) describe the use of a robot to support children

Figure 11.11 The Kiwi robot was designed by researchers from the University of Southern California for research into personalized support of children with autism and elderly users. (Source: Maja Matarić, University of Southern California)

diagnosed with diabetes. Kidd's early research developed into a robotic start-up and healthcare robot called Mabu.

Robots can also be used as prosthetic devices. The restoration of the function of the lower limbs, arms, and hands through robotics has received considerable attention (Bogue, 2009). Although these developments are largely the concern of mechatronics, there is a role for HRI in the study of the acceptance and usability of robotic prostheses.

Figure 11.12 Ommie (2022-present) is a robot that helps people manage their anxiety through deep breathing. (Source: Kayla Matheus and Yale University)

11.4.4 Robots to support mental health

A subset of healthcare that is getting increased attention since the COVID-19 pandemic is mental health, which is an issue of rising importance worldwide. The development of robotic technologies to help support mental health is concomitantly occurring in many different domains (Riek, 2016). Researchers have been working with teenagers to develop robots that assist teens in managing their anxiety and other mental health challenges at school (Karim et al., 2022; Björling et al., 2020); robots to achieve anxiety reduction have also been evaluated with adults (Matheus et al., 2022) (see Figure 11.12). Participatory design has also been used to create robots that adults can use to manage symptoms of depression (Lee et al., 2017; Randall et al., 2019; Bhat et al., 2021). Along with benefiting people with mental health conditions, robots can also be used to alleviate the burden of care for caregivers and to improve relationships between caregivers and care receivers (Moharana et al., 2019).

11.5 Robots as personal assistants

Smart-home assistants, unobtrusive devices that are placed in the home or the office and are often voice-operated, have been a recent and largely unexpected success of cloud-connected technology. Technology giants such as Amazon, Google, Microsoft, Apple, and Samsung have raced to build voice-operated assistants, and some offer hardware products that are built around this technology. Amazon's Alexa, Apple's Siri, Microsoft's Cortana, and the Google Assistant have found embodiment on a range of devices, with shapes and sizes ranging from a hockey puck to a shoebox. These devices offer a vast range of services, but they are most often used to request simple information, such as the time, weather, or traffic, or to stream music. These devices can engage in only very short social exchanges, often limited to chitchat, such as telling a joke.

Recently, a number of commercial ventures have been launched that offer social robots as personal home assistants, perhaps eventually to rival existing smart-home assistants. Personal robotic assistants are devices that have no physical manipulation abilities and limited locomotion capabilities. They have a distinct social presence and have visual features suggestive of their ability to interact socially, such as eyes, ears, or a mouth (see Figure 11.13). They might

Figure 11.13 Personal assistant robots: from left to right, the Nabaztag robot (2009–2011), the Jibo robot (2017–2018), and the Buddy robot (2018–present). (Source: Jibo, Jibo Inc.; Buddy, Blue Frog Robotics)

be motorized and can track the user around the room, giving the impression of being aware of the people in the environment. Amazon's Astro (Figure 2.11) may even be able to deliver a beer, as long as someone puts it in its cupholder, and can allow homeowners to check in on their homes while they are away. Although personal robotic assistants provide services similar to those of smart-home assistants, their social presence offers an opportunity that is unique to social robots. For instance, in addition to playing music, a social personal assistant robot would express its engagement with the music so that users would feel like they are listening to the music together with the robot (Hoffman and Vanunu, 2013). These robots can be used as surveillance devices, act as communicative intermediates, engage in richer games, tell stories, or be used to provide encouragement or incentives.

11.6 Service robots

Service robots are designed to help humans in various onerous, often called "dull, dirty, and dangerous," tasks. The tasks performed by such robots are typically simple and repetitive, and they often do not involve explicit interaction with people. HRI research considers such robots when they operate in everyday human contexts and therefore come into regular contact with people, including house-cleaning and delivery robots and robots that offer personal assistance.

11.6.1 Cleaning robots

Cleaning robots are widely used in homes. The most well-known cleaning robot is Roomba; it is also the most commercially successful personal service robot to date. It is a small robot, approximately 30 cm in diameter, that has two wheels to enable it to move around, dust sensors to know where it needs to clean, cliff sensors to avoid falling down the stairs, and of course, vacuuming capability. The initial version of the Roomba moves around randomly in a house, turning when it comes to a wall, and over a period of time, it manages to clean up the room. (In general, that is; pets can undermine this goal horribly—see the accompanying box). Some more recent cleaning robots have mapping and localization capabilities, as well as collision-avoidance capabilities, which allow them to cause fewer problems with furniture and other things in a house. There are many other vacuum-cleaning robots for the home, as well as the mopping robot Scooba.

Dreaded by every pet-owning Roomba user, the *Poopocalypse* is the unfortunate yet inevitable event where a pet leaves a dropping somewhere in the house, and the Roomba encounters it before the owner can clean it up, spreading it all across the house. These incidents are common enough that iRobot formulated an official response, warning Roomba users not to use their Roomba unsupervised if they own a pet (Solon, 2016).

