4

Design

What is covered in this chapter:

- How a well-designed robot can lift interactions to the next level (physical design);
- How people do not treat robots as an assembly of plastic, electronics, and code but, rather, as humanlike entities (anthropomorphism);
- How HRI research draws on psychological theories of anthropomorphism to design and study people's interactions with robots;
- Design methods and prototyping tools used in human–robot interaction.

How does a pile of wires, motors, sensors, and microcontrollers turn into a robot that people will want to interact with? Although it sounds like magic, the trick of turning metal and plastic into a social interaction partner is in the iterative and interdisciplinary process of robot design.

Robot design is a fast-growing field of research and practice in human–robot interaction (HRI), and the need to develop robots that are able to interact with humans challenges existing ways of designing robots. To date, most robots are developed by engineers, and their ability to interact with humans is then tested later on by social scientists. This process of design starts from the inside and builds up to the outside—solving technical issues first and designing the robot's appearance and behavior to fit. For example, a mobile platform such as a TurtleBot (see Figure 4.1) might be used as a starting point, with the desired sensors and actuators added to the body later on. If time allows, a casing could be designed to cover up all the technology. The robot's appearance and the specific social interaction capabilities then have to be built on top of this technical infrastructure. This common approach to robot building is also known as the "Frankenstein approach": we take whatever technology is available and put it together to get certain robotic functions. A lack of consideration of the social context of use within the design process can lead to surprising effects in robot interaction, however.

Alternative, more holistic approaches to robot design start by con-

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Figure 4.1 A TurtleBot2 (2012–present) platform. (Source: Yujin Robot)

sidering who will use it, where, and how. Based on the characteristics of the users and context of use, one can then decide on specific robot design features, such as appearance, interaction modalities, and level of autonomy. This might be termed a more "outside-in" mode of developing robots, in which the design process starts from the interaction that we expect the robot to be engaged in, which will determine its outside shape and behaviors. Once the design has been settled upon, we work all the technology into it.

Designers are trained to approach the design of artifacts in this way (see Figure 4.2 for an example) and are able to make valuable contributions (Schonenberg and Bartneck, 2010). The unique contributions include the aesthetics of the robots, but designers also have the skill to create thought-provoking robots that challenge our understandings of the roles of humans and robots.

This form of robot design often requires incorporating expertise from several disciplines—for example, designers might work on developing specific concepts for the design, social scientists may perform exploratory studies to learn about the potential users and context of use, and engineers and computer scientists need to communicate with the designers to identify how specific design ideas can be realistically instantiated in working technology (Šabanović et al., 2014). HRI design can take advantage of existing robots, designing specific behaviors or use tasks for them that fit particular applications, or it can involve the development of new robot prototypes to support the desired interactions. In either case, HRI design both takes advantage of existing design methods and develops new concepts and methods specifically suited to the development of embodied interactive artifacts (i.e., robots).

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Figure 4.2 Mythical robots designed from the outside to the inside. First, the shape of the robots was sculptured before fitting the technology into it.

4.1 Design in HRI

4.1.1 Robot morphology and form

A common starting point for designing HRI is to think of what the robot is going to be doing. There is a debate about whether form follows function, in which the shape of an object is largely determined by its intended function or purpose, or if the reverse holds true. However, in HRI, form and function are inherently interconnected and thus cannot be considered separately.

Contemporary HRI designers have several different forms of robots to choose from. Androids and humanoids most closely resemble humans in appearance, but they have a lot to live up to in terms of capabilities. Zoomorphic robots are shaped like animals with which we are familiar (e.g., cats or dogs) or like animals that are familiar but that we do not typically interact with (e.g., dinosaurs or seals). HRI designers, eager to make robot appearances commensurate with their limited capabilities, also often design minimalist robots, which explore the minimal requirements necessary for inspiring social HRI, such as Muu (see Figure 4.4, left), or Keepon (see Figure 4.4, middle). The arguably most minimalistic robot is the busker robot, which consisted of a pair of animated sandals on top of a box with a signpost in front of it proclaiming "Naked Invisible Guy" (Partridge and Bartneck, 2013) (see Figure 4.4, right).

Figure 4.3 Robovie-MR2 (2010) is a humanoid robot controlled through a cell phone.

Recently, along with these organism-based robots, the HRI field has started considering "robjects," interactive robotic artifacts whose design is based on objects rather than living creatures (e.g., Robot Ot-

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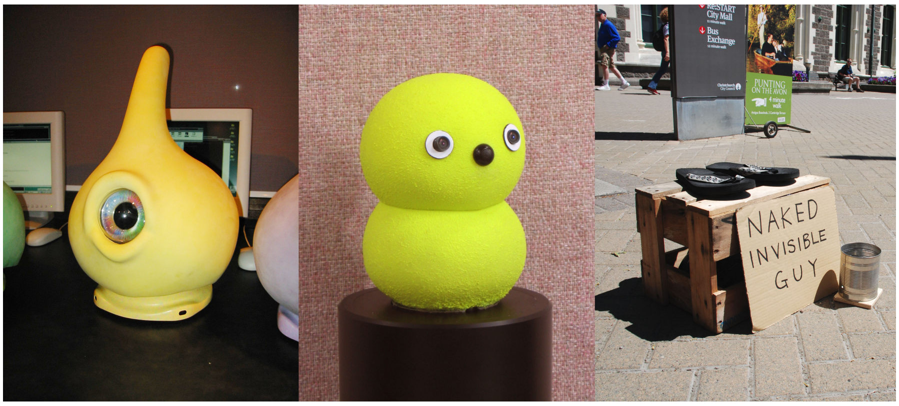

Figure 4.4 Zoomorphic and minimalistic robots: Muu (2001–2006), Keepon (2003–present) and Naked Invisible Guy.

Figure 4.5 Sociable Trash Box robots are an example of robjects—robotic objects with interaction capabilities. (Source: Michi Okada)

toman, social trashcans (see Figure 4.5), robotic piggy banks (Fink et al., 2014). Because the design space of robots is relatively large and considers questions regarding form, function, level of autonomy, interaction modalities, and how all those fit with particular users and contexts, an important aspect of design is figuring out how to make appropriate decisions about these various design aspects.

4.1.2 Affordances

Another important concept in HRI design is the notion of affordances. This notion was initially developed as a concept in ecological psychology (Gibson, 2014), where it referred to the inherent relationship between an organism and its environment. For example, a person might want to throw a rock when he or she sees it, but a mouse would want to hide behind it. This concept was amended by Don Norman (Norman, 2008) to describe the perceivable relationships between an organism and its environment that enable certain actions (e.g., a chair is something to sit on, but so is a stair).

