Noname manuscript No.
(will be inserted by the editor)

An Attachment Framework for Human-Robot Interaction

Nicholas Rabb · Theresa Law · Meia Chita-Tegmark · Matthias Scheutz

Received: date / Accepted: date

Abstract Attachment theory is a research area in psychology that has enjoyed decades of successful study, and has subsequently become explored in realms beyond that of the original infant-caregiver bonds. Now, attachment is studied in relation to pets, symbols (such as deities), objects, technologies, and notably for our purposes, robots. When we discuss attachment in Human-Robot Interaction (HRI), is "attachment" to a robot the same as being attached to a pet? Or does it more closely resemble attachment to a technology device such as a smartphone? Through untangling the concept of attachment in HRI, we summarize a breadth of the existing attachment literature in a unified spectrum. We present a notion of *weak* attachment, and *strong* attachment before setting both as distinct ends of a spectrum of attachment. We motivate this spectrum by teasing out the underlying theoretical basis for strong attachment, and how capabilities of the attachment figure could lead to stronger or weaker attachment. This more nuanced, multi-dimensional representation of attachment allows us to present a clarified categorization of where various human-robot bonds explored in HRI studies fit on the spectrum, where robots in general could place, and how a clearer definition of human-robot attachment can benefit future HRI studies.

Keywords Human-robot interaction, attachment, emotional bond, social bond

N. Rabb · T. Law · M. Chita-Tegmark · M. Scheutz
HRI Lab, Tufts University
200 Boston Avenue, Medford, MA 02155
E-mail: {nicholas.rabb, theresa.law, mihaela.chita_tegmark, matthias.scheutz}@tufts.edu

1 Introduction

Attachment theory is a research area of psychology that has enjoyed decades of successful study, and has subsequently become explored in realms beyond that of the original infant-caregiver bonds. Now, attachment is studied in relation to pets, symbols (such as deities), objects, technologies, and notably for our purposes, robots. Attachment in Human Robot Interaction (HRI) weaves its way into plethora of studies, but as is typical in a game of telephone over the decades, attachment in HRI often presents as a far cry from its original psychological conception.

When we discuss attachment in HRI, what do we really mean by that attribution? In the psychological study of Attachment Theory, researchers use the word "attachment" to denote a very strong bond someone has with an attachment figure who, in their mind, provides so much security and safety to the individual that they are very dependent on the attachment figure – to the point where separation from that figure would result in serious psychological distress [1]. Psychological Attachment Theory was pioneered as a study of infants' attachment to their caregivers, and has since been extended to encompass people's attachment to pets [99], symbols or deities [61], or objects [57]. In line with [26] we question whether robots are truly the objects of our attachment to the degree that we experience classic infant-caregiver markers of anxiety and avoidance in our bonds with them. Is "attachment" to a robot more or less the same as being attached to a pet? Or does it more closely resemble attachment to a technological object such as a smartphone? These questions are important to ask of attachment in HRI lest the sub-field over-attribute strong psychological phenomena to

human-robot bonds, or otherwise fail to recognize when markers of strong bonds are present.

Distinctly from attachment frameworks rooted in social psychology, many studies of attachment in Human Computer Interaction (HCI) refer to Norman's [75] investigation into people's penchant to attach to everyday objects [95, 88, 51]. This definition of attachment is framed as a cumulative sum of positive experiences with the object in question. This notion of a cumulative sum of positive experiences, as compared with the social psychological definition, is one of the most prominent examples of how the term "attachment" is used across disciplines, but without reconciliation between definitions. This definition is used heavily in HRI but then the subsequent attachment attribution is often interpreted in the social psychological sense. As we will elucidate, this notion of attachment is weaker than that described by social psychology.

In HRI, it has become important to distinguish sharply between the social psychological meaning given to attachment, and the HCI definition. The HRI literature uses the term "attachment" loosely at times, which both makes the findings and discussion of studies less precise, and also has the potential to mislead readers regarding the effect robots are having on human participants.