Commercial service robots coming onto the market have provided HRI researchers with opportunities to study how people respond to and use such robots in everyday circumstances. Fink et al. (2013) performed ethnographic studies of Roombas in user homes to identify common use patterns, and they also noticed how users prep their homes so that Roomba can do its job. Other researchers have found that users sometimes like to display Roombas as a sophisticated technology, whereas at other times, they try to disguise or hide them because they are deemed unsightly (Sung et al., 2007, 2009). Forlizzi and DiSalvo (2006) also explored how people's models of service affect the way they expect robots to interact with them, including how robots can best recover from mistakes made while providing services, such as bringing users the wrong drink.

11.6.2 Delivery robots

Delivery robots carry objects from one place to another. Warehouse robots are the ones that are most frequently used, like the ones used in Amazon warehouses. There are many start-ups that seek to provide delivery robots, for outdoor use as well as for inside buildings. Outdoor delivery robots include those used for delivering food and daily goods from supermarkets and restaurants. There were serious needs for such robots during the COVID-19 pandemic, when people were asked to stay home. Although perhaps desirable for the direct users, these robots sometimes turn out to be a nuisance for bystanders, who have to dodge them on already-busy city streets. Robots can also help people carry their belongings and follow them as they move around public spaces, such as the Gita series of commercial robots.[1]

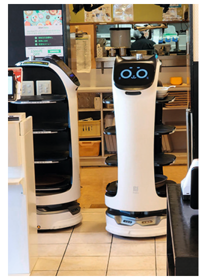
Mutlu and Forlizzi (2008) showed that the workflow and patient profile of the hospital ward in which the Aetheon TUG delivery robot was deployed could make the difference between a successful and unsuccessful

[1] See https://piaggiofastforward.com

ISBN: 9781009424233 (https://www.cambridge.org/9781009424233).

implementation. Some hotels use room-service robots to deliver goods from the service desk to guest rooms. Delivery robots are also used in restaurants (see Figure 11.14). Because delivery robots are increasingly used in human co-located environments, they need better HRI capabilities. For instance, a robot in a restaurant needs to avoid obstructing customers while delivering dishes to tables or should at least be designed in a way to let customers avoid it without becoming annoyed by it.

Figure 11.14 BellaBot delivery robot.



11.7 Security robots

Among the various available applications, robots used for security purposes are among the most controversial. Robots are also commonly considered as potential providers of security in homes and public spaces. These robots could provide services ranging from patrolling around the environment to a police robot that could use real force against people. A security robot that patrols around may not necessarily invite controversy in some cultures, such as in Japan. Some of them have a function to record unusual events, and some may approach suspicious persons in a friendly way, without being intimidating or scary. These robots are often designed to work with human workers, to save their time in roaming around when no problematic events are occurring and only asking for help in important moments. However, in some other cultures, similar robots invited more controversy. For instance, the K5 robotic security guard (see Figure 11.15) has been deployed at some shopping malls in the United States. It roams around the environment to monitor crime and alerts human authorities if it senses something suspicious. A prime example of a service robot that was not accepted in its environment, the K5 robot has fallen victim to a variety of abusive behaviors, ranging from an attack by a drunken man while patrolling a parking lot in Mountain View, California, to being tackled and covered in barbecue sauce while attempting to chase off homeless people from a nongovernmental organization's doorstep in San Francisco.

Figure 11.15 Knightscope K5 (2013–present). (Source: Knightscope)

Police robots have invited even more serious societal controversy, resulting in prevention of their use. For instance, New York City police once tried to use a robotic dog, Spot from Boston Dynamics, for surveillance purposes. Having a robot to observe a dangerous place could potentially save citizen and police lives; however, citizens were concerned about this use, and the trial was terminated (Zaveri, 2021). Recently, even more controversy was caused by a decision to allow robots to be used by the police as weapons against perpetrators, even allowing for the use of "deadly force" via robot (Abené, 2022). This inspired discussion on whether police should be able to injure or kill people using a robot, in cases where this might save the lives of citizens or police and there is no alternative choice. The robots were initially approved for this use; however, just a week later, San Francisco supervisors reversed their decision and rejected such usage because of the objections from citizens (Press, 2022). Ethics scholars have also commented on the potential lethal use

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of robots in policing, calling for a moratorium on such designs because of the legal and technical challenges inherent in such technologies (Asaro, 2016).

11.8 Collaborative robots

Collaborative robots are gaining importance in the automation industry. Traditional industrial robots typically are stiff, strong, and have limited sensory capabilities. Because of this, humans are not allowed near a powered industrial robot. In contrast, collaborative robots—or *co-bots*, for short—have safety features and a mechatronic design that allow them to operate near people or even work together with people.

Some co-bots are equipped to interpret or produce social signals, such as the Walt robot, which has a face attached to its robotic arm (see Figure 11.16). The Baxter robot (see Figure 2.9) is a two-armed robot that is able to display a range of facial expressions on its screen, signaling various internal states. An embarrassed blush, for example, signals to the human coworker that the robot is at a loss about what to do next.

The deployment of co-bots in industrial manufacturing contexts and the workplace in general may fundamentally change the notion of collaborative teamwork. In positive scenarios, co-bots should be able to help humans get more pleasure and efficiency from their work. In the worst case, collaboration with robots could backfire through a reversal of the roles of humans and robots, leading to humans serving robots rather than vice versa.