A designer needs to design a product while making its affordances explicit. Furthermore, he or she needs to incorporate user expectations and cultural perceptions. For Norman, these "design affordances" are also an important way to develop common ground between robots and humans so that people can understand robot capabilities and limitations appropriately and adapt their interactions accordingly. A robot's appearance is an important affordance because people tend to assume that the robot's capabilities will be commensurate with its appearance. If a robot looks like a human, it is expected to act like a human; if it has eyes, it should see; if it has arms, it should be able to pick up things and might be able to shake hands. Another affordance can be the robot's interaction modalities. If a robot speaks, for example, saying "Hello," people will also expect it to be able to understand natural language and carry on a conversation. If it expresses emotions through facial expressions, people might expect it to be able to read their emotions. Other robotic affordances can be based on technical capabilities; for example, if it has a touch screen on its body, people might expect to interact with the robot through the touch screen. Because robots are novel interaction partners, the affordances used by designers are particularly important for signaling appropriate ways of engaging with them.

4.1.3 Design patterns

Because the focus of HRI is the relationship between humans and robots, the task of HRI design is not only to create a robotic platform but also to design and enable certain interactions between humans and robots in various social contexts. This suggests that the main units of design that need to be considered are not only the characteristics of individual robots (e.g., appearance, sensing abilities, or actuation) but also what Peter Kahn calls "design patterns" in HRI, inspired by Christopher Alexander's idea of design patterns in architecture (Kahn et al., 2008) Such patterns describe "a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice" (Alexander, 1977, p. x).

Within HRI, Kahn et al. (2008) suggest that patterns should be abstract enough that you can have several different instantiations, that they can be combined, that less complex patterns can be integrated into more complex patterns, and that they serve to describe interactions with the social and physical world. For example, the didactic communication pattern (where the robot assumes the role of a teacher) could be combined with a motion pattern (where the robot initiates a movement and aligns it with the human counterpart of the interaction) to create a robotic tour guide. Kahn et al. suggest that HRI design patterns can be developed based on observation of human interactions, prior empirical knowledge about humans and robots, and designers'

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experiences with HRI, through an iterative design process. Some patterns they developed and have used in their designs are things like the "initial introduction" of the robot, or "in motion together," where the robot moves along with the person. Although Kahn et al.'s design patterns are not meant to be exhaustive, they emphasize the idea that the design should focus on the relationship between humans and robots.

4.1.4 Design principles in HRI

When combining the two ideas of design affordances and patterns in the process of HRI design, the usual design types that robots may be divided into, such as androids and humanoids, zoomorphic robots, minimally designed robots, or robjects, are no longer the main design focus or question. Instead, designers consider how different robot forms and capabilities fit into or express particular HRI design patterns and how they can be designed as affordances that appropriately signal the robot's interaction capabilities and purpose. With this in mind, HRI researchers have suggested some of the following principles to consider when developing the appropriate robot forms, patterns, and affordances in HRI design.

Matching the form and function of the design: If your robot is humanoid, people will expect it to do humanlike things—talk, think, and act like a human. If this is not necessary for its purpose, such as cleaning, it might be better to stick to less anthropomorphic designs. Similarly, if it has eyes, people will expect it to see; if it talks, they will expect it to be able to listen. People can also be prompted to associate specific social norms and cultural stereotypes with robots through design; for example, researchers have shown that people might expect a female robot to be more knowledgeable about dating or that a robot made in China would know more about tourist destinations in that country (Powers et al., 2005; Lee et al., 2005)

Underpromise and overdeliver: When people's expectations are raised by a robot's appearance or by introducing the robot as intelligent or companion-like, and those expectations are not met by its functionality, people are obviously disappointed and will negatively evaluate the robot. Sometimes these negative evaluations can be so serious that they affect the interaction. To avoid such problems, it is better to decrease people's expectations about robots (Paepcke and Takayama, 2010), which might have been increased by how robots are portrayed in society, as described in the "Robots in Society" chapter (see Chapter 11). This might even include not calling your design a robot because the word itself often connotes quite advanced capabilities to members of the public.

Interaction expands function: When confronted with a robot, people will, in effect, fill in the blanks left open by the design depending on

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their values, beliefs, needs, and so on. It can thus be useful, particularly for robots with limited capabilities, to design them in a somewhat open-ended way. This allows people to interpret the design in different ways. Such an open-ended design approach has worked particularly well with, for instance, the seal-like robot Paro (see Figure 2.6). This baby seal robot invokes associations with pets that people have had, but it also does not get compared to animals they know, such as cats and dogs, which would inevitably lead to disappointment. As a consequence, Paro becomes a natural part of the interactions with humans and passes as a petlike character even though its capabilities are significantly below those of a typical domestic animal or that of an actual seal baby (Šabanović and Chang, 2016).

Do not mix metaphors: Design should be approached holistically—the robot's capabilities, behaviors, affordances for interaction, and so forth should all be coordinated. If you design a humanlike robot, people may find it disturbing if it has skin covering only some parts of its body. Similarly, if the robot is an animal, it may be strange for it to talk like an adult human or try to teach you mathematics. This is related to the Uncanny Valley (see p. 52) because inappropriately matched abilities, behaviors, and appearance often lead to people having a negative impression of the robot.

> Take a look at the two pictures in Figure 4.6. How do they make you feel? Although both of these android representations of the science-fiction writer Philip K. Dick are perhaps a bit strange and uncanny, the one that seems unfinished and shows the robot's insides also mixes design metaphors—the robot is both humanlike and machinelike, making it even more disturbing.

Like Kahn's design patterns, these design principles are not exhaustive but are meant to inspire thinking about how to approach designing HRI in a way that acknowledges and incorporates the interdependence between human and robot capabilities, the need for interaction partners to be intelligible to and support each other, and the effects of the context of interaction on its success.

4.2 Anthropomorphization in HRI Design

Have you ever found yourself yelling at your computer because it suddenly crashes while you are working on an essay that is due in just a few hours? You urge the computer to please bring it back again after restarting, gently touching the mouse after realizing that, indeed, the file reopens and you can continue. You sigh in relief because "Genius"—that's what you call your computer when no one is around to hear you—has not let you down. In fact, what you have pictured now is an

Figure 4.6 Philip K. Dick Robot (2005; rebuilt in 2010).

ordinary scenario of a person humanizing an object, anthropomorphizing it. What a tongue twister. But what's it about, in fact?

Anthropomorphization is the attribution of human traits, emotions, or intentions to nonhuman entities. It derives from ánthrōpos (meaning "human") and morphē (meaning "form") and refers to the perception of human form in nonhuman objects. We all experience anthropomorphism in our daily lives. "My computer hates me!"; "Chuck (the car) is not feeling well lately"; "That grater looks like it has eyes"—you've either heard or uttered the sentiment before. The latter is a special example of anthropomorphization called *pareidolia*, the effect of seeing humanlike features in random patterns or mundane objects. The *Viking 1* spacecraft took a photo of the Cydonia area on Mars on July 25, 1976 (see Figure 4.7). Many people saw a face on Mars's surface, which sparked many speculations about the existence of life on Mars. The National Aeronautics and Space Administration (NASA) sent its Mars Global Surveyor to the exact same location in 2001 to take higher-resolution photos under different lighting conditions, which revealed that the structure photographed in 1976 is certainly not a human face.

