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Evaluating Human-Robot Interaction

Focusing on the Holistic Interaction Experience

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Abstract The experience of interacting with a robot has been shown to be very different in comparison to people's interaction experience with other technologies and artifacts, and often has a strong social or emotional component—a difference that poses potential challenges related to the design and evaluation of HRI. In this paper we explore this difference, and its implications on evaluating HRI. We outline how this difference is due in part to the general complexity of robots' overall context of interaction, related to their dynamic presence in the real world and their tendency to invoke a sense of agency.

We suggest that due to these differences HCI evaluation methods should be applied to HRI with care, and we present a survey of select HCI evaluation techniques from the perspective of the unique challenges of robots. We propose a view on social interaction with robots that we call the *holistic interaction experience*, and introduce a set of three perspectives for exploring social interaction with robots: visceral factors of interaction, social mechanics, and social structures. We demonstrate how our three perspectives can be used in practice, both as guidelines to discuss and categorize robot interaction, and as a component in the evaluation process. Further, we propose an original heuristic for brainstorming various possibilities of interaction experiences based on a concept we call the interaction experience map.

Keywords Human-robot interaction · Evaluation methods · Frameworks

1 Introduction

The recent and rapid advancement of robotic technology is bringing robots closer to tasks and applications which include direct interaction with people in their everyday environments such as homes, schools, hospitals and museums. Consequently, interaction between people and robots has become increasingly socially situated and multi-faceted [47]. Social and emotional levels of interaction play a critical role in a person's acceptance of and overall experience with any technology or artifact [2, 10, 17, 59], and we contend that this relationship is particularly prominent, unique and intertwined for interaction with robots.

While studies strongly support the idea that interaction with robots is complex and draws deep social and emotional responses [9, 59, 80], few researchers have directly explored how this affects the *evaluation* of interaction between people

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and robots. This brings to light a basic question of whether specific consideration is needed for evaluation of HRI and whether classic HCI methods can be applied directly to HRI. This question has been raised before (see, e.g., [25]), but as far as we know there still is a need for thorough research of the general thematic differences between HRI evaluation and HCI evaluation, and for exploring practical frameworks for HRI evaluation.

In this paper we outline how robots' social and physical presence, and their tendency to evoke a sense of agency, creates a complex interaction context very different from that of interaction with other technologies and artifacts. We argue that this wider context should be explicitly considered when evaluating HRI, and provide a survey of what we believe are particularly relevant HCI methods, and how they apply and relate to these HRI challenges.

We present a new set of three perspectives for exploring social interaction with robots to help evaluators explicitly target various social facets of the holistic interaction experience. We illustrate the use of our perspectives as empowering vocabulary, demonstrate how to use them in practice, and how to use them to classify and analyze HRI instances. Further, we demonstrate how the perspectives can be used throughout evaluation, and present a heuristic that leverages our perspectives for exploring HRI experience possibilities.

2 Why Is Human-Robot Interaction Unique

In this section we argue that robots elicit unique, emotionally charged interaction experiences, and that this stems from the ways in which robots integrate into everyday settings. Our discussion emerges from the simple observation that people naturally tend to treat robots similar to how they may treat living objects, and ascribe them with lifelike qualities, such as names, genders and personalities, even when the robot is not explicitly designed to incur social responses [27, 73].

Here we consider the question of uniqueness in terms of what it means for interaction with robots, and focus our discussion around how robots encourage social interaction, how they elicit a unique sense of *agency*, and how they demand attention to the greater, holistic, interaction context.

2.1 Robots Encourage Social Interaction

Studies have shown that people naturally tend to respond socially and to apply social rules to technologies [57, 62]. Given that robots are a form of technology, it can be expected that this also happens when interacting with them (e.g., as with [27, 73]). Robots also have well-defined physical manifestations, can exhibit physical movements and can autonomously interact within peoples' personal spaces, properties that set them apart from other technological artifacts such as a PC or microwave [59]. Further, the tangible nature of robots, and their ability to autonomously move and act in proximity of personal spaces [22, 37], is considered to have a unique effect on the social structures surrounding interaction [43]. As such, the way in which people apply social rules to robots, and the extent of this application, can be expected to be different than for other computational technologies.

Previous studies in non-robot human-computer interaction cases show that peoples' social tendencies toward technology can be deepened through socially-evocative technology designs [62]. Even for robots without explicit social designs, simple movements and abilities are often construed as lifelike [27, 73], perhaps having this effect. Therefore, it is likely that robots that explicitly utilize such mediums as familiar human-like gestures or facial expressions in their designs will further encourage people to interact socially with them in a fundamentally unique way.

2.2 From Anthropomorphism to Agency

People have been found to anthropomorphize robots more than other technologies and to give robots qualities of living entities such as animals or other humans (e.g., [3, 4, 12, 26, 29, 30, 53, 72, 73]). We posit that perhaps this anthropomorphism embedded within physical, social contexts is closely related to how people readily attribute intentionality to robots' actions regardless of their actual abilities or explicit designs. We believe that this intentionality helps give rise to and strengthen a sense of agency in the robot—the word *agency* itself refers to the capacity to act and carries the notion of intentionality [20]. People attribute agency to many things (see, e.g., "the intentional stance" [18], which argues that this helps people build expectations), including even simple movements and motions [1, 38] and various other technologies (e.g., video game characters, movies [62]), we argue that the robot's physical-world embeddedness and socially situated context of interaction creates a unique and affect-charged sense of *active agency* similar to that of living entities. In a sense, then, for many people interacting with a robot is more like interacting with an animal or another person than with a technology—the robot is an active physical and social player in our everyday world.