11.9 Self-driving cars

Self-driving cars are, in essence, robots in which the user is in the passenger's seat. Although fully autonomous vehicles (AVs) are still not widely available, most new cars now have some form of onboard advanced driver-assistance system (ADAS) technologies, such as lane following, adaptive cruise control, automatic parking, predictive braking, pedestrian protection systems, and

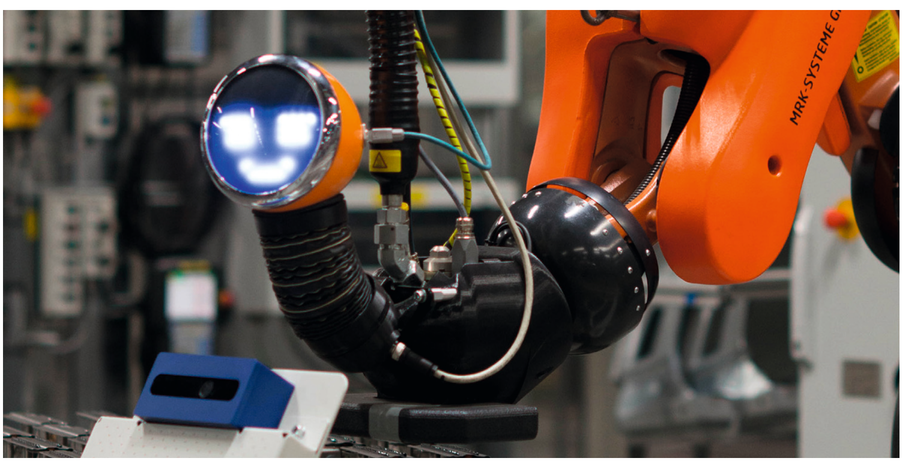

Figure 11.16 Walt (2017–present), a collaborative robot, working at the Audi car factory in Brussels to apply glue to car parts. It has a headlight-shaped head with an animated face to communicate its internal state to its human coworkers. (Source: Copyright IMEC)

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blind-spot warning systems. The Society of Automotive Engineers (SAE) International has developed a taxonomy to describe six increasing levels (SAE levels 0 through 5) of capability for driving automation systems, which are widely used to describe and understand these capabilities.[2] Most current AVs have achieved level 3 under the SAE standards, whereas Waymo's 2020 safety report claimed that its AVs had the ability of level 4, which would mean that the AV can demonstrate 28 core competencies from the recommendations made by the U.S. Department of Transportation. These technologies, unlike the traditional adaptive cruise control or lane assistance, also include a safe stop when the system fails (Waymo, 2020).

Most traditional car manufacturers, many start-up companies, and large IT companies are currently heavily investing in the development of AVs. Some companies already have products in the market. Although the levels of autonomy are reasonably well defined, the terminology used by the car industry is much more ambiguous. For example, Tesla's cars have a driver-assistance system that conforms to level 2 of the SAE levels of driving automation, which the company calls "Autopilot"—a name that suggests the far more advanced full autonomy of SAE level 5 (Layton, 2022). In its July 14, 2020, decision (Az. 33 O 14041/19), the Munich Regional Court ruled that Tesla branding its autonomous tech as "Autopilot" is misleading to consumers. In May 2021, the California Department of Motor Vehicles started to investigate Tesla over its self-driving claims (Mitchel, 2021). Starting in 2020, Tesla began stating the following on its "Autopilot" website: "Current Autopilot features require active driver supervision and do not make the vehicle autonomous." Only in 2021 and after at least three years of delays did Tesla roll out its "Full Self-Driving" software update in its beta program (Hawkins and Lawler, 2021). The latter enables drivers who paid for the "Autopilot" to use many driver-assist features on local, nonhighway streets. Other manufacturers offer driving-assist features, such as adaptive cruise control and lane following. General Motors, like many other traditional car manufacturers, is dramatically increasing its spending on the development of AVs (Wayland, 2021). Even Apple is developing an AV, initially envisioned without a steering wheel or pedals but then redesigned for full autonomy only on highways (Bloomberg, 2022).

AVs are expected to have a considerable impact on the future of transportation (Litman, 2020; National Roads and Motorists' Association, 2018). Positive effects of AVs include the potential to be more environmentally friendly by driving more economically (Fagnant and Kockelman, 2015). Because of their ability to communicate with each other and with the infrastructure, AVs are able to reduce traffic congestion by rerouting vehicles to their destinations. They also have the potential to radically change our transportation system because ride-sharing and even car ownership sharing become much easier to implement. Our society could be serviced by a fleet of autonomous robotic taxis that could even offer carpooling trips. Such AVs would also enable

[2] See www.sae.org/standards/content/j3016_202104/

people who are currently unable to drive to take advantage of an individual-based transportation system. Children, people with disabilities, and the elderly could safely ride to their destinations (Lutin et al., 2013).

Possibly most important, AVs are able to increase road safety (Petrovic et al., 2020). The U.S. National Highway Traffic Safety Administration showed that 94% of car crashes can be attributed to human error (Department of Transportation, 2015). AVs do not get drunk, high, or distracted. They can be programmed to comply strictly with speed limits and traffic rules. They can even warn each other about accidents or obstacles on the road ahead. It has even been argued that once AVs have reached a safety record that is better than that of average human drivers, humans should be banned from driving altogether (Sparrow and Howard, 2017). As we design and plan for the expanded use of AVs, we need to keep in mind that the projections regarding the lifesaving capabilities of AV use commonly assume widespread adoption of these vehicles, in which all or a majority of cars on the roads are autonomous. The actual capabilities of current vehicles and AV research (Nascimento et al., 2019) and the adoption of AVs on the road are still a long way away from this best-case scenario.