Anthropomorphization is a natural outgrowth of the significance of social interaction and social cognition in human life. It is also a main theme of design and research in HRI. We will discuss anthropomorphism here in some detail as a case study of a specific design theme in HRI that incorporates technical development, psychological study, and design to enable social HRI. A robot's level of anthropomorphism is one of the main design decisions that robot designers need to take

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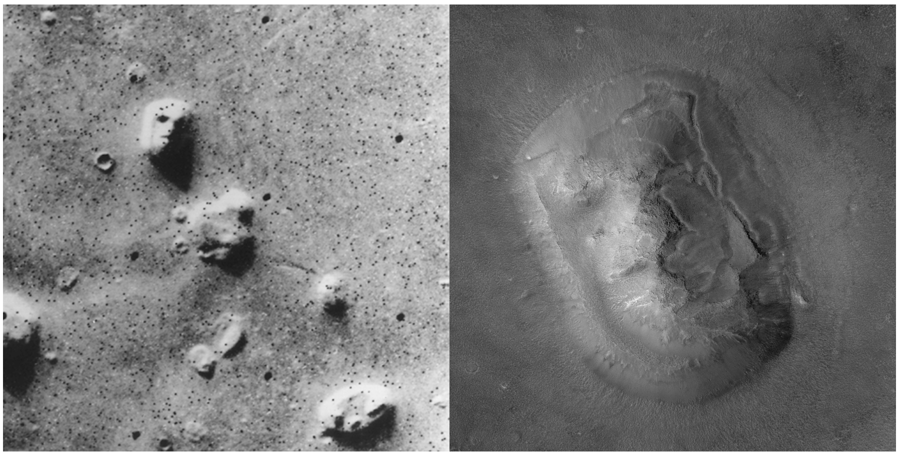

Figure 4.7 The face on Mars is an example of pareidolia. On the left is the photo from 1976, and on the right is the same structure photographed in 2001. (Source: NASA/JPL, NASA/JPL/MSSS)

into account because it influences not only the robot's appearance but also the functionality it needs to offer.

4.2.1 Anthropomorphization and robots

People's innate predisposition to anthropomorphize the things around them has become a common design affordance for HRI. In anthropomorphic design, robots are constructed to have certain humanlike characteristics (see Figure 4.9), such as appearance, behavior, or certain social cues, which inspire people to see them as social agents. At one extreme, android robots are designed to be as humanlike as possible; some have been fashioned as exact replicas of living humans, like a moving Madame Tussaud's wax figure (like Geminoid in Figure 4.8), or as representations of aggregated human features (e.g., Kokoro). Humanoid robots use a more abstract notion of human-likeness in their anthropomorphic designs. ASIMO, for example, has a human body shape (two arms and legs, a torso, and a head) and proportions, but it does not have eyes. Rather, its head resembles an astronaut's helmet. Nao similarly has a humanlike body, as well as two light-emitting diode (LED) eyes that can change in color to connote different expressions, but no mouth. Some other humanoids, such as Robovie, Wakamaru, and Pepper, are not bipedal but have arms and have heads with two eyes.

Nonhumanoid robots, however, can also have anthropomorphic features. The minimalist Keepon has two eyes and a symmetrical body, as well as displays of behavioral cues for attention and affect that inspire anthropomorphization. Google's autonomous car prototype has an almost cartoon-like appearance, with wide-set headlights and a button nose that suggest an anthropomorphic appearance. Finally, giving robots an animal-like appearance and/or behavior, for example, Pleo

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Figure 4.8 The Geminoid HI 4 robot (2013), a replica of Hiroshi Ishiguro. (Source: Hiroshi Ishiguro)

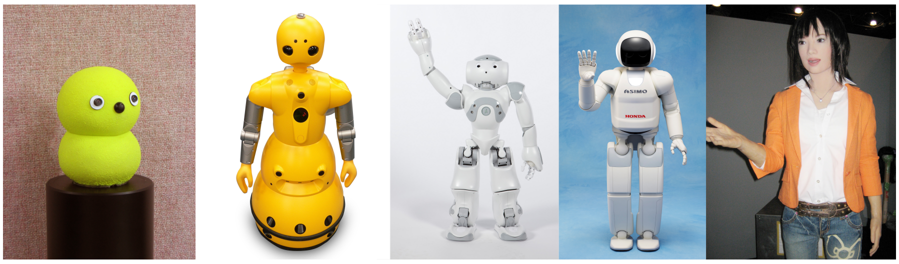

Figure 4.9 People readily anthropomorphize all kinds of robots, with appearances ranging from minimalist to indistinguishable from the human form. From left to right: Keepon, Wakamaru (2005–2008), Nao (2008–present), ASIMO (2000–2018), and Kokoro's Actroid (2003–present) android.

(see Figure 10.5) and Roomba with a tail by Singh and Young (2012), can also be seen as a form of anthropomorphic design because it takes its inspiration from people's common anthropomorphization and social perception of animals.

Anthropomorphism has been key to animation designers for some time, only relatively recently sparking the interest of social psychologists. Disney's Illusion of Life (Thomas et al., 1995) has inspired several social robotic projects, such as Wistort et al.'s Tofu, which displays the animation principles of "squash" and "stretch" (Wistort and Breazeal, 2009), and Takayama et al.'s work with the PR-2 using animation to give the robot apparent goals, intentions, and appropriate reactions to events (Takayama et al., 2011). Animation principles such as anticipation and exaggerated interaction have also been applied to robot design, for example, in Guy Hoffman's Marimba player (Hoffman and Weinberg, 2010) and music companion robots (Hoffman and Vanunu, 2013). These anthropomorphic designs take advantage not only of appearance and form but also of behavior in relation to the environment and other actors to evoke ascriptions of human-likeness.

Anthropomorphism in robot design includes factors related to form and appearance as well as factors relating to behavior, but all rely on people's ability to imaginatively imbue robots with traits and abilities that go a bit beyond what they might in fact have.

4.2.2 Theorizing anthropomorphism

A psychological perspective

In the classic engineering-oriented literature on anthropomorphism, researchers have mainly focused on assessing the perceived appearance of the robot. Going beyond this notion, recent theorizing in psychology has provided a complementary perspective on the nature of anthropomorphism. The theoretical framework proposed by Nicholas Epley and colleagues (Epley et al., 2007) has been influential both in psychology and in robotics and serves to broaden our understanding of the notion of anthropomorphism, its causes, and its consequences. Epley and colleagues have suggested three core factors that determine anthropomorphic inferences about nonhuman entities: effectance motivation, sociality motivation, and elicited agent knowledge. Let us introduce these concepts briefly.

Firstly, effectance motivation concerns our desire to explain and understand the behavior of others as social actors. This might be activated when people are unsure about how to deal with an unfamiliar interaction partner. Most people are still relatively unfamiliar with robots as social interaction partners, so it is easy to imagine that being asked to socially engage with a robot could elicit effectance motivation in them, thus increasing their tendency to anthropomorphize robots. People might therefore attribute humanlike characteristics to robots to psychologically regain control over the novel situation they find themselves in. In this case, anthropomorphization can reduce the stress and anxiety associated with human–robot interaction.