Due to agency and intentionality, people perceive robots to make autonomous, intelligent decisions based on a series of cognitive actions [4, 18, 57, 62]. Considering this perspective helps explain why people readily attribute lifelike qualities to robots. Further, agency contributes to the development of expectations of the robot's abilities (such as learning ability) or can create the expectation that the robot will be an active social agent, all in a much more prominent way than with more traditional technologies. In fact, it has been demonstrated that people tend to believe that even simple robots engage in some social interaction in a reciprocal manner, and that people tend to develop strong affective and emotional attachments to robots (e.g., [27, 28, 52, 73]). While people do sometimes exhibit emotional attachment to other artifacts (e.g., a Tamagotchi toy or on-line virtual avatar), robots are unique in that they can actively respond to people's affections as a physical, social actor similar to a living entity directly embedded in people's real-world physical environments (closely linked to the person's embodiment). Thus, we argue that robots can legitimize and validate the social relationships [4] in a fundamentally different way than other technologies.

Overall, research suggests that robots become *active agents* in people's environments in a similar fashion to living entities, such that these robots naturally integrate into social worlds and encourage emotional involvement in ways not generally encountered with more traditional technologies.

2.3 Embodied Interaction Experience

Interaction is embodied within our social and physical worlds [22, 64, 77]. A person's experience cannot be fully or properly understood by reductive accounts or limited perspectives [20], and includes difficult-to-quantify thoughts, feelings, personal and cultural values, social structures, and so forth [16, 20, 22]. From a person's point of view, the meaning of experience cannot be separated from the wider, holistic context, and this has important implications for HRI.

Robots' unique *active agency* and lifelike presence makes this wider context a particularly prominent part of interaction experience. The meaning of human-robot interaction often reaches well beyond the simple point of interaction (particular interface and particular actions) in a stronger and deeper way than interaction with many traditional, more passive technologies and artifacts, making HRI a very unique instance of HCI. Following, social norms may manifest very prominently with robots as they may exist between people (e.g., will people be too shy to undress in front of an advanced household robot they are not familiar with?). This stance is supported by emerging HRI literature, for example, work that suggests the need of considering how specific robot characteristics interplay with each other [15], or work that suggests that interaction with a robot may be context dependent [14].

The general idea of the holistic interaction context, and how robots fit into this, is outlined in Fig. 1. The user experience of interaction, embedded within a wide context, is greatly influenced by the robot. The robot itself is a prominent and very active social and physical player within this context, with its influence similar in many respects to a living entity. The human and robot mutually shape the experience similar to how two living agents may do. Our discussion here highlights how deeply interaction with robots is embedded in the social and physical worlds, and the uniqueness of this integration, compared to non-robotic HCI instances (such as interaction with a PC for example).

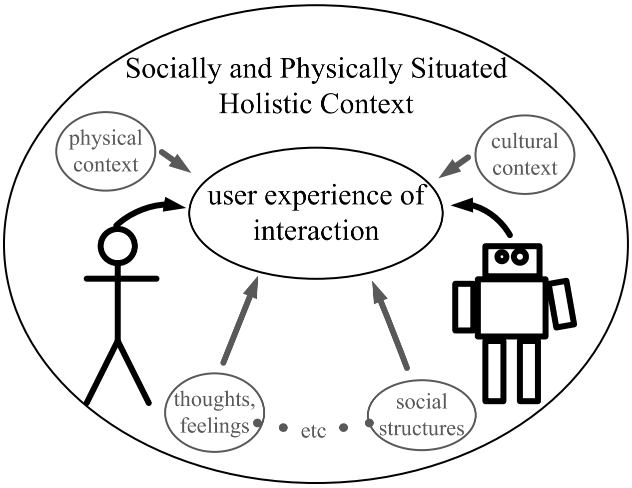

Fig. 1 A person's experience of interacting with a robot is influenced by many real-world social and physical factors, where the robot itself plays an active role similar to that of a living entity

In this section, we emphasized the unique nature of interaction with robots. We discussed how robots, by their very nature, encourage social interaction on levels that may differ from social interaction we experience with other technologies. Following from this, robots are (often not by design) anthropomorphic and generate a strong sense of *active agency* similar to a living creature. Overall this generates a very unique, socially and physically embedded context for interaction experience.

3 Existing HCI and HRI Evaluation Methods

Our goal in this section is to provide a selected summary of methodologies, techniques, and concepts from both HCI and HRI, focusing on a subset that we believe can be useful in relation to the unique and deep social component of interaction between a person and a robot. We attempt to explore how existing HCI and HRI evaluation techniques and frameworks apply to the unique social properties of robots, framing them in this targeted light in the process of discussion, and highlight where we feel additional techniques are needed.

We develop our discussion from the following evaluation approaches: task completion and efficiency, emotion, and situated personal experience, and conclude with a discussion on frameworks for exploring social interaction with robots. We do not intend to apply a hard-lined categorization here of the existing work, but rather use the views as a means to frame our discussion.

3.1 Task Completion and Efficiency

Given the effectiveness oriented nature of most classic computerized tasks and computer interfaces, traditional HCI evaluation has often taken a task completion and efficiency approach to usability evaluation, focusing directly on how an interface supports a user in their desired tasks, actions, and goals [21, 24, 58, 66].

This trend also exists in HRI where questions explored often center around control oriented issues, performance quality, the person's tactical awareness of the robots' environment, error rates and action mistakes, etc. (e.g., [23, 36, 63, 79]).

In addition to the direct utilitarian importance, these concrete measures of task accomplishment and efficiency can be used as part of wider, interaction-experience oriented explorations (and thus, for evaluation of social HRI). For example, these quantitative measures can support other data which highlights points related to engagement and interest (e.g., through task completion time or number of pauses), or whether and how much a person understands what the robot is trying to convey (e.g., through error rates). These techniques alone, however, can only provide limited insight on the social aspects of interaction, and so other techniques are needed for a more comprehensive view of the holistic HRI experience.