It is important, therefore, to remember that AVs are large and potentially dangerous robots that exhibit autonomous behavior. Although AVs can avoid some human errors, they are also likely to introduce new sources of HRI errors. Although many social robots and conversational agents rarely pose a threat to our physical well-being, several crashes of AVs have demonstrated the destructive potential of these robots not only for the drivers but also for pedestrians and cyclists. For example, Tesla cars with active autopilot have been involved in several fatal crashes, starting as early as 2016[3]. The first bystander killed by an AV was Elaine Herzberg, who was struck and killed by an autonomous Uber car on March 18, 2018. The accident report notes that the autopilot was programmed with a certain threshold to continue driving even if an abnormal sensor reading was received (National Transportation Safety Board, 2019). This threshold is necessary because otherwise, AVs would have to stop too frequently, creating a safety risk for others. Some risk taking is part of conventional driving as well. For example, our streets would be much safer if the speed limit were universally reduced to 30 km/h, but that might also increase traffic bottlenecks and certainly the time to reach our destination. We accept the trade-off between safety and speed in the design of our driving rules, despite the fact that it results in thousands of deaths each year, based on societal norms and legal frameworks. When it comes to design decisions that govern the behavior of AVs, however, discussions are ongoing about what the effects of various machine perception capabilities, control and planning algorithms, and design factors would be and how to understand and manage risk and differential outcomes to AV drivers and others sharing the road with them (e.g., see Evans et al., 2020; Geisslinger et al., 2021; Cunneen et al., 2019).

[3] www.tesladeaths.com

The progress in the aviation industry can serve as an example of how to interpret the risks and possibilities of AVs as part of our transportation systems. In the early days of aviation, piloting an airplane was incredibly dangerous. Both Wright brothers crashed with their airplanes and suffered severe injuries. It did not stop them from building the first motorized airplane. Since then, air travel has become one of the safest forms of transportation. According to the National Transportation Safety Board, there is, on average, less than 1 fatality per 100,000 flight hours.[4] It has to be pointed out that most airplanes already extensively use autopilots. Whereas the aviation industry has very strict safety regulations, processes, and reporting, the same cannot yet be observed for AVs. Fatal AV crashes may receive a disproportionately large amount of media attention, which can inhibit their development and, in turn, cost people's lives (Bohn, 2016). It is also important to consider that technology alone cannot bring the desired benefits; social and physical structures and regulations will need to be in place to support the responsible and acceptable use of AVs. Furthermore, there are many open questions about how AVs and traditional vehicles will be able to most successfully share the road in the extended time of transition to more widespread adoption of AVs.

Independent, accurate, and reliable information about the safety of AVs is necessary, similar to the reporting done in the aviation industry. Without such clear information about the safety record of AVs, it will be difficult, if not impossible, for people to consent to their usage, which further complicates the regulation of risk and responsibilities. It has been shown that communicating the risks of AVs is a challenge in itself (Bartneck and Moltchanova, 2020). But the risk and responsibilities are still being negotiated between the manufacturers, insurance companies, governments, and drivers. The Department of Motor Vehicles in California is a good example of making safety data of AVs available publicly. California's AV incidents are being published online and have already been analyzed up until the year 2017 (Favaro et al., 2017).

The uptake of AVs and the associated regulatory changes are unparalleled within the HRI community. This has partly to do with danger that AVs pose to humans, but it is also due to their high potential usefulness. It can be argued that AVs are the most commercially successful form of HRI. The interaction between AVs, drivers, and other participants in the road traffic, however, remains difficult.

Many of these systems require an effective human–machine interface for the driver of the car. In addition, self-driving cars require interfaces that allow them to interpret the actions and intentions of other traffic users, and the car will need ways of expressing its intentions to other users (Brown, 2017). Car drivers use a wide range of signals to communicate their intent to others. For example, slowing down when nearing a crosswalk can signal to pedestrians that they have been noticed and that it is safe to cross. The Jaguar Land Rover developed a more explicit way of communicating with pedestrians by putting "googly eyes" on its cars to signify attention.

[4] See www.bts.gov/content/fatality-rates-mode

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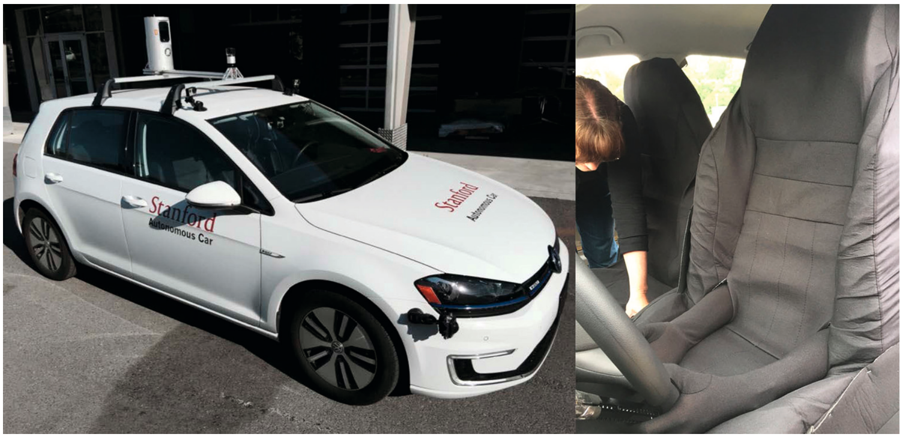