Second, anthropomorphization of robots could also be caused by sociality motivation, particularly by people who lack social connections. In this case, people may turn to nonhuman entities as social interaction partners to address their feelings of situational or chronic loneliness. Supporting this idea, previous research has shown that people who have been made to feel lonely in an experimental situation, or who are chronically lonely, anthropomorphize robots to a greater extent than people who are sufficiently socially connected (Eyssel and Reich, 2013).

Lastly, elicited agent knowledge refers to the way in which people use their commonsense understanding of social interactions and actors to understand robots. For example, Powers et al. (2005) showed that people who considered women to be more knowledgeable about dating norms behaved toward male and female robots as if they also had differing competencies regarding dating; for instance, they used more time and words to explain dating norms to a male robot. This factor in particular can be used to guide the design and technical implementation of social robots for various tasks.

These three determinants shed light on the psychological mechanisms underlying why we tend to humanize nonhuman entities. This includes the attribution of emotions, intentions, typically human traits, or other essentially human characteristics to any type of nonhuman entity, real or imagined (Epley et al., 2007). The basic assumption is that people use self-related or anthropocentric knowledge structures to make sense of the nonhuman things—or in our case, robots—around them. Human resemblance in appearance and behavior triggers anthropomorphic judgments, and people may thus attribute traits and emotions to a technical system despite the fact that the system, indeed, is merely a piece of technology. This, in turn, not only affects the social perception of robots but also the actual behavior displayed toward them during an interaction. Research by Reeves and Nass (Soash, 1999) has already demonstrated in the context of human–computer interaction (HCI) that anthropomorphization of computers and other media occurs automatically. Whether this holds true for robots, though, is currently still under empirical debate (Zlotowski et al., 2015). The three-factor model of anthropomorphism, however, has been thoroughly empirically tested and validated with social robots (Eyssel, 2017).

The Uncanny Valley

Mori (1970) made a prediction about the relationship between the anthropomorphism of robots and their likeability (see Figure 4.10). The idea is that the more humanlike robots become, the more likable they will be, until a point where they are almost indistinguishable from humans, at which point their likability decreases dramatically. This effect is then amplified by the ability of the robot to move.

Mori et al. (2012) translated the original paper to English in collaboration with Mori himself. It is important to note that Mori only proposed this idea and never did any empirical work to test his ideas. Moreover, Mori used the term 親和感 (shinwa-kan) to describe one of his key concepts. The translation of this concept to English remains challenging—it has been translated as likeability, familiarity, and affinity. Other researchers have approached the problem by asking participants about the eeriness of the robot instead. Unfortunately, Mori's theory has been used and abused to explain a huge number of phenomena without proper justification or empirical backup. It is often used to explain why certain robots are being perceived unfavorably, without studying the exact relationship between the features of the robot at hand and its likability. Anthropomorphism is a multidimensional concept, and reducing it to just one dimension does not model reality

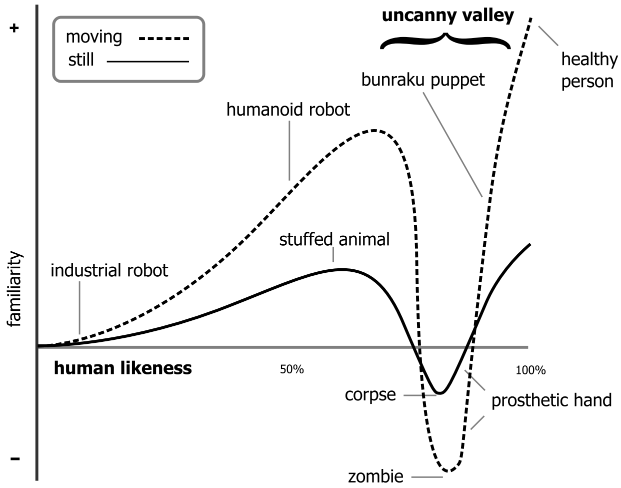

Figure 4.10 Mori's Uncanny Valley theory.

adequately. Moreover, the more humanlike robots become, the greater is the risk of getting a certain aspect of their appearance or behavior wrong and thereby decreasing the level of likability (Moore, 2012). A simple possible explanation of why humanlike robots are liked less than, for example, toy robots, is that the difficulty of designing a robot to perform to user expectations increases with its complexity.

4.2.3 Designing anthropomorphism

Robot designers treat anthropomorphism as a characteristic of the robot itself, whereas social scientists see anthropomorphism as something that a human attributes to the robot. Considering both of these together suggests that anthropomorphism is about the relationship between robot design and people's perceptions of robots.

Design approaches

To trigger anthropomorphic inferences, robot designers can take into account the dimensions of robot appearance and behavior, among many other aspects. By exploiting these aspects, they can achieve an immediate perception of the robot as more or less humanlike.

Robot appearance

Graphical illustration shows us that often only a few lines on a sheet of paper are needed to evoke the human form. In the same manner, anthropomorphism in robots can be very simple: just having two dots suggesting eyes and a simple nose or mouth is sufficient to suggest the robot is humanlike. This can be further enhanced by adding more human features, such as arms or legs, but these do not necessarily do very much to further increase the anthropomorphization. Although there

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are many reasons why robots look increasingly humanlike, anthropomorphization can be achieved with only a minimal set of humanlike features. Whereas androids mimic human appearance in most ways, simple robots such as Keepon and R2D2 are already very effective at triggering people to anthropomorphize. Thus, a large body of research has documented how minimal design cues might be sufficient to elicit a humanlike perception.

Robot behavior

A second approach to increasing anthropomorphization is to design the behavior of an artifact such that people perceive humanlike characteristics in its behavior. Heider and Simmel (1944) showed how simple geometric shapes—triangles and circles—moving against a white background evoked people to describe their interactions in terms involving social relationships (e.g., these two are friends; this one is the attacker) and humanlike feelings and motivations (e.g., anger, fear, jealousy). Animators understand how motion, rather than form, can be extremely powerful for expressing emotions and intents. A surprisingly wide range of humanlike expressive behavior can be communicated through movement alone, without the need for humanlike form.

> *The Dot and the Line: A Romance in Lower Mathematics* is a 10-minute animation film by Chuck Jones, based on a short book by Norton Juster. It tells the story of the amorous adventures of a dot, a line, and a squiggle. Even though the visuals are minimal, the viewer has no problem following the story. It is a prime example of how motion rather than form can be used to communicate character and intent.

Many robots are not humanoid in form or do not have humanlike features but are still anthropomorphized. A robot vacuum cleaner trying to wriggle its way out from under a table will be described as "being lost" or "not knowing what it wants," humanlike descriptions that have little to do with the actual perception and processing of the robot but that help us communicate to others what the robot is doing.