Through untangling the concept and proper attribution of attachment in HRI, we summarized a breadth of the existing attachment literature in a unified spectrum, inspired by [26]. We present a notion of *weak attachment*, and *strong attachment* before setting both as distinct ends of a spectrum. Both types of attachment can be viewed as manifestations of differing degrees of social psychological attachment criteria of secure base (security and support for exploration and self development) and save haven (comfort in times of distress) functions, as well as proximity seeking and separation distress behavior; strong attachment has presence of all four to a high degree, and weak attachment may have only presence of a few, or insignificant presence of all four. Through our analysis of human attachment with pets, symbols, objects, technologies, and robots, we more deeply specify how each of the criteria may be met on the functional basis of a given attachment figure; thus giving a more detailed framework to use in HRI study. Such a framework then allows us to describe the nature of potential or observed attachment bonds in human-robot pairs, and subsequently use the spectrum of weak and strong attachment to characterize the intensity of the bond. The framework allows us to draw clear links between theoretical perspectives from other disciplines (e.g. social psychology, human-computer interaction), to justified use of methodological tools – such as questionnaires – from those disciplines, and comment on attachment patterns for different kinds of robots in a nuanced manner.

Importantly, we want to emphasize that this is intended as an entirely value-neutral approach to attachment. A great deal of HRI literature relating to human-robot attachment is framed as an ethical problem: can humans attach to robots, and if so, what ethical questions does that raise [84, 91, 51, 88]? We will not argue whether such attachment to any of the aforementioned attachment figures is good, bad, or anything in between. Our purposes lie simply in presenting a more nuanced and comprehensive depiction of attachment and where HRI studies land given such a framework. We believe this systematic analysis is an important and novel contribution to the HRI literature that should be used for further ethical analysis by other researchers.

In summary, this paper presents the following contributions: (1) A brief overview of sub-fields of attachment study including that related to human attachment between infants and caregivers, with adolescents and adults, pets, symbols (as in deities), objects, technology, and finally, robots; (2) A deeper investigation of social psychological attachment criteria that motivates a framework to be used for characterization of human-robot bonds; (3) A presentation of *weak attachment* versus *strong attachment*, and the implications of different attachment intensities along a spectrum; And finally, (4) analyses of notable human-robot bonds, as described by HRI studies, which are related to human-robot attachment, and where they fall on the spectrum of attachment.

2 Background

The first attempt at looking at the relevant HRI literature and creating a more robust framework for human-robot attachment, to our knowledge, comes from Collins et al. [26]. They reference the same goal as we do: clarifying use of the term "attachment" in HRI through an investigation into the relevant social psychology literature. Using Collins et al. as a starting point, we investigate attachment literature from the vantage point of attachment figures a human could potentially become attached to; including humans, pets, objects, symbols (such as deities), technology, and robots.

Importantly, we distinguish between the study of attachment as an effect of *having needs met* rather than *meeting needs*. In this paper we focus on robots as attachment figures, meeting hu-

man needs, rather than the other way around. We feel that addressing human needs is ultimately the end goal for creating and using robots, and that "vulnerability" in robots is often just a stepping stone towards achieving a broader goal. For example, Paro may act as if it needs or appreciates care, but its ultimate intended function is to offer emotional and conversational support to people [85]. However, we acknowledge that the directionality of the attachment relationship between humans and robots can sometimes be perceived by the human as flipped. Humans do attach from a sense of empathy or caregiving responsibility as well, and some people have been shown to assume the role of protecting, teaching or caring for robots [19,88,49]. Indeed, some robot designs rely on this emotional and behavioral dynamic to increase the robot's acceptance by leveraging our nurturance instincts (e.g., [60,62,91]). Making the robot act vulnerable can also amplify its agency by enticing people to help the robot or teach the robot new actions. Some social robots' interaction styles are modeled after pets, which have an ambiguous profile in terms of perceived attachment directionality: pets can act as a safe haven or secure base for humans, but they also require care and depend on the human to act as a safe haven or secure base for them. Playing the role of a caregiver may increases the person's perception of, and positive affective behavior towards the robot but this elicitation of affect should ultimately be just a part of a more comprehensive (emotional) service provided by the robot.