Figure 11.17 A mock-up of a self-driving vehicle, in which a driver is disguised as a car seat, used to study people's responses to the behavior of self-driving cars. (Source: Wendy Ju)

Interaction with the driver does not only happen through the car's interface but also often requires autonomous technology to communicate why a decision was made. Koo et al. (2015) show how a message that explains why an action was taken, such as automated braking, is preferred over a system that merely reports the action.

HRI studies can help understand how traffic users and passengers respond to autonomous cars. Rothenbücher et al. (2016) present a paradigm in which a driver is disguised as a car seat, giving the impression that the car is self-driving (see Figure 11.17). This deception allows for carefully controlled studies on how people perceive and respond to self-driving cars without the need for a fully self-driving car.

The Partners in Automated Vehicle Education showed in its 2020 report that Americans are skeptical of current AV technology.[5] Again, clear and reliable information from independent sources is necessary to build the trust of the general public toward AVs. Kyle Loades, the chairman of the National Roads and Motorists' Association, explained that the best way to adopt a new technology and build up users' trust is through trials (National Roads and Motorists' Association, 2018). The success of the trials can, of course, only be evaluated if the resulting data are being shared openly.

11.10 Remotely operated robots

11.10.1 Applications of remotely operated robots

There are several application examples of remotely operated robots. Robots used for planetary exploration have some autonomous navigation capability, and they receive commands from human operators on Earth as well. PackBot (see Figure 11.18) is a scout robot used in a military context; a human operator tele-operates PackBot while it searches for bomb traps, thus clearing the road for military vehicles. Also in the military context, a human operator can

[5] See https://pavecampaign.org/wp-content/uploads/2020/05/PAVE-Poll_Fact-Sheet.pdf

Figure 11.18 PackBot (2016–present). (Source: Endeavor Robotics)

operate a drone from a faraway location during military operations. In search-and-rescue scenarios, an operator controls a robot that moves on the ground or through the sky to find a person in need.

Apart from military contexts, drones have even been used in domestic (Obaid et al., 2020) and educational contexts (Johal et al., 2022), with such types of drones being coined "social drones"(Baytas et al., 2019), that is, drones that operate autonomously in spaces co-shared with humans. Tele-operation also represents a relevant use case in the medical domain (Partikska and Kattepur, 2022; Al Momin and Islam, 2022), for instance, when it comes to robot-assisted surgery.

In these tele-operation scenarios, a human operator commonly needs to work with some level of autonomy in the robot. A robot may autonomously navigate around, but the operator may need to provide destinations for efficient use. The robot's ability to avoid risks (e.g., collisions with obstacles or attacks from a hostile entity) can be poor, and hence the operator needs to intervene before the robots are seriously damaged.

> People in the military have reported becoming very attached to their robots, despite the fact that these were designed without any capability for social interaction. Military robots have been named, have been awarded battlefield promotions, and have received medals of honor from their human supervisors (Garreau, 2007).

11.10.2 Human–robot teams

Depending on the complexity of the task and the level of autonomy, one operator could control multiple robots, or one robot would need multiple

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operators for control. Such a *human–robot team* has long been a focus of HRI research, typically in the case of robots for navigation tasks, exploring the appropriate level of autonomy and efficient numbers of robots and humans in a team (Goodrich and Schultz, 2008). Those studies include studies to control a robot team (robot swarms) all at once, such as giving a command to a team and controlling the formation of the robot team.

More recently, studies of human–robot teams have started to cover robots used for social interaction (Glas et al., 2011). Fully autonomous robots capable of natural social interaction are still a rather futuristic scenario; however, once some difficult components, such as natural-language understanding and error handling, are addressed by human operators, it will be more realistic to use capable semiautonomous social robots in various daily-life scenarios. For this future scenario, studies of human–robot teams are indispensable.

Operators interact with remotely operated robots via a user interface (see Figure 11.19); here, there are many common HRI problems to address, as with other types of human–robot interactions. For instance, the robot system needs to acquire an appropriate level of trust from the operator—not too much, not too little. There are similar ethical issues to be considered. For example, if the autonomy system fails, who is responsible? Is it ethical to design a system that would allow such a failure of autonomy?

At a more general level, the study of team dynamics involving multiple robots and humans is highly relevant because although HRI research most often studies dyads of mainly one robot interacting with one human, in public spaces, such as shopping malls or museums, it is likely that a robot will encounter multiple humans. This, of course, will bring technical challenges for human–robot dialogue (e.g., person recognition, turn-taking, joint attention). Work by Jung et al. (2015) has investigated the supporting role of robots in ameliorating team conflict and has shed light on the longitudinal evolution of trust in human–robot teams (De Visser et al., 2020); for an overview, see Sebo et al. (2020).