3.2 Emotion and Affective Computing

Some research in HCI specifically targets socially situated interactions between people and computing technologies, with a particularly strong focus on human emotion. Much of the research in this area is performed under the title of affective computing, a domain which explores how interaction with an interface influences the emotional state, feelings, and satisfaction of the person [61], whether through deliberate design (e.g., [5]) or as an incidental artifact of interaction (e.g., [45, 61]). This area of research also includes the evaluation of interaction with virtual agents, work of particular interest to HRI [40] as virtual agents can also elicit agency and social presence (although not physical), and an area of potential influence for the evaluation of social interaction with robots. Given the socially situated and active-agency nature of interaction with robots, we feel that this body of work is particularly relevant.

One approach to evaluation of affective interaction monitors biological features such as heart rate, blood pressure or brain activity, or measures the number of laughs, number and duration of smiles, and so forth [19]. These methods can serve to quantify the difficult-to-quantify social-oriented aspects of interaction with robots such as types and amounts of emotion, affect, or the social involvement of the person. However, evaluators should note the limitations incurred when using such methods. Arguably, the ability to understand the rich and multi-faceted nature of social interaction will be limited and the validity of the gained insight reduced, particularly given the holistic HRI experience, when emotions are simplified to a set of external quantities and discrete categories [45, 70].

Other affective-computing approaches attempt to focus on participant self reflection, where people directly report on their experience with an interface and how it makes them feel (e.g., see [5, 8, 41, 42]). Examples include think-aloud techniques, interviews, and surveys. This has the added benefit of accepting participants as expert evaluators of emotion and judges of their own social interaction experience (with robots). Sometimes, creative techniques are used to help people reflect on aspects that are difficult to express with words. One such example is the sensual evaluation instrument which asks people during interaction to handle a set of abstract, molded props [45, 64] that represent emotional states. Participants are later asked use the props as physical memory aids and descriptive tools for their experience. Self reporting, regardless of the media and mediators used, has the complication of often being done in retrospect (after, not during, an experience) and relies on people understanding their own emotions and being reflective enough, and confident enough (i.e., not shy) to discuss them openly.

Affective computing techniques can be very useful for exploring how people feel about robots, and how the robot affects their emotional state. The holistic interaction experience, however, points to a wider picture that includes such things as social structures, and how all of these concerns relate to the physical, cultural, and social context where interaction is taking place.

3.3 Situated Personal Experience

A person's experience of interaction is situated within a broad social and physical context that includes such things as culture, social structures, and the particular environment they are interacting with. As such, we argue that the experience itself is very complex and elusive concept that is difficult to explore with evaluation.

Existing evaluation approaches that focus on personal experience (and the context within which it happens) often aim to describe and unpack interaction experience rather than to explicitly measure it. Some argue that it is important to accept the complex, unique, and multi-faceted nature of experience (as perfect understanding is perhaps impossible [65, 70]), and evaluation should aim to find themes and in-depth description of the complexity [5, 41, 45].

This stance can be used to explicitly recognize the holistic and embodied nature of interaction with robots and we can leverage many of the related data collection and analysis techniques toward this goal. In fact, an emerging body of work in HRI considers interaction as a holistic and contextual experience that considers issues such as how a robot meshes into existing social structures (exemplified in [27, 49, 72, 73]).

The approach of accepting complexity often uses qualitative oriented techniques such as thick, detailed description based on participant feedback and interviews (e.g., [78]), collecting multiple viewpoints (for example, across participants), or more structured approaches such as Grounded Theory [70], culture or technology probes [31], or contextual design [7]. Longer term interaction or interplay with social structures are often targeted with in-situ, context based ethnographic (e.g., [13]) or longitudinal field studies (e.g., [27, 73]).

Another important consideration in relation to the holistic context of interaction is the idea that each person and their experiences are unique. This means that rather than trying to find an average user, context sensitive evaluation should perhaps value that individuals have unique, culturally grounded experiences, and evaluators should take care when generalizing any affective experience across people [8, 70]. Further, the evaluators themselves will have similar culturally rooted personal biases towards the robots, participants, and the scenario. This bias, which some argue is unavoidable, should be explicitly considered and disclosed with the evaluation analysis [70].

The involvement of social structures in HRI highlights that, since we argue that robots are viewed as lifelike entities, it is possible that person-person norms may manifest between people and robots. For example, perhaps the observer effect [48] may be particularly powerful when interacting with robots: interaction between a boss and a worker may change when they are being videotaped as, say, the boss may feel more pressure to act in a socially acceptable manner—the same change may happen between a person and a robot.

While these approaches consider many of the wider social and contextual components of the holistic HRI experience, they do not directly target the lower-level considerations of a person's emotions. Further, there is no explicit consideration of *how* these techniques can be applied to robots specifically, and it is up to the evaluator to devise appropriate methods. As such, we maintain that there is a need for structures and methodologies that aid evaluators in applying specific techniques such as the ones outlined above to the evaluation of social interaction experience with robots.

3.4 Frameworks for Exploring Social Interaction with Robots

So far in this section we discussed how existing HCI and HRI evaluation methods and techniques relate to the holistic and contextual nature of HRI. Complementary to this, evaluators can use frameworks as a means of dissecting this holistic, complex whole into more targeted and focused units or perspectives, and use this as a means to direct evaluation. Frameworks can provide common vocabulary, provide means for comparison, and can serve as sensitizing tools to help evaluators focus on particular concepts. In terms of HRI, then, we argue for the need of frameworks to help evaluate and target such concepts as personal comfort, internal emotional experience, and social integration when reflecting on interaction experience.

One common (and relevant) example in HCI is Norman's three-level framework for analyzing how people interact with and understand everyday objects (or products, in this case), with an explicit concern for emotion [58]. Norman's framework highlights the stages a person may go through when dealing with a product over time: (a) initial, visceral impact, (b) behavioral impact, or how a person feels during use, and (c) reflective impact, the thoughts one has after interacting with a product. The idea of *active agency*, however, suggests that the robot may not fall into the standard "product" category and as such this framework is limited in targeting the holistic interaction experience.