In the style of much of social psychological attachment theory – in the vein of Bowlby [13] and Ainsworth et al. [1] – we wish to present relevant research pertaining to "caregivers" meeting the needs of those who become attached. This is the manner of attachment we will be investigating in robots throughout our paper. We can first begin with human-human attachment, as it is the most researched and the original impetus for attachment theory.

2.1 Human-Human Attachment

Much of the work on human-human attachment stemmed from studies by Bowlby [13] observing how infants reacted to different styles of caregiving from their mothers. He was the first to suggest that based on caregivers' attitudes and behaviors towards their infants, the infants would respond in systematic ways. This led to the theory that humans are born with an innate system that allows us to cope with stressful situations; one that elicits behavior directed at an *attachment figure*. The theory also postulates that in our earliest years, this system is "tuned" and its parameters tweaked to form the systematic ways we bond with others years down the road.

The work was continued by notable researchers such as Ainsworth [1], who first provided empirical research to support Bowlby's theory. Later, Hazan [45], Shaver [46], and Zeifman [44], further elaborated on the nature of the attachment figure, extending the scope to encompass adult relationships. Ainsworth notably distinguished different attachment styles based on infants' reactions to their caregiver's actions in the Strange Situation experiment. Infants' reactions and attachment styles were organized into three distinct categories: those of *anxious* attachment, *avoidant* attachment, and *secure* attachment – with the former two describing maladaptive conditions, and the latter as one to strive for.

Linking with Bowlby's theorized Internal Working Models (IWMs) of our selves and attachment figures, these categories were shown to apply to individuals based on how their early life attachment figure(s) interacted with them. These IWMs can be thought of as "the way we view others and ourselves." Along with Ainsworth's empirical methods, contemporary researchers like Hazan [45], Shaver [46], and Zeifman [44] have demonstrated that this way that we view others, based on our childhood experiences, is not specific to just our caregivers, but instead becomes generalized and applies to close relationships later in life.

Specifically, an attachment bond would form if the caregiver met the infant's needs for security and affectionate comfort when distressed; with these two functional roles played by the attachment figure being labeled the *secure base* and *safe haven* functions. Attached infants were also observed *seeking proximity* to their attachment figures, and displaying *separation distress* in their absence. These functions are considered criteria for leading to the formation of an attachment bond: if a caregiver functions as a secure base, infants would use the security provided as means to explore and learn, always knowing that safety is available when distress occurs; an infant would likewise recognize that the caregiver is capable of soothing their distress – the safe haven function. A securely attached infant is one whose caregiver is generous in providing security and safety, leading to the infant learning to properly utilize the caregiver's functions in a balanced manner. In contrast, maladaptive anxious attachment patterns were relegated to infants who attempted to maximize proximity to caregivers, and avoidant

patterns were characterized by minimal proximity seeking. Regardless of attachment style, an attached individual is also noted as exhibiting behaviors of proximity seeking and separation distress; the functions enable attachment bonds to be formed, and evidence of attachment lies in the subsequent behaviors. These four features of attachment have been teased out as criteria for attachment by Hazan and others, so we use them for our investigation. For excellent reviews of these ideas, we encourage readers to read Granqvist, Mikulincer, and Shaver's [42], or Bretherton's [17] summaries of the research.

Since its original investigation in the context of infant-caregiver relationships, attachment patterns have been shown to recur in adolescent and adult relationships. Bowlby theorized this in his early work, and experimental results have confirmed that patterns formed in early life stay with us into relationships later in life unless intentionally attended to. Ainsworth [2], Hazan [45], Shaver [46], and Zeifman [44] have all displayed that the same behaviors relating to secure base, safe haven, proximity maintenance, and separation distress are displayed in attachments beyond infancy.