Robot builders can actively encourage anthropomorphization. One effective method is to increase the reaction speed of the robot to external events: a robot that immediately responds to touch or sound will be perceived as more anthropomorphic. Such *reactive behavior*, in which the robot responds quickly to external events, is an easy approach to increase anthropomorphization. The robot jolting when the door slams shut or looking up when touched on the head immediately conveys that it is both alive and responsive. *Contingency*, responding with behavior that is appropriate for the context of the interaction, can also be used to enhance anthropomorphization. When a robot detects motion, for example, it should briefly look toward the origin of the movement. If the event—such as a tree swaying in the wind—is irrelevant to the robot, it should look away again, but if it is relevant—such as a human waving hello to engage the robot in interaction—the robot should sustain its gaze.

Although robot builders will often prefer a combination of both form and behavior to inspire users to anthropomorphize their robots, certain types of robots may be limited in how humanlike they can be. Android robots, which appear virtually identical to people, are technically limited in their behavioral repertoire. On the other hand, the developers of many toy robots are under pressure to make the hardware as cheap as possible and thus opt for an effective combination of simple visual features and reactive behaviors. It is important to also take people's expectations into account; the more apparently humanlike the robot, the more people will expect in terms of humanlike contingency, dialogue, and other features.

Impact of context, culture, and personality

People's perceptions of anthropomorphic robot design are often affected by contextual factors. Some people are more likely than others to anthropomorphize things around them, and this can affect how they perceive robots, as previous research has shown (Waytz et al., 2010). A person's age and cultural background can also affect their likelihood of anthropomorphizing or their interpretation of the robot's social and interactive capabilities Wang et al. (2010).

The context in which the robot is used, furthermore, can support anthropomorphization. In particular, just putting a robot in a social situation with humans seems to increase the likelihood that people will anthropomorphize it. The collaborative industrial Baxter robot, when used in factories alongside human workers, was regularly anthropomorphized by them (Sauppé and Mutlu, 2015). Furthermore, it seems that people who work alongside robots prefer them to be designed in more anthropomorphic ways: people preferred that Roomba have the ability to display its emotions and intentions with a dog-like tail (Singh and Young, 2012). Workers using Baxter put hats and other accessories on it and wanted it to be more polite and chitchat with them (Sauppé and Mutlu, 2015). Workers in a car plant using a co-bot, which was named Walt (see Figure 10.12) and had been designed to have a blend of social features and features reminiscent of a vintage car, considered the robot to be a team member (El Makrini et al., 2018). Office workers who were given a break management robot gave it names and requested that it be more socially interactive (Šabanović et al., 2014).

Seeing other people anthropomorphize robots can also suggest that anthropomorphization is a social norm to be followed. Researchers found that older adults in a nursing home were more likely to en-

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gage socially with Paro, the seal-like companion robot, when they saw others interacting with it like a pet or social companion (Chang and Šabanović, 2015). Clearly, anthropomorphic inferences may emerge instantly upon a first encounter and likewise become reshaped as a function of long-term interaction and acquaintance with a technical system.

4.2.4 Measuring anthropomorphization

Along with identifying anthropomorphization of robots as a common occurrence in HRI, researchers also need to know how to measure its presence in an interaction. According to the influential three-factor model of anthropomorphism, anthropomorphism extends to nonhuman entities the attribution of mental and emotional states that are essentially human. HRI researchers seeking to assess the human-likeness of a robot's form or behavior draw from the large body of literature on measuring humanity attribution among humans. These days, the HRI community measures a variety of related constructs, including asking research participants about the extent to which they would attribute mind (i.e., agency and experience (Gray et al., 2007)) or human nature and human uniqueness, which are typical human traits (Haslam, 2006). Similarly, other research has assessed psychological anthropomorphism and asked whether people perceived a robot to be capable of experiencing uniquely human emotions (Leyens et al., 2001), intentions, or free will (Epley et al., 2008).

A measure for anthropomorphism specifically developed for HRI is the Godspeed questionnaire. It has been widely used in the field and has been translated into several languages (Bartneck et al., 2009). More recently, researchers have started developing additional related scales, such as the ROSAS scale (Carpinella et al., 2017) and the revised Godspeed questionnaire (Ho and MacDorman, 2010).

Although many of these measures rest on self-reports and questionnaires, other, more subtle behavioral indicators (e.g., language use, application of social norms that are used in human–human interaction, such as in proxemics) may also be used to investigate the consequences of implementing humanlike form and function in social robots. Enriching the repertoire of measurements from direct to more indirect approaches will be beneficial, not only for the current research in the field of social robotics but likewise as a form of external validation of theorizing in psychology.

4.3 Design methods

Design in HRI spans a variety of methods inspired by practice from various disciplines, from engineering to HCI and industrial design. Depending on the method, the starting point and focus of design may

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weigh more heavily on technical exploration and development or on exploring human needs and preferences, but the ultimate goal of design in HRI is to bring these two domains together to construct a successful HRI system.

The design process is often cyclical in nature, following this pattern:

1. Define the problem or question.
2. Build the interaction.
3. Test.
4. Analyze.
5. Repeat from step 2 until satisfied (or money and time run out).

4.3.1 Engineering design process

The engineering design method is, as the name suggests, commonly used in engineering. Starting from a problem definition and a set of requirements, numerous possible solutions are considered, and a rational decision is made on which solution best satisfies the requirements. Often, the function of an engineered solution can be modeled and then simulated. These simulations allow engineers to systematically manipulate all the design parameters and calculate the resulting properties of the machine. For well-understood machines, it is even possible to calculate the specific design parameters necessary to meet the performance requirements. If a new aircraft takes off for its maiden flight, engineers can be almost certain that it will fly. It is important to note, however, that they cannot be absolutely certain because the new aircraft will interact with an environment that is not completely predictable in all its detail. Enough is understood, though, to be very sure of the macroscopic properties of the environment, allowing the engineers to design an aircraft that crosses the boundary from simulation to actual prototype without any hiccups. However, validating a solution in simulation is not always possible. The simulation might not be able to capture the real world in sufficient detail. Or the number of design parameters can be so high that a complete simulation of all possible designs becomes computationally impossible because it would take a computer years to calculate how each solution performs.

Engineers working in HRI tried to design a robot to teach eight- and nine-year-olds what prime numbers are. They believed that the children's learning would benefit from having a very personal and friendly robot, so they programmed the robot to make eye contact, use the child's first name, and politely support the child during the quite taxing exercises. They compared the friendly robot against a robot in which the software to maintain an engaging relation was switched off, expecting that robot to be the worse teacher. They were dumbfounded when the aloof robot turned out to be the better teacher by a large margin, showing how their preconceptions regarding robot design were firmly out of touch with the reality of using a robot in the classroom (Kennedy et al., 2015) (see Figure 4.11).

To make things even more difficult, some design problems can be ill-defined, or insufficient information is available about the requirements or the environment. In this case, designers may say that they are dealing with a "wicked design problem" (Buchanan, 1992), which has changing, incomplete, interdependent, or indeterminate requirements that make it difficult to follow a linear model of design thinking in which problem definition can be cleanly followed by a process of problem solution. HRI design often is such a wicked design problem because there is a lack of information about the appropriate behaviors and consequences of robots in social contexts. Another approach to take in this case is to focus not on producing the absolute best solution, but on producing satisficing solutions Simon (1996). Satisficing is a portmanteau of *satisfy* and *suffice*, meaning that the resulting solution will be just good enough for the purpose it is meant to serve. This is a common problem-solving approach in all human endeavors, and it is almost unavoidable in HRI, where technical capabilities may never reach the ultimate design requirement of the robot performing just as well or better than people.