Figure 11.19 The T-HR3 robot (2017–present) can be remotely controlled using a dedicated user interface. (Source: Toyota)

Figure 11.20 OriHime robots are remotely operated by people with disabilities, who are depicted on the name tags worn by the robots. (Source: Photos by Waki Kamino)

11.10.3 Telepresence robots and avatar robots

Telepresence robots have started to appear on the market as well and can be used, for example, to give a presentation at a remote place or to interact with people in a different location. Telepresence robots can come in many shapes, from mechanistic to zoomorphic to highly humanlike. They can be robots with screens displaying virtual characters, representing the people who control them. Such a robot is also referred to as an *avatar robot*, given that it represents the alter ego of the person who operates it to work in their place. Avatar robots can be used for various applications, such as customer service, learning, entertainment, and healthcare, as explained in this chapter, and also can be used for physical tasks (see, e.g., Figure 11.19). In the Dawn Avatar Robot Café in Tokyo, workers with physical disabilities interact with customers by remotely operating the humanoid telepresence robots OriHime and OriHime-D (see Figure 11.20) (Kamino and Šabanović, 2023). Recent research on a semiautonomous Geminoid robot, the android ERICA (Kubota et al., 2022), showed that interlocutors even align their attitudes to those of the robot they tele-operate. Using physically embodied telepresence robots rather than videoconferencing systems may be particularly useful in educational settings, such as when a student is absent because of illness (Fitter et al., 2018; Newhart et al., 2016). It may also support long-distance learning (Schouten et al., 2022).

11.11 Future applications

Many of the applications introduced in this chapter are already available today. As technologies keep advancing, however, other types of future applications will emerge. For instance, researchers envision that daily appliances can be more automated and connected, as a network of devices within a smart home, for example. Several research groups also envision that individual robots can provide interfaces for such smart homes (Bernotat et al., 2016). Researchers have also started exploring how people might react to robotic furniture and appliances. Sirkin et al. (2015) studied how a robot ottoman should interact with people and also explored interactions with an interactive chest of drawers. Yamaji et al. (2010) developed a set of social trash boxes that use social cues, such as approaching and bowing, to motivate people to throw away their trash; they also created a set of robotic dishes that can be summoned by a user by rapping on the table. Osawa et al. (2009) investigated how people may respond to home appliances being anthropomorphized, such as equipping a refrigerator with eyes or a printer with a mouth so that it can speak to a user.

Future developments of robots will also likely extend the capabilities within existing application domains. For example, healthcare robots are now being developed not only to provide companionship but also to monitor the behavior and health status of their users (e.g., Autom) and also possibly to assist with tasks of daily living (e.g., Care-O-bot). Educational robots may take on more active roles in tutoring, particularly in domains such as second-language learning (Belpaeme et al., 2015). Following data-based applications in other domains, robots might also take advantage of their interactive capabilities to collect different kinds of information on users. We can expect robotic sensing and interaction capabilities to become more distributed in our lived environment, engaging with us through various everyday devices that may not immediately come across as robots.

11.12 Problems for robot application

There are various problems that might prevent successful market updates in the commercial market and as applications in everyday life. These include the potential for robot design to lead to misplaced and eventually disappointed expectations, overreliance on and addiction to robots, misuse and abuse of robots, and engagement with robots taking people’s attention away from other concerns.

11.12.1 Public relations

A significant number of social robots do not seem to have any current practical use. At best, they are communication platforms, such as Pepper. At times, companies start developing or using robots for no other reason than to promote themselves. Being perceived as being active in the area of robots, AI, and cryptocurrency (feel free to extend this list with the latest technology buzzwords) is enough for some companies to engage with the respective technologies. Nippon Telegraph and Telephone Corporation (NTT), for example, started a whole subsidiary called “NTT Disruption” that bought the failed robot Jibo (see Figure 11.13). NTT Disruption was disrupted in 2023 and closed for good. The traditional Japanese telecom company is not alone in its quest to inspire investors. XPeng, a Chinese electric vehicle manufacturer, developed a rideable robotic unicorn. Kawasaki has its own rideable robotic goat called "Bex." Although it might be fun to ride on these robots, this can hardly be considered a practical form of transportation.

It is not only technology companies that engage in robot public relations (PR). Many companies buy robots without having any good use for them. The Christchurch International Airport, for example, bought several Pepper robots without any possibilities of a practical benefit from it. They are used as glorified boomboxes, playing back the same information over and over without any interaction with passengers (see Figure 11.21).

Figure 11.21 Pepper at the Christchurch airport.

Marketing in itself has a function in our society. Grabbing the attention of potential customers and clients is important. But the business of attracting attention is fast paced and relentless. A TV commercial, for example, has a short life span. The Henn na Hotel in Tokyo started in 2015, with its main attraction being its robotic workforce. Although this might have initially attracted visitors, its novelty did wear off, and in 2019, the hotel reduced its robotic workforce by half to cut down on operation costs.

Developing robots is difficult and takes time. Although PR can offer a boost in attention and finances, it is a very unreliable foundation on which to build a robotic future.