The framework given by Bowlby and beyond is useful for characterizing some of the strongest social behavior patterns displayed in human relationships. Being able to point to formation in infancy, and examine relationships through anxious, avoidant, or secure behavior, has been helpful in both theoretical research and clinical practice. For our purposes, it presents an opportunity to more finely distinguish relationships between humans and robots – dissecting what researchers in HRI are saying when they discuss human-robot "attachment" in order to ground it in empirically verified theory with a long and robust history.

Perhaps even more notably, the scope of attachment theory research has not ceased at the border of human-human relationships. More recent attachment research has brought the framework to relationships between humans and pets, objects, deities, and technologies – so-called *secondary attachments*. We now turn to brief investigations of the relevant literature concerning each subsection of attachment research. Creating a wide scope of potential attachment figures will allow us to build an even more fine-grained theory of attachment within which we will place different purported HRI attachments.

2.2 Human-Pet Attachment

It appears that a pet would be a natural candidate for attachment bonds to form [54]. We anecdotally or personally likely know of such bonds between pet owners and animals, even as far as in the sense of a pet functioning as a secure base and safe haven, and eliciting proximity maintenance and separation anxiety behavior. Zilcha-Mano et al. [99] give an excellent review of relevant literature indicating that these attachment criteria are indeed met by human-pet relationships. They argue that owners feel close to their pets, seek and enjoy this closeness (proximity); that pets provide owners with affection, support, comfort, and relief in times of need (safe haven); that pets can serve as a means from which their owners can pursue activities and take risks with confidence (secure base); and that loss of a pet is very distressing, causing mourning and grief (separation distress).

Further, Zilcha-Mano et al. note that pet relationships are also organized by the orthogonal dysfunctional attachment styles of anxious and avoidant. Pet attachment anxiety may manifest as worries that something bad may happen to a pet, a strong need for proximity to a pet, reassurance-seeking from the pet to assert self-worth, or anger when a pet prefers proximity of others. Avoidant human-pet attachment would present discomfort with physical or emotional closeness to a pet, striving to maintain emotional distance from it, preventing the pet from intruding on personal space, or difficulties depending on a pet and turning to it when distressed. In fact, their study additionally found that there is a moderate correlation between pet attachment styles and that of the owner's human-human attachment style.

2.3 Human-Object Attachment

Though it may seem counter-intuitive that a phenomenon such as attachment – one that is closely facilitated by emotional feelings of safety and comfort – would apply to people's relations with objects, there is a growing body of evidence in support of this manner of attachment. Early research conducted by Winnicott theorized that children attach to objects such as blankets or stuffed animals – so-called *transitional objects* [97]. The theory states that children cope with awareness of a caregiver's occasional unreliability through the reliability of cherished objects. It goes on to further theorize that children's lack of control over their environment is alleviated by total control over such objects.

However, similarly to human-human attachment, more recent experimental evidence is building to support the claim that human-object attachment is not simply limited to infants. Keefer, Landau, Rothschild, and Sullivan argue in a series of papers that attachment to non-human targets can be viewed as compensation for lack of similar attachment with human others [57,59,58]. They experimentally demonstrate that when primed with unreliability of close others, participants scored higher on an attachment to objects measure. The key factor that they highlight in their studies is the ability of objects to always be reliably present – criteria that human attachment figures may not always meet.

Norman additionally extends a notion of attachment to objects to attachment to places, identifying our penchant to have, "favorite corners of our home, favorite locations, favorite views" [75]. Likewise, Bachelard eloquently describes our attachment to our homes as, "shelter[ing] daydreaming, the house protects the dreamer... It is body and soul" [8]. He continues and writes that, "its corners and nooks conceal the sweetness of solitude; its rooms frame our experience of relationship. Its shelter, stability, and security work to concentrate our unique inner sense of self..." When basic human needs commonly include shelter, it should be no surprise that we can strongly attach to the places that provide us safety or comfort.