Closer to HRI is Drury et al.'s *HRI awareness* conceptual framework, and specifically, the awareness (understanding) that both the people and robots have of the social structures and activities within a group [23]. This work focuses on robots as team members in goal oriented tasks, and does not consider interaction outside this professional role. Perhaps the most explicit social interaction framework for robots is the classification of robots based on their social design characteristics and capabilities [9], although this work is focused only on the robot design (and not a person's experience) and stops short of considering the wider context or the more general social interaction that may occur.

To summarize, within the breadth of existing evaluation techniques and methods in HCI and HRI that we present above, there is no clear method that covers the breadth and depth of the holistic interaction experience for interacting with robots. Further, there is a lack of frameworks which can synthesize various existing methods together to target the holistic and socially embedded nature of interacting with robots. In the following section, we present our initial take on classifying this rich interaction into a set of articulated concepts. We describe interaction experiences with robots using three perspectives: visceral factors, social mechanics, and social structures. These new perspectives can be leveraged in practice for designing and evaluating the social interactions between people and robots, and serve as lenses to help examine the wider context within which interaction happens.

4 Perspectives on Social Interaction with Robots

We present a set of perspectives for exploring social interaction with robots. We envision that these perspectives can be integrated into existing HCI and HRI evaluation methods, serve as sensitizing concepts, and provide a new vocabulary that will encourage investigators to focus more on unpacking the emotional and social aspects of interaction. Our approach is based on the uniqueness of interaction with robots, related to the holistic context of interaction, robots' *active agency* and dynamic physical presence. While these perspectives were developed with HRI in mind, we note that our ideas can also be applied to evaluation of other, non-robotic entities with similar characteristics.

We categorize social interaction between people and robots into three perspectives: visceral factors of interaction (e.g., the immediate, automatic human responses), social mechanics (e.g., the application of social languages and norms), and the macro-level social structures related to interaction.

Perspective One (P1), visceral factors of interaction, focuses on a person's biological, visceral, and instinctual involvement in interaction. This includes such things as instinctual frustration, fear, joy, happiness, and so on, on a reactionary level where they are difficult to control.

Perspective Two (P2), social mechanics, focuses on the higher-level communication and social techniques used in interaction. This includes both the social mechanics that a person uses in communication as well as what they interpret from the robot throughout meaning-building during interaction. Examples range from gestures such as facial expressions and body language, to spoken language, to cultural norms such as personal space and eye-contact rules.

Perspective Three (P3), social structures, covers the development of and changes in the social relationships and interaction between two entities, perhaps over a relatively long period of time (longer relative to P1 and P2). P3 considers the changes in or trajectory of P1, P2, as well as how a robot interacts with, understands, and even modifies social structures.

These three perspectives are not a hard-line categorization of the various components of interaction, or a linear progression of interaction over time. Rather, interaction happens simultaneously and continuously on all three perspectives, and there is crosstalk between the perspectives for any given interaction—these categorizations provide different views on this complex relationship.

As we'll discuss below, given a particular robot, interface, scenario, or research question, certain perspectives may be of greater interest than others. However, we contend that components of all three perspectives exist in any interaction between a human and a robot. Following, not explicitly considering a particular perspective may limit the view and hinder potential understanding of a social interaction scenario.

Below we offer detailed descriptions of the three perspectives. Our approach revolves around using the perspectives to categorize and introduce existing literature and themes, serving as a simplistic case study highlighting the usability and applicability of the perspectives.

4.1 Perspective 1 (P1)—Visceral Factors of Interaction

People have many visceral, perhaps largely instinctual, reactions to the world around them [58, 59]. These reactions are often difficult, if not impossible, to quell or restrict. Some of these reactions are nearly universal to all humans, such as smiling when happy, while others are cultural or individual oriented, such as fear of insects or particular associations such as having a positive response to a Christmas theme. Many of these reactions are entirely internal, with very little or no outwardly noticeable effect, while others such as recoiling from a spider are very externalized in their expression. Interaction continues to occur from this perspective (P1) even for engaged or long-term interaction.

Clear examples of P1 visceral interaction exist in the field of HRI. One example that highlights the importance of visceral interaction is the problem of eeriness, where as postulated by the Uncanny Valley theory [54], discomfort in interaction rapidly increases as a robot's lifelikeness to a human rises above a certain level [39]. Another example is people's reluctance to interact with an anthropomorphic robot that appeared taller than them [50]. A rehabilitation robot, Paro, was specifically chosen to take the form of a baby seal to elicit positive emotional responses from people [52]—people reported a great deal of emotional attachment toward the robot. Other work uses familiar cartoon artwork to explicitly anthropomorphize robots, and make them both familiar and fun, and give them a communication vocabulary of, e.g., simplified and exaggerated facial expressions, that people can intuitively understand [81]. All of these examples fall under our P1 perspective.

Visceral (P1-type) reaction is not limited to robots with explicit anthropomorphic designs. As one example, the shape, speed, and patterns of a robot's movements also contribute to visceral reactions. In particular, Roomba users reported both excitement and enjoyment from watching how the robot moved around the space, even though the movements were random [73]. A similar finding was reported in a search and rescue study where people could not clearly see the robot, but could only see the lights and hear its movements and motors. Based on the way that the robot moved (e.g., with aggressive and sudden movements, or slower and softer movements), people reported feeling either more or less threatened by the robot, resulting in a deepening of the traumatic symptoms reported [6]. The robot Keepon works largely on this principle, evoking P1 reactions of fun and enjoyment from people simply through the way that it moves [53].

In other work, research showed how people were very hesitant to destroy (or "kill") a mechanically designed robot, with the hesitance related to the degree of "intelligence" shown by the robot [4]. Arguably, this was related to people's visceral (P1) reluctance to harm something which appears to be living. A related study found a similar relation, where people were hesitant to shut off a robot that pleaded to stay turned on [3].