11.12.2 Addressing user expectations

Users often enter into interactions with robots with certain expectations, often rooted in exposure to specific conceptions of robots in the popular news media, fiction, or the promises made in robot advertising. The design and presentation of robots can also inspire certain expectations in users. For example, if a robot speaks in English, users will likely expect that it will be able to understand spoken English. The more humanlike the robot looks, the more human capabilities it may be expected to have. The cost of disappointing user expectations can be that the robot is perceived as incompetent, and people are therefore less willing to use it. Paepcke and Takayama (2010) showed that it is possible, however, to manage user expectations by describing the robot's abilities realistically; in fact, it is better to set expectations lower rather than higher. User expectations could also be managed through the design; for example, many social robots are designed with infant-like appearances to decrease expectations and increase tolerance for error (Hegel et al., 2010).

11.12.3 Addiction

There is a concern that robots—specifically, social robots—will make people overreliant on the social and physical interaction offered by robotic devices. One can easily imagine a future in which some people prefer robots as interaction partners, perhaps even as life partners, over humans Borenstein and Arkin (2019). A less extreme scenario would be one where robots are preferred

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over people for some interactions. Although this is not necessarily cause for concern—many people already prefer online shopping over a trip to the store, for example—we should be wary of the negative consequences of substituting social human interaction with social robot interaction. One concern is that robots will be seen to offer friendship, a state that, of course, is artificial to the robot but might be perceived as genuine by the human user (Elder, 2017). Conversations with a robot could be pleasant, even cathartic, but there is a danger that because the robot panders to the user, offering an interaction that is pleasing, this might make the user overreliant on the robot, causing the human to crave the robot's company. Because robots are most likely to be under the control of corporations, to some extent, there is a concern that dependence, and perhaps even addiction, will be a sought-after property in robots. Lessons should be learned from our interaction with connected devices when designing robots (Turkle, 2016).

Gazzaley and Rosen (2016) provide an interesting read about the "dark side" of our high-tech age.

11.12.4 Attention theft

As can already be observed with mobile devices, technology attracts our attention, and robots, too, could cause "attention theft." Neuroscience research has demonstrated that our attention is grabbed by motion and sound, and this is exacerbated when the sound and movement are lifelike and social (Posner, 2011). Robots pose an easy opportunity for attention theft, either unintentionally or by design. When designing and deploying robots, care should be taken that the robot has a mechanism to identify when not to engage with the user or draw attention through its actions, however unintentional. In particular, this should be carefully done in cases where the robot might attract attention away from a human interaction partner.

11.12.5 Loss of interest by user

The so-called novelty effect is frequently discussed in the HRI literature, suggesting that people pay more attention to a novel entity and express a preference to use it because it is unfamiliar; however, such effects are usually not long lasting (Kanda et al., 2004; Koay et al., 2007b). Researchers have tested various robot applications in research contexts and have revealed that the novelty effect lasted anywhere from a few minutes to, at most, a few months. Therefore, even if a one-shot experiment were to reveal positive outcomes regarding the performance and evaluation of a robot, we cannot be sure that the positive effect will prevail in the long run. Longitudinal studies are needed to provide further evidence for positive HRI over time. An important goal is to enable robots to sustain users' interest over time and across multiple interactions (Tanaka et al., 2007; Kidd and Breazeal, 2007; Kanda et al., 2007b).

11.12.6 Taking advantage and robot abuse

One of Asimov's laws for robotics is that the robot should never do harm or allow harm to be done to a human. Although this seems a necessity to attain the level of trust that is required for humans to accept robots invading their everyday lives, it may also provide the unintentional side effect of people trying to take advantage of the rule. If everyone knows that self-driving cars will automatically yield when cut off, will anyone ever let them merge? If a patrolling robot is programmed to avoid bodily contact (lest the human get hurt in the process), how exactly is it supposed to prevent a burglar from running away? Tests with self-driving cars have already shown that humans will capitalize on the robots' tendency to avoid conflict (Liu et al., 2020). Analyses of human–chatbot interactions indicate that users will try to get the chatbot to engage in sexual role play (see, e.g., Brahnam and De Angeli, 2012; Keijsers et al., 2021), even though the chatbot in this case is not intended for that use and cannot respond in kind.

Taking this behavior more to the extreme, one runs into the issue of robot abuse. It has been noted by various scholars that a small but pervasive minority of humans will engage in a negative way with robots when they are left unsupervised. This tendency has been observed across countries and on different continents—for example, Japan, (Brscić et al., 2015), South Korea (Salvini et al., 2010), the United States (Vincent, 2017; Mosbergen, 2015), and Denmark (Rehm and Krogsager, 2013). Moreover, although children seem especially prone to engage in robot-bullying behavior (see Figure 11.22), presumably due to their strong tendency to anthropomorphize and as part of developing their social skills, adults have also been recorded kicking, hitting, and verbally abusing robots.

Figure 11.22 A child kicking a robot in a shopping mall.

Notably, the abusive behavior that is generally displayed shares more similarities with intimidation and bullying than with vandalism. This makes sense, considering that robots are recognized as social agents by humans. The exact motivation for why people bully robots has not been found out yet, although frustration (Mutlu and Forlizzi, 2008), entertainment (Rehm and Krogsager, 2013), and curiosity (Nomura et al., 2016) have been suggested to play a role.