4.3.2 User-centered design process

As mentioned previously, relying only on the engineering design method can guide HRI development only so far, particularly when the intended uses of HRI are in open-ended interactions and spaces, outside labs or tightly controlled factory environments. In the process of satisficing, we may all too often choose not to measure the things that matter but instead only care about what is easy to measure. One way to address these issues is to focus more specifically on the people who will use the robot and the contexts of use they inhabit throughout the design process. This can be done through user-centered design (UCD). UCD is not specific to HRI and is used in many other design domains, such as HCI, and is a broad term used to describe "design processes in which end-users influence how a design takes shape" (Abras et al., 2004). The users can be involved in many different ways, including through

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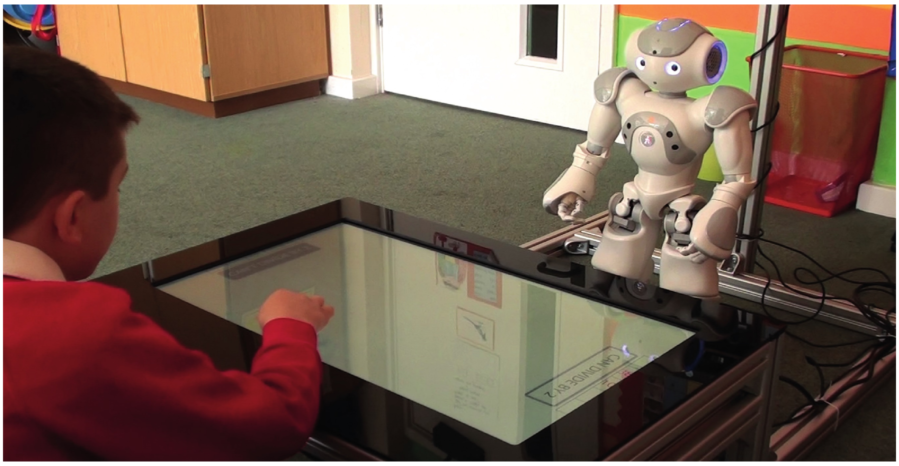

Figure 4.11 Boy learning math with a robot.

initial analyses of their needs and desires that can help to define the design problem, by asking them to comment on potential robot design variations to see which ones are preferable, and through evaluations of various design iterations of the robot and of the final product to evaluate its success among different users and in different use contexts.

Developers are typically confronted with having to make design decisions for which there are no obvious answers. Do people prefer the robot to have a red torso or a blue torso? Will a chirpy voice on a retail robot invite more people into the store? To answer these questions, they often build prototypes of the different design options and test them with their target audience. By carefully eliciting responses from the users, often using methods similar to those used in experimental research (see Chapter 9), the developers can ensure that the preferences or differences that they observe are not just coincidences but are really caused by the design feature under consideration. The results then inform the developers in building the best design option, and the cycle continues with new problems or design decisions. It is important to run these cycles as early as possible because the cost of making changes to the system increases dramatically later in the process. The credo is "test early; test often."

Designers often focus mainly on the people they think will use their products directly (i.e., the primary users), such as the nurses and patients who interact with a drug-delivery robot. It is, however, also important for designers to consider people who might only intermittently come into contact with the artifact or use it through an intermediary (i.e., the secondary users), such as other medical staff who see the robot in the hallway, and those who will be affected by the use of the artefact (i.e., the tertiary users), such as people whose job might be replaced or changed due to the introduction of new robotic technology. These various people involved in and affected by the robot's uses are called stakeholders, and an initial step in the design process can involve doing some research to identify who the relevant stakeholders are. Once the stakeholders are identified, the designers can then involve them in the design process through a variety of user-centered methods, which can include needs and requirements analyses, field studies and observations, focus groups, interviews and surveys, and user testing and evaluations of prototypes or final products (Vredenburg et al., 2002). You can learn more about several of these methods in Chapter 9 of this book.

Figure 4.12 Snackbot (2010), a system developed at Carnegie Mellon University to study robots in real-world settings.

> Carnegie Mellon University's Snackbot was designed through a user-centered process that involved taking into consideration the robot, people, and the context. It was iteratively performed over 24 months and involved research on where people could already get snacks in the building to establish need, initial technology feasibility and interaction studies, multiple prototypes, and further studies of how the robot was used and the effects of different forms of dialogue and robot behaviors on user satisfaction. (Lee et al., 2009) (see Figure 4.12)

4.3.3 Participatory design

Recently, HRI researchers have started applying more collaborative and participatory design approaches to HRI. Both collaborative and participatory methods seek to include the potential users and other stakeholders, or people who might be affected by robots, in the process of making decisions about appropriate robot design from early on in the design process. This is clearly distinct from the notion of bringing users in at the evaluation stage, where the design is partially or fully formed and users' input is largely used to test particular factors and assumptions already expressed in the design. In this way, participatory design recognizes the expertise people have about their everyday experiences and circumstances.

Participatory design has been present in the design of other computing technologies, particularly information systems, since the 1970s, when it was used to enable workers in organizations to participate in the design of software and other technologies that they would use in their work later on. Participatory design in HRI has been working on developing ways for users to become engaged in the process of making design decisions about robots—for instance, by testing and developing particular behaviors for robots, designing robot applications for their local environments, and conceptualizing how existing robotic capabilities can potentially address their needs and fit into their everyday contexts. DiSalvo et al. (2008) performed one of the early participatory design projects in HRI in their "neighborhood networks" project.

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Here, community members used a robotic prototype provided by the researchers to develop environmental sensors for their neighborhood. In another participatory project, roboticists and visually impaired community members and designers worked together in a series of workshops to develop appropriate guidance behaviors for a mobile PR-2 robot (Feng et al., 2015). Participatory design has also been used in various healthcare and educational applications for HRI (see, e.g., Šabanović et al., 2015).

Participatory design is always challenging, but working on participatory design with robots has its particular difficulties. One is the fact that people have many different preconceptions about robots but little knowledge about the technology involved in making them, which leads to unrealistic design ideas. At the same time, designers have little knowledge of the day-to-day lives and experiences of people in many of the applications in which HRI is most needed (e.g., eldercare). While working with older adults and nursing home staff to develop assistive robots for older adults with depression, Lee et al. (2017) and Winkle et al. (2018) focused on supporting a process of mutual learning between HRI researchers and participants, which allowed both sides to explore and teach each other about their different areas of expertise. This also helped support participants' learning to start thinking about design beyond just designing for themselves. Participatory design is still new in HRI, but with more and more applications being envisioned for diverse populations and everyday contexts, it is becoming an increasingly important component of the HRI design methods toolkit.