Distinctly from attachment frameworks rooted in social psychology, many studies of attachment in Human Computer Interaction (HCI) refer to Norman's [75] investigation into people's propensity to attach to everyday objects [95,88,51]. Despite occupying a very small portion of the broader work on emotional design, the HRI community frequently refers to this definition of attachment when discussing human-robot attachment: as a cumulative sum of positive experiences with the object in question. There are aspects of identity innate to an accumulation of experiences and memories created with an object.

This notion of a cumulative sum of positive experiences, as compared with the social psychological definition, is one of the most notable examples of the uses of the term "attachment" across disciplines, without drawing links and clearly pointing differences between definitions. We should be careful to note that Norman was likely not intending to make any significant contributions to study of human attachment with objects, though his assertions have made a strong impact with the HRI and HCI communities. As we will elucidate, this notion of attachment is weaker than that described by social psychology. Our investigation will aim to systematically tease these apart.

Attachment to objects provides an important revelation regarding the nature of attachment: feelings of security, safety, and comfort do not need to come from biological others to mitigate distress. This idea will factor into any investigation of human-robot attachment, as robots are neither object nor human, but rather something in between.

2.4 Human-Symbol Attachment

Perhaps most surprising is that a body of research exists which theorizes about and demonstrates the human ability to allow abstract symbols to serve attachment figure functions. This type of attachment is most frequently cited in the context of religious attachment with deities, but also spans attachment with celebrities, talk show hosts, or fictional characters through parasocial relationships.

Keefer, Landau, and Sullivan briefly review attachment behavior relating to media personae [58]. Similarly to object attachment, participants in a handful of experiments were shown to be able to alleviate feelings of loneliness by thinking about favorite TV shows, or favorite TV characters. They further note that people with high attachment anxiety are more likely to develop these parasocial relationships.

However, perhaps most interesting is the rich literature surrounding attachment to symbols in the sense of deities. Granqvist et al. summarize some of the pioneering work by Kirkpatrick [61] as they explore effects of religious attachment [42]. Attachment with God is observed to have many of the same cognitive models and behaviors present in traditional attachment theory: proximity-maintenance by praying, being in "God's home," and seeing God as omnipresent and near; having a safe haven function as God soothes distress during times of illness, injury, fatigue, or alarming events; and secure base function as God is viewed as strong, wise, and offering a sense of personal competence and control. These theoretical attachments to God were tested and shown to be present, especially when attachment relationships are insufficient or others are unavailable [42, 58].

Anxious and avoidant patterns are additionally shown to be present in people's relationships with God. However, distinct from human-human attachment, Granqvist et al. are careful to note that, "... such differences between religious attachments and secular, mundane attachments may make it advisable to consider religious relationships to be

attachment-like relationships rather than attachments proper" (emphasis our own) [42]. In line with human-object and human-pet attachment, it appears that these secondary attachment figures are best suited to situations when human others are insufficient or not present.

2.5 Human-Robot Attachment

Attachment in HRI literature is discussed in varied ways. Sometimes it is discussed in the context of psychological attachment theory [26], and in others, loosely without a rigorous definition of what is meant. Across studies, however, is a pervasive presence of warnings about robots' potential to foster attachment with their human counterparts and lead to unethical situations. Sharkey and Sharkey discuss this in depth, and apply the psychological attachment framework to situations where robots may care for children [84]. Turkle relays worries about interactions she observed with children ascribing serious levels of intentionality, emotion, and cognition to robots such as My Real Baby – warning that "relational artifacts" understand nothing, but push our "Darwinian buttons" and cause people to respond as if they were in relationship [91]. Even Norman, in his aforementioned 2004 book on emotional objects, briefly warns of the ethical implications of "humanoid robots that have emotions and to which people might form strong emotional attachments" [75].

Despite the widespread agreement that attachment in HRI seems to be problematic, definitions vary. One definition of attachment that is often referenced in HRI literature is that of Norman [75] which states that attachment represents the sum of cumulative emotional episodes a user experiences towards a device. This is the definition used by Weiss et al. in their study of children's emotional attachment to the robotic dog AIBO [95]. Sung et al. extend this definition to also include people's inter-personal and social responses to the robot (in this case a Roomba), in addition to their emotional ones [88].