Robot abuse poses a number of problems. Obviously, a robot that is repeatedly attacked (as reported by e.g. Salvini et al., 2010; Mosbergen, 2015) may get damaged and will need to be replaced or repaired, and for this duration of time, it will not be able to fulfill its tasks. Similarly, obstruction (as observed by Brscić et al., 2015; Mutlu and Forlizzi, 2008) will prevent a robot from carrying out whatever it needs to carry out to be useful. Moreover, tackling (Vincent, 2017) or stepping in front of a moving robot (Liu et al., 2020; Brscić et al., 2015) may result in a collision, which may not only damage the robot but also injure any humans involved. Verbal abuse, although perhaps not directly disruptive to the task, may still disturb any bystanders and make them uncomfortable.

Unfortunately, abusive behavior has been shown to be remarkably persistent. Verbal reprimands or requests to stop from the robots have been shown to have little effect. Shutting down until the abuse has stopped (Ku et al., 2018) or running away from the bullies (Brscić et al., 2015) have been somewhat successful, but these methods may not always be feasible. Active intervention from bystanders has been shown to be unlikely, both in field studies (Salvini et al., 2010; Rehm and Krogsager, 2013) and in experimental settings (Tan et al., 2018). The field of HRI will have to continue investigating the motivation behind and effective deterring of these human behaviors in order to allow robots to effectively do their jobs in society.

11.13 Conclusion

Markets for robots are growing (Haegele, 2016), but many of the robots that are available on the market still feature limited capabilities for social interaction, for instance, pet robots and service robots. In the domain of navigation, great strides have been made, as documented by applications such as delivery robots and self-driving cars. Before deploying any such technologies, empirical research and evaluation studies need to be conducted in order to test and validate the new technologies and get them ready for the market. With more research in open-ended, real-world contexts, it is likely that researchers will come up with new application concepts for robots and find novel niches that existing robotic technologies can successfully occupy.

Questions for you to think about:

- Try to think about a couple of new future applications that are not yet mentioned in the chapter. For each application that comes to mind, briefly describe possible technical problems and solutions.
- Suppose you would be able to prepare the technical solutions for the applications you thought of in the previous question. Think about market potential: Who are the targeted users, how expensive will your robots be, and which consumers would be willing to buy the respective robots?
- Suppose your applications are successful in terms of technical preparation and the potential market. What problems might they cause? How would you avoid or at least reduce such problems?

11.14 Exercises

The answers to these questions are available in the Appendix.

** **Exercise 11.1 Application areas** What roles are social robots likely to play in the field of education? Select one or more options from the following list:

1. Platform for learning how to program
2. Janitor
3. Student
4. Tutor
5. Teachable agent
6. Principal

**** Exercise 11.2 Application areas** In which application areas are social robots expected to make a strong impact? Select one or more options from the following list:

1. Politics
2. Cleaning
3. Military
4. Therapy for mental illness
5. Tour guiding
6. Burglary

**** Exercise 11.3 Autonomous vehicles** What benefits are AVs expected to deliver to society? Select one or more options from the following list:

1. Reduce traffic congestion
2. Enable people with disabilities to ride
3. Enable elderly to ride
4. Reduce price of vehicles
5. Enable better car co-ownership
6. Enable children to drive
7. Reduce fuel price
8. Increase driving speed
9. Reduce electricity consumption
10. Improve road safety
11. Increase number of vehicles on the road
12. Reduce emissions
13. Increase number of colors for cars

*** Exercise 11.4 Robots and their applications** Select the true statements from the following list:

1. BellaBot is a delivery robot.
2. PackBot is a delivery robot.
3. K5 is a cleaning robot.
4. Jibo is a tele-operated robot.
5. Roomba is a cleaning robot.

*** Exercise 11.5 Dependency** Humans do not abuse robots. True or false?

1. True
2. False

Future reading:

- The International Federation of Robotics publishes the *World Robotics Report* each year. (Part of the report is free to download: https://ifr.org/free-downloads/).
- Broekens, Joost, Heerink, Marcel, and Rosendal, Henk. Assistive social robots in elderly care: A review. *Gerontechnology*, 8(2):94–103, 2009. doi: 10.4017/gt.2009.08.02.002.00. URL https://doi.org/10.4017/gt.2009.08.02.002.00
- Ford, Martin. *The Rise of the Robots: Technology and the Threat of Mass Unemployment*. Oneworld Publications, London, 2015. ISBN 978-0465059997. URL http://worldcat.org/oclc/993846206
- Leite, Iolanda, Martinho, Carlos, and Paiva, Ana. Social robots for long-term interaction: A survey. *International Journal of Social Robotics*, 5(2):291–308, 2013. doi: 10.1007/s12369-013-0178-y. URL https://doi.org/10.1007/s12369-013-0178-y
- Nourbakhsh, Illah Reza. *Robot Futures*. MIT Press, Cambridge, MA, 2013. ISBN 9780262018623. URL http://worldcat.org/oclc/945438245
- Belpaeme, Tony, Kennedy, James, Ramachandran, Aditi, Scassellati, Brian, and Tanaka, Fumihide. Social robots for education: A review. *Science Robotics*, 3(21):eaat5954, 2018. doi: 10.1126/scirobotics.aat5954. URL http://doi.org/10.1126/scirobotics.aat5954