4.4 Prototyping tools

Although it is possible to develop simple robot prototypes from generally available materials such as cardboard or found objects, several prototyping kits and tools for creative interactive technologies have recently become available on the market. These make it possible for a wide variety of people with different levels of technical expertise and economic resources to try their hand at robot design. They also enable more rapid and iterative development of robot designs by making the representation of interaction a simpler thing to create.

Perhaps the earliest type of kit that could be used for developing different robot designs was the first-generation LEGO Mindstorms system, which provided bricks for building and specialized bricks for programming and actuating simple robot prototypes. Bartneck and Hu (2004) used LEGO robots to illustrate the utility of rapid prototyping for HRI, and the first case studies had already appeared in 2002 (Klassner, 2002).

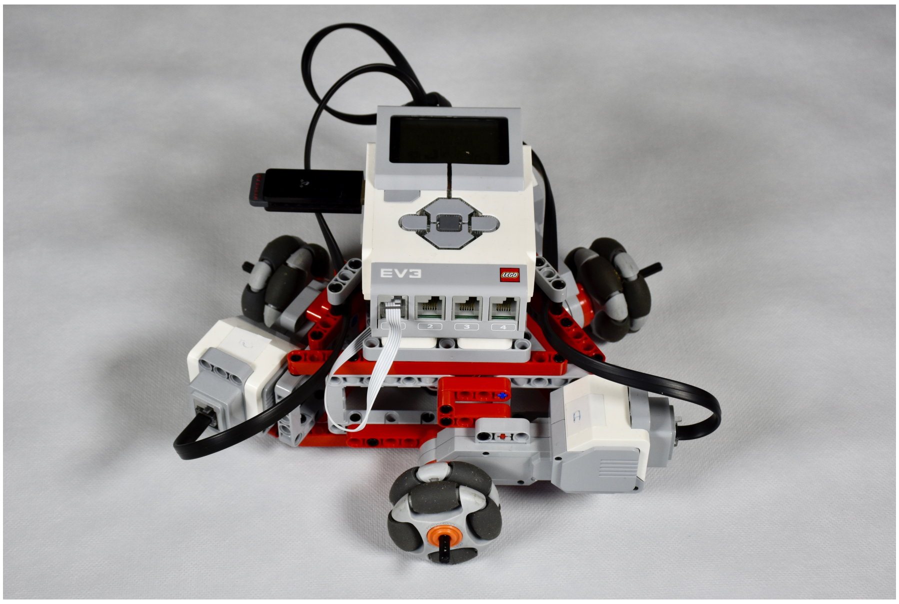

Figure 4.13 LEGO Mindstorms (1998–present) was the brainchild of Seymour Papert, an MIT professor who was an avid proponent of using computers to support child learning.

The Vex Robotics Design System[1] is also widely known and used, and its advanced version is the kit of choice for the popular FIRST Robotics Competitions.[2] More recent additions to the array of kits available are Little Bits, which provides easy-to-use plug-and-play electronic bricks, including sensors and actuators, among others, that can be used to quickly and easily create interactive prototypes.

The Arduino microcontroller[3] is very affordable and has a large hobbyist community providing open-source designs and code, as well as a wide array of peripherals (sensors, motors, LEDs, wireless units, etc.) that allow for more flexibility in design but require more technical know-how.

Other equipment, such as the Raspberry Pi[4] single-board computer and affordable and even portable three-dimensional (3D) printers not only make HRI prototyping easier but also may even be said to be making it accessible to the masses (or at least to college students).

Designers also incorporate other existing technologies into robot design, including smartphones. Even an average smartphone these days has sufficient computing power to control a robot. Furthermore, it has many built-in sensors (microphone, camera, gyro sensor, accelerometer) and actuators (screen, speaker, vibration motor). Robovie-MR2 is an early example of integrating a smartphone into a robot to control all

[1] `https://www.vexrobotics.com`
[2] `https://www.firstinspires.org/`
[3] `https://www.arduino.cc`
[4] `https://www.raspberrypi.org`

of its functions (see Figure 4.3). Hoffman calls this the "dumb robot, smartphone" approach to social robot design (Hoffman, 2012).

Available technologies for prototyping continue to develop, fueled at least in part by ongoing efforts to engage more students, hobbyists, and even potential users in technology design.

4.5 Culture in HRI design

As not only an interdisciplinary but also an international field of research, HRI design has been particularly interested in the question of cultural effects on perceptions of and interactions with robots. Culture, the different beliefs, values, practices, language, and traditions of a group of people, plays into robot design both in the form of factors introduced by designers and the context in which users interpret different HRI designs.

Researchers commonly make connections between cultural traditions and the design and use of robots, particularly contrasting the norms, values, and beliefs in the East and West: animist beliefs have been used to explain the perceived comfort of Japanese and Korean populations with robots (Geraci, 2006; Kaplan, 2004; Kitano, 2006), whereas human exceptionalism has been suggested as a source of Westerners' discomfort with social and humanoid robots (Geraci, 2006; Brooks, 2003). Holistic and dualistic notions of mind and body (Kaplan, 2004; Shaw-Garlock, 2009) and individualist and communitarian social practices (Šabanović, 2010) have been identified as design patterns represented in the design of robots and potential human interactions with them.

In addition to these generalized connections between culture and robotics, HRI researchers have been studying cultural differences in and effects on people's perceptions of and face-to-face encounters with robots. In a comparison using Dutch, Chinese, German, U.S., Japanese, and Mexican participants, it was found that U.S. participants were the least negative toward robots, whereas the Mexican participants were the most negative. Against expectations, the Japanese participants did not have a particularly positive attitude toward robots (Bartneck et al., 2005). MacDorman et al. (2009) showed that U.S. and Japanese participants have similar attitudes toward robots, suggesting that such factors as history and religion may affect their willingness to adopt robotic technologies. Survey evaluations of the seal-like robot Paro (see Figure 2.6) by participants from Japan, the United Kingdom, Sweden, Italy, South Korea, Brunei, and the United States found that participants generally evaluated the robot positively but identified different traits as most likable according to their country of origin (Shibata et al., 2009).

In the context of human–robot teamwork, Evers et al. (2008) found that users from China and the United States responded differently to robots and that human team members found robots more persuasive when they used culturally appropriate forms of communication (Lindblom and Ziemke, 2003). Findings from two generative design studies with participants in the United States and South Korea, which asked users to think about robotic technology in their own homes, showed that user expectations of and needs for robotic technologies are related to culturally variable conceptions of the home as relation oriented in Korea and more functionally defined in the United States (Lee et al., 2012). The growing body of work on cross-cultural differences in HRI and their potential design implications identifies that cultural considerations should be taken into account when designing robots both for international and local uses.

4.6 From machines to people, and the in between

As the previous discussion shows, designing human–robot interactions involves making many decisions about the form, function, and desired effects of robots. HRI designers, however, also bring deeper philosophical, ethical, and even political commitments into their work. Although these can be unconsciously brought into HRI research, we think it is useful for HRI scholars to consciously engage with these concerns in the course of their robotics research and development.