This perspective (P1-type) of human reactions to the world is a very powerful and important part of the user experience of interaction: fear, happiness, excitement, dread, and so forth, can have a large impact on the overall interaction experience. Robots make visceral reflection a particularly relevant component of interaction, as they elicit a sense of lifelike agency, and hence strong visceral responses that can play an important role in the reactions to the interface, to its acceptance or rejection. Thus in HRI, visceral impressions form a crucial component of the overall experience, and P1 can be used to focus attention on these factors when assessing interaction with a robot.

4.2 Perspective 2 (P2)—Social Mechanics

Many robots are designed to explicitly try to understand and communicate using social techniques such as those that are used between people (or perhaps between a person and an animal). This kind of communication consists of an extremely diverse set of social signals, responses, and other communication techniques, e.g., such as the use of speech and voices, facial expressions, and bodily gestures. We collectively refer to these communication techniques as the *social mechanics* of interaction, our second perspective (P2).

People are very good at interpreting and understanding social mechanics, and in fact appear to be inclined to explain interaction using such communication techniques even where there is no communication intended [59]. This tendency toward P2 may be particularly strong when interacting with robots, as their physical embodiment and *active agency* help make interaction with people inherently social. For example, although the Roomba cleaning robot has no internal social model and was only programmed to sweep the floor, people understand its actions and attribute intentionality to it the same as they may for another person or animal—that is, they used P2 to explain the Roomba's actions. Further, in practice people have been found to name their Roomba, have (mostly one-sided) conversations with it, and even dress it up to match its personality [27, 73].

Clear examples of robots that use P2 social mechanics are those that use such techniques as eye gaze cues, or head-nod recognition as an important part of interaction [56, 68, 69], robots that have person oriented strategies for stopping to yield in the hallway [60] or approaching seated people [33], and those that convey an expression or mood [32]. Robots' use of P2 social mechanics extends beyond these more clear-cut examples, and includes subtle characteristics such as the tone and inflection of actions, components that can play a crucial role in overall interaction experience. For example, it is conceivable that seemingly localized design decisions, such as a sporadic or rough (or *jerky*) arm movement, can taint the overall impression: one robot that debates using rough (perhaps aggressive) hand gestures may be received quite differently from another that uses smooth (perhaps docile) ones, or they would also be seen as different if the robots used a monotonous or bored versus excited voice in their statements. In practice, a recent study identified that a subtle indication of team play (i.e., by using the word "we") could largely increase the tolerance people have of robots' mistakes [35].

For much of this area of research, the aim is to define how robots can comply with social practices and appear normal and acceptable in our lives. One approach to this has been to attempt to make robots that break what we accept as *normal* behavior, as a means to both provide understanding of how people react when things go wrong, and to find the boundaries of what is seen as wrong. Notable research includes a robot that cheats while playing a game [67], one that purposefully talks in a disconnected manner [74], and one that uses inappropriate gaze cues to disrupt the flow of interaction [55].

Robots require difficult-to-achieve skills and a vast amount of knowledge and awareness of the context of interaction to use many social mechanics to the level that people do. This problem is exacerbated as many social mechanics vary based on who the robot is interacting with (e.g., children versus elders), and their background and culture (e.g., Asian versus Hispanic). One method used to reduce this complexity is to program robots that can *learn* from their particular context on how to interact. This mimics how actual people work in the real world, and as such we see the teaching and learning paradigm as a very familiar social mechanic for people who must teach robots. In these projects, people explicitly demonstrate to a robot how to perform a task using their existing teaching skills, such as to push a sequence of buttons [11, 51], or observe and follow behaviors [76]. One particular study showed that people perceived a robot that could learn as being more capable than the one that performed canned behaviors [76].

From our investigation it appears that social mechanics (P2) may be the most extensively studied area in HRI, perhaps because it is often a clear part of the overall social interaction experience, and thus a clearer target for design. In this section, we have outlined what we feel are some of the current and active social mechanic areas in HRI. Exploring the vast landscape of P2-type interaction is a rich area for future work.

4.3 Perspective 3 (P3)—Social Structures

In addition to the more obvious P1 (visceral) and P2 (social mechanics) components of HRI, interaction between a person and a robot (or people and robots) extends into the holistic context of interaction. That is, the human environment and social structures are themselves components of interaction, where they both influence and are influenced in the process. One example of this kind of interaction is the relationship between a domestic robot and the social structures of the home: the existing home practices and contexts help define how people will perceive and interact with the robot, and the simple existence of the robot itself, and the fact that people interact with it, has an impact on the greater structures of the home [80].

Research in this area has shown that, e.g., adopting cleaning-robot technology (a Roomba, in this case) in homes may shift who is responsible for the cleaning duties, from adults to young adults, and from women to men [27]. Other work has shown that robots can be attributed with moral rights and responsibilities of their own within the home and family [28]. In one case, a family expressed sadness at having to exchange their broken Roomba (named "Spot") for another one, rather than having it fixed. The same phenomena has been found in military contexts, where a bomb reconnaissance robot (named "Scooby Doo" by the soldiers) became a team member and was given medals by the team. When Scooby Doo was destroyed in the line of duty, the soldiers demanded that the robot be repaired rather than replaced at a fraction of the cost [30], showing how the robot became a team member of sorts.

Time can be a useful factor to consider in relation to how a robot fits into social acceptance and social structures; time can help highlight the extent of influence and a trajectory of how the social structures vary and evolve. For example, research has shown how a novelty factor can exist for robots, where they initially have an impact on structures, but are soon forgotten, with social structures returning toward their previous state. This has been demonstrated in research, where an office-assistant robot became forgotten after three months [44], and a robot which was deployed into a classroom had much less interaction with children after two months [46]. Not all changes tend toward less use. Some studies have shown, e.g., how people build emotional bonds with robots that strengthen over time, treating them as more than mechanical beings, such as with people who treated their Roomba vacuum as a member of the household [71].