One of the most basic decisions that robotics researchers make is the type of robot they want to work on—is it meant to resemble a human or be more like a machine? Another decision can involve the main goals of the work—is it focused on producing technical developments, understanding humans, or perhaps developing HRI systems that can be used for specific applications and contexts of use? These decisions have significance beyond just the design and use of the robot, however. One could argue that the creation of robots by their designers, in particular those in which robotic copies of actual people are created, is an immortality project. Such projects are "symbolic belief systems that promise that the individual will not be obliterated by the demise of his or her physical body" (Kaptelinin, 2018). Hiroshi Ishiguro's work on android copies of living human persons is a case in point, in which the robotic copy can aim to stand in the place of that specific person, both in current and ostensibly future interactions. Ishiguro himself describes how he feels his own identity is interconnected with the robot, which persists as a replica of his past and younger self that he now feels the pressure to emulate (Mar, 2017). But the relationship between machine-like robots and designers can be just as deep. Describing his work with industrial robots, Japanese roboticist Masahiro Mori defined the relationship between humans and machines as being "fused together in an interlocking entity" (Mori, 1982). This close relationship has direct consequences for the form and function of the robot on the one side and the designer on the other side, as well as on the future consequences and uses of the robot in society.

Robot design can also be guided by a personal commitment to specific social and philosophical values, such as improving access to resources for broader populations, increasing participation in the design of and decision-making about robots, or contributing to the solution of pressing social issues. Roboticist Illah Nourbakhsh described how his personal values affect his robotic projects as follows:

> One way out is to say my work is purely theoretical, who cares how somebody applies it? I didn't want to do that. I wanted to say my work involves theoretical components, but I'm taking it all the way to seeing a real result in the physical world. And furthermore, I want it to be socially positive in some measure... I want to work on something so socially positive that not only do I hope everyone uses it, but I want to see at least one used case to fruition. Then you have this feedback loop from real-world application back to engineering design. (Šabanović, 2007, p. 79)

In this way, the choice of what type of HRI project to pursue and the goals to focus on in design can reflect personal or collective values (e.g., of the research group or of project collaborators). After all, time is limited and valuable, so it makes sense to consciously choose what we hope to make of it.

One of the authors finds inspiration for his design in the work of Robert M. Pirsig (see Figure 4.14), who put it this way:

> The real [aesthetics] lies in the relationship between the people who produce the technology and the things they produce, which results in a similar relationship between the people who use the technology and the things they use. (Pirsig, 1974)

Pirsig emphasizes the crucial role of obtaining peace of mind in order to arrive at good design as the barrier between the designer and the object to be designed dissolves:

> So the thing to do when working on a motorcycle, as in any other task, is to cultivate the peace of mind which does not separate one's self from one's surroundings. When that is done successfully then everything else follows naturally. Peace of mind produces right values, right values produce right thoughts. Right thoughts produce right actions and right actions produce work which will be a material reflection for others to see of the serenity at the centre of it all. (p. 305)

Once peace of mind is achieved and the barrier between the object and the designer is broken down, the design work can start. This work is similar to that of artists. It takes patience, care, and attentiveness to

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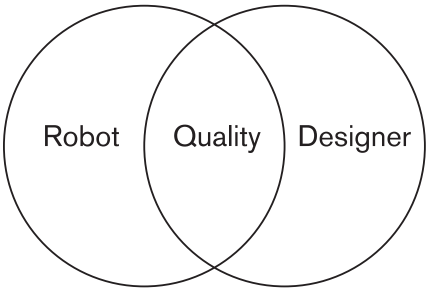


Figure 4.15 Quality in the design of robots.

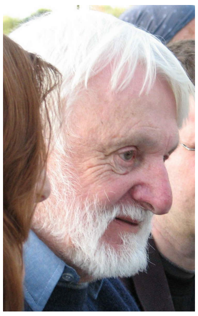
what you are doing. A good indicator of whether the design is progressing in a good direction is the inner peace of the designer. If you are in harmony with what you design, then the robot and your thoughts change together in a state that is often described as "flow" (Csikszentmihalyi and Csikszentmihalyi, 1988). The materials and the inner state of mind will come to rest at the point where the design is complete and good. Peace of mind, according to Pirsig, is not only the prerequisite for good design work, but it also accompanies good design work and is also its final goal:

> Peace of mind isn't at all superficial to technical work. It's the whole thing. That which produces it is good work and that which destroys it is bad work. The specs, the measuring instruments, the quality control, the final checkout, these are all means toward the end of satisfying the peace of mind of those responsible for the work. What really counts in the end is their peace. (p. 302)

The connection between the robot and its designer is far deeper than you may assume. Robert M. Pirsig spent his whole life working out *The Metaphysics of Quality*, in which he argues that there is no fundamental difference between the designer and the object he or she designs. What connects them is "quality" (see Figure 4.15).

Considering the peace of mind of the designer might sound strange at first, but Pirsig argued that in the moment of the perception of quality, there is no division of objects and subjects. In the moment of such pure quality, the subject and the object are one (Pirsig, 1974, p. 299). Artists might be familiar with the experience of unity with their work, and the work of designers and engineers might be enhanced if they, too, would be more sensitive to this connection.

Figure 4.14 Robert M. Pirsig (September 6, 1928–April 24, 2017) is the author of *The Metaphysics of Quality*, which has inspired many designers.



4.7 Conclusion

Designing robots requires multidisciplinary expertise, often by means of a team, and a process that takes the users and the interaction context into consideration. Various prototyping tools are available to quickly build and test robots. Once the users and their interactions with the

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robot are understood, the robot needs to be designed from the outside in—starting with the potential users and use context to develop design concepts and the technical specifications for the robot. HRI designs also express, whether consciously or unconsciously, the social and ethical values of the designers.

The robots' anthropomorphism is one of the most important design considerations in contemporary HRI. We provided a detailed description of the construct of psychological anthropomorphism as a prime opportunity for a fruitful exchange between disciplines, leading to a broader overall understanding of the concept in the social sciences and robotics. Beyond the theoretical and methodological gains from investigating anthropomorphism, HRI studies have also shown the importance of considering humanlike form and function in robot design for perceived interaction quality, HRI acceptance, and enjoyment of the interaction with humanlike robots.

Questions for you to think about:

- Find examples of pareidolia in your environment.
- Think about the features of a humanlike robot in terms of "design affordances." Which affordances should be considered in humanlike robots?
- Try to think about "design patterns" for social robots that greet people daily. Find and describe repeatedly reused patterns in behavior.
- Imagine you have to design a robot. Consider the necessary steps, taking a participatory design approach.
- Discuss the role of user expectations in robot design. What are important points to consider if you want to market your robot?
- What is your opinion: Should a social robot have very few humanlike cues, or should it be highly anthropomorphic in design (e.g., like an android)? Which robot would be accepted more by people in general? Why?
- Think about a robot that you might want to have in the near future. Picturing this robot, try to think about a way to encourage more anthropomorphization based on its behavior. Which behaviors should the robot show to be perceived as humanlike?

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