HRI work that explicitly targets P3 interaction is rare, perhaps due to the complexity and difficulty of exploring, explaining, or perhaps measuring social structures and the influence that HRI may have. This problem is exacerbated for longitudinal studies which may cover large and complex environments, such as homes and offices. However, P3 can occur whether explicitly designed for or not [80], and it is becoming more common to study P3 for robots, regardless of their explicit ability or intention to either interpret or interact on social structures (e.g., [26, 28, 72, 75]).

5 Applying the Perspectives in Practice

In the previous section we framed existing work instances on social interaction with robots into a new categorization of three perspectives. Part of our goal with this is to organize various concepts related to the difficult-to-define term *social* into a more comprehensive form (although we do not claim a complete cover of *social*). Further, we believe that our articulation of the three perspectives can serve as lenses on interaction and be used to sensitize researchers to the holistic interaction experience. In the remainder of this section we elaborate on how we believe these perspectives can serve as concrete tools throughout the evaluation process. We illustrate this by first breaking evaluation into a rough categorization of *study design*, *conducting the study*, and *analysis of data and results*. Then we discuss how the perspectives can be used in each case.

5.1 Study Design

For many, study design begins with the formalization of research questions and hypotheses. Given the holistic interaction experience, we argue that it is important to at least consider a wide range of social factors and potential interactions. Here we show how the three perspectives can be directly used to help with this process.

Not only do the perspectives offer a vocabulary to help articulate the social characteristics of interaction experience, but they also provide a mechanism by which the experimenter can define the focus of their particular interest. For example, a person may hypothesize that a particular robot will elicit happiness and pleasure (P1: visceral reactions). When this occurs, the person will respond by using some social mechanics (P2), such as smiling broadly or bobbing their head.

The perspectives can also be used in the design of the evaluation itself, providing clear mechanisms for directed brainstorming and discussion. In particular, they can help assess if and how the types of questions in the study address the targeted social interactions. Further, by utilizing the concept of P1, P2, and P3, evaluators can consider the holistic interaction context beyond their immediate study scope. Following, the perspectives can serve as tools to narrow or expand the evaluation scope as desired. It may even give the evaluator clear directions for additional questions to consider. This applies to both the overall design of the experiment and the detailed parts, such as actual questionnaires and survey forms. We present a more in-depth and concrete method for leveraging the perspectives in brainstorming in Sect. 6.

5.2 Conducting the Study

While the study is being conducted, the three perspectives can serve as a means to remind the evaluator of various social issues of importance.

The three perspectives can be used during task completion and efficiency-type explorations to raise more socially oriented questions, such as how the person's P1 reactions or the robot's P2 communication are related to the observations, or how the observed results may influence the broader social structures (P3). This sensitization role can be particularly useful for field studies which involve direct observation, note taking, or unstructured interviews, which can take unexpected turns. For example, as the evaluator notes an observation, the perspectives can be used to help consider the observation from different angles, building toward a more holistic view on interaction experience.

The perspectives can also be integrated directly into the data collection instrumentation, e.g. note paper could have pre-generated sections that highlight P1, P2, P3. For physiological measurements the perspectives can help widen or help define the target information of interest to the observer. For instance, the frequency and timing of observations can be selected to target long-term interaction (one of the core P3 properties).

Overall, the perspectives can be used as a framework under which to apply existing HCI and HRI evaluation techniques. We believe that this could be a way to (a) add structure that steers toward social interaction with robots, and (b) sensitize the evaluator to the holistic view on interaction experience.

5.3 Analysis of Data and Results

For the analysis of the evaluation results, the three perspectives can be used to dissect and direct data exploration. P1, P2, P3 can be used to keep the experimenter grounded on the participant's experience and to remain explicitly focused on the social aspects of interaction.

Also, the perspectives can become tools to probe the data from different social angles. When the evaluator uncovers a particular finding or develops a hunch, they can directly use the three perspectives to consider other related data or findings: they can ask "how does this relate to the three perspectives?", "how does this finding impact the interaction experience on the three perspectives?", or "how do findings and data from the other perspectives influence this finding?" For example, if it appears that people do not like to interact with a given domestic robot when guests are over, then the following hypothetical statements could be considered. Perhaps the robot's P2-type communication, or people's P1-type reactions to the robot, are intimate and inappropriate in group situations. Maybe the P3 integration into the home makes it uncomfortable to interact with the (lesser) robot in front of guests. For whatever reason, how does not interacting with the robot around guests impact the long-term P1-type reactions, direct P2 interactions, or P3 integration?

The perspectives also can serve as a powerful, but simple in notation, vocabulary for communicating findings. Our perspectives enable complex, multi-level social interactions to be clearly expressed. As an example, in a hypothetical study, "People found the robot to be creepy, which they expressed both in P1-type externalized reactions and P2 gestures such as 'keep away' hand gestures, and this had very strong P3-type interactions with the home." In this example, the perspectives highlight the difference between perhaps sometimes involuntary P1 and voluntary P2 interactions, and the more individual P1, P2 in comparison to related P3 social structure impacts, which are perhaps more difficult to describe without the perspectives.

6 A Method for Brainstorming Interaction Experience Possibilities

As outlined in Sect. 5.1, the three perspectives can be leveraged in study design and brainstorming. The overall idea has emerged from our own experiences of evaluating HRI: there have been times during our own evaluations when we asked ourselves, "how would a person react to this?" "in what ways?", or during data analysis, "why did the person react this way?" In these instances we found it particularly useful to explore interaction scenario possibilities, and used our anchor on the person's social experiences to push discussion. In this paper we have formalized this *social anchor* into our three perspectives, and developed our methods into a heuristic, in the form of a concrete method, to leverage the perspectives in exploring the interaction possibilities space. Our method is based around the idea of developing and using an *interaction experience map*.

Having a detailed resource that outlines a range of interaction possibilities and outcomes, for a given HRI scenario,

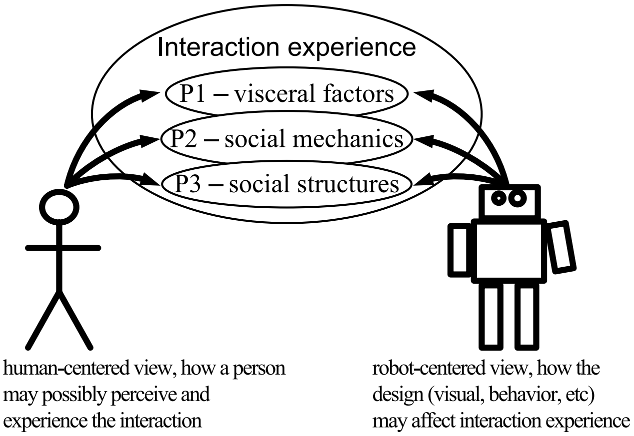

Fig. 2 Interaction experience, mutually shaped by two active agents: human and robots

can be a useful tool for both evaluation design and analysis of the results. Such a detailed database, or an *interaction experience map*, could be consulted to explore alternative outcomes in an interaction scenario or to help explain unexpected observations or results—an approach reminiscent of cognitive walkthroughs [34]. Unfortunately, such resources generally do not exist, particularly for exploratory research of cutting-edge robot systems, and experimenters must often do this kind exploration themselves, repeatedly, for each study they run. With this approach the problem then becomes one of doing a thorough and well-rounded job of probing and exploring possibilities.

The idea of the *interaction experience map*, and related processes, has emerged from how we used the three perspectives in our own HRI evaluation projects. We present and propose here a refined and formulated methodology for leveraging the perspectives to build an *interaction experience map*.

6.1 Outlining the Interaction Experience Map

We take a holistic view (as outlined in Sect. 2.3 and Fig. 1) on interaction experience, using the three perspectives as a structural framework to focus our exploration (Fig. 2). As highlighted in the figure, all three perspectives on the holistic interaction experience can be considered from the viewpoint of the human or the robot. The human-centric view considers how the person feels about, approaches, and interprets the interaction experience, and the robot-centric view considers how the robot itself, including its design, behavior and actions, influences the experience.

6.2 Mapping Interaction Experience Possibilities

Here we propose a process that can help develop and create a map of interaction experience possibilities. The key points of this process are that (a) both the human- and robot-centric views are explicitly and simultaneously considered, and (b) the three perspectives serve as direct brainstorming and sensitizing tools. We propose that the *interaction experience map* can be generated in an iterative and exploratory manner, where the three perspectives prod the experimenter to consider the targeted facets of interaction.

6.2.1 Human-Centered View

For the human-centered view, the evaluator can start by brainstorming possible interaction scenarios which may happen in regards to a person and the particular robot or interface. In this stage of the process the evaluator generates a list of high-level scenarios that could conceivably take place, such as, e.g., a person trying to have an extended conversation with the robot even though the robot does not intelligently respond, or the person completely ignoring the robot, and so forth.

Then, for each scenario listed in the first step, P1, P2, P3 can be used as probes to consider the interaction experience possibilities within the scenarios, and to sensitize the exploration to the particular social considerations. Following our previous example, a person conversing with a robot exhibits social mechanics P2 elements of conversation and gestures, but they may also have visceral P1-type reactions when the robot does not respond as expected. This may include frustration and annoyance, which the person may externalize by means of body language, communication which the robot may be able to detect. One emerging question is how does being frustrated with the robot, and being unable to have an in-depth conversation, influence how the robot is ultimately used, adopted, and integrated into its target environment (P3)?

For each idea and social reaction, we encourage the experimenter to consider alternate possibilities as a means to generate additional interaction possibilities. For example, rather than being frustrated with a limited robot, the person may find the robot silly and the situation humorous, or the robot insistent and perhaps intimidating. Following, each of these alternates can be then constructed into additional possible interaction scenarios, e.g., perhaps the robot will be perceived as humorous and the person will use the robot for its entertainment value. Finally, the process can loop in an iterative fashion and these new interaction scenarios can be again analyzed using the three perspectives. This entire process is outlined on the left of Fig. 3.

6.2.2 Robot-Centered View

Simultaneous to the human-oriented exploration, a similar process is followed for the robot-centered case. First, the experimenter brainstorms robot design characteristics that they

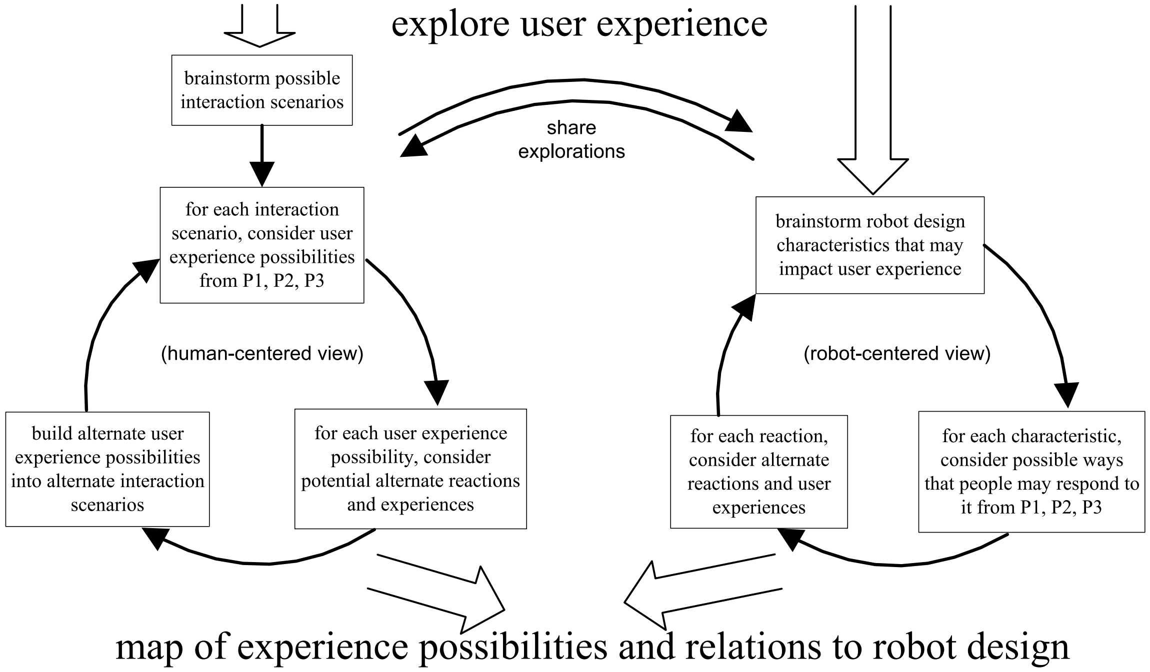

Fig. 3 Example process of using the three perspectives to fuel an exploration into experience possibilities

expect may influence the interaction experience. For example, the fact that the robot has a face, makes loud noises when it moves, or even that it is the color red.

Then, for each characteristic that was identified, the experimenter considers how people may react to it, and thus, how it may influence interaction experience. Here the three perspectives can be used as exploration probes, e.g., people may find the red color to mean warning or danger (on P2 or perhaps P1), and the robot being noisy may severely hinder its deployment success as it may clash with existing P3 social structures.

For each reaction possibility discovered, consider alternate ways that the interaction experience may be affected. For example, the red color may be seen as being festive or warm, or the noise may be perceived as a friendly quirk of the robot, or perhaps that it represents the robot complaining while working. Finally, the next step is to use these alternate experience possibilities to re-think and re-brainstorm which characteristics may impact experience, and this leads to another iteration of the entire process (as outlined on the right side of Fig. 3). For example, now that we have considered that the red, noisy robot may be seen as a festive robot with a quirky, fun sound, we can consider which other design aspects could support this identity, such as perhaps the particular face of the robot or the way that it moves.

6.3 Bringing it Together

As highlighted in Fig. 3, ideas and discoveries should be shared between the simultaneous human- and robot-centered processes. This hints at the flexibility that we see as being inherent in this process, despite the structured and directional method presented in Fig. 3—by no means do we suggest that the experimenter constrain their brainstorming to the process we present here.

This flexibility also matches our own experiences of map exploration, the foundations of where this process began. In practice, we jumped between various methods of design and brainstorming, using components of our method presented here when we felt they were particularly useful. We see our map-building process as a guide and aide to brainstorming. While this process can be followed structurally, particularly as a way to start exploration, in practice we see it as something the experimenter can turn to for hints and ideas for pushing the brainstorming to new directions—particularly in relation to the three perspectives. This is highlighted by the fact that, as presented, this process has no explicit end and could conceivably yield a very large map. In practice, it is up to the sense and judgment of the experimenter to decide which possibility directions to pursue and which ones to cut.

As currently presented, our process does not have mechanisms for grounding exploration on anything but the opinions of the experimenter, and so this highlights the fact that the resulting map is grounded only within the experimenter's own sense of judgment.

The overall result of this process is a very comprehensive set of socially focused and context-aware considerations on interaction experience possibilities between a person and a robot, both in terms of how the person will experience the interaction and how the robot itself may influence this experience.

7 Future Work

Our perspectives (and the techniques surrounding the experience possibilities map) need to be practically and formally deployed in actual evaluations, as a way to better understand the scope of our proposed methods and to validate our approach. Related to this, we need to develop more concrete methodologies and tools for how the perspectives can be used by evaluators. We hope that these will emerge as we apply the techniques in actual studies.

Our analysis of related HCI and HRI evaluation methods presented in Sect. 3 was based on techniques which we feel are particularly relevant. However, there are many other techniques which we have not yet explored, such as research-through-design and video based evaluations, and it remains a question how our perspectives will relate to other methods.

The three perspectives as presented only cover a portion of interaction possibilities within the holistic context, and we intend to consider which other perspectives are needed in this framework to offer a better cover. For example, currently we do not explicitly handle the differences between a single robot versus groups of robots, or actual changes to the physical structures of the home in addition to the social ones, such as with roombarization where homes are physically modified to accommodate the robot [73]. Further, while our perspectives and technique focus on highlighting particular robot characteristics, we do not address how the combination of characteristics can be an important factor. That is, the meaning and influence of one robot design characteristic will be highly dependent on the other characteristics of the robot. Following this, we need to further investigate how these robot particulars relate to the characteristics and personality of a given person interacting with the robot.

Our current perspectives are presented as a means to aid in evaluation, to help a person consider interaction possibilities. It can also be interesting to consider how a robot could internally use the perspectives in forming its understanding of social interaction.

Finally, while we present our perspectives and interaction experience map as being a tool explicitly for HRI, the question remains as to how much of an overlap exists between these methods and applicability to other technologies. We envision that these perspectives may be useful for any technology which has a very strong social presence, and are excited about future exploration in this area.

8 Conclusions

Robots, by their very nature, encourage social interaction and create a unique interaction experience for people. The exact mechanics behind this phenomenon are perhaps yet unknown, but we argue that it is related to how robots integrate into everyday settings, encourage anthropomorphism and create a unique sense of *active agency*—people naturally tend to treat robots similar to living entities. While the fields of HCI and HRI provide many well-tested evaluation techniques, we feel that a gap exists in considering how these should be applied to HRI in a way that acknowledges and targets its holistic and contextual nature. As such, we call for this question to be further explored and for researchers to devise techniques and methods that explicitly target the unique properties of HRI.

In this paper, we have presented one such approach in the form of a new set of perspectives that evaluators can use to help target the social and contextual nature of HRI, highlighted how the perspectives can be used as a powerful vocabulary to discuss and classify existing work and evaluations, and demonstrated how we feel it can be integrated into evaluation. Overall, we see this paper as both a call for considering the unique challenges posed for evaluating robots, as well as offering an initial step in both highlighting the issue and offering initial solutions.

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