Also inspired by Norman, Huber et al. propose the following definition: "An enduring attachment can be defined as the sum of all cohesion episodes a person has made with another person or object. A cohesion episode is characterized by joint experiences with this other person or object in which cohesion factors are present" [51]. They further characterize cohesion factors as comprising of four categories: (1) shared factors (values, interests, preferences etc.) (2) charisma factors (sympathies and attractiveness), (3) personal factors (openness, vulnerability integrity, empathy etc.) and (4) social factors (reciprocity and equality).

This line of thinking has led the community to several research strands which underlie emotional bonding or social elicitation generally. Anthropomorphization [32] of robots is widely studied [15, 56, 95, 31] because it fits into this paradigm of broader sociality [63]. Others have studied robots' ability to elicit emotional reactions [72, 85], to provide intimacy cues [33, 78, 96], to generally be useful [30, 48], and to engender nurturing behaviors in humans [19, 49, 62]. When attachment is thought of only as deep relational bonds, then the degree to which the robot would be an object of attachment would be influenced by anthropomorphism and the other above mentioned phenomena. While these lines of study reveal many important effects of human-robot relationships, we question whether this formulation of attachment probes deeply enough into the potential causes of human-robot attachment. Particularly, given studies like Sung et al.'s [88] and Forlizzi and DiSalvo's [36], the fact that some people strongly attach to robots like Roomba – which is neither anthropomorphic, emotional, nor intimate – begs deeper investigation. In this paper, we attempt to highlight what may be deeper psychological processes affecting attachment formations.

Some HRI researchers disagree with this more diffuse formulation of attachment. Collins et al. [26] seem to be the first to suggest that the term attachment should be reserved for relationships that feature all the four criteria identified in social psychology (safe haven and secure base functions, and separation distress and proximity seeking behavior). They recognize that social robotics is not advanced enough today for any relationship with a robot to fulfill all of these criteria and thus fully qualify as attachment. They rather argue that – if viewed instead as a model for defining a spectrum of bonds rather than benchmarks to be achieved – these criteria are useful for identifying the degree to which bonds between humans and robots resemble attachment bonds. This fits more in line with Sharkey and Sharkey's [84] conceptions of problematic bonds with robots, and extends Turkle's [91].

What is clear is that before embarking on more studies of HRI, the notion of "attachment" would do well to be defined with a sharper edge that is carved from work spanning an array of attachment definitions. As mentioned above, there lies the goal of this paper: to take the plethora of existing literature and make sense of it in a unifying way through a more systematized spectrum of attachment. In the next section, we will theorize a set of heuris-

tics that possibly underlie the varied definitions of attachment. Our hope is that this formulation of attachment will shed light on where the bulk of robots in HRI literature falls – whether closer to human-object attachment, or to human-human attachment, with sufficient rationale. To begin, we will deconstruct attachment as we understand it in a way that unifies the disparate definitions.

3 Attachment Functions, Behaviors, and their Components

We motivate our framework with work that has already been done in social psychology. Later on, we will argue that the presence of social psychological attachment criteria should be treated as the strongest form of attachment that could arise, so we will analyze the relevant research in those terms: secure base and safe haven functions, and proximity maintenance and separation distress behaviors (see Fig. 1). We will also later distinguish weaker forms of attachment from those which present all of these four features to a high degree.

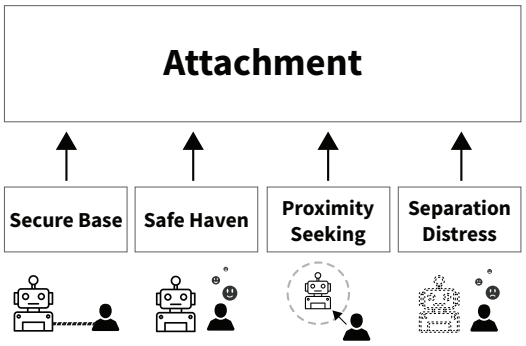

Fig. 1: Features of Psychological Attachment

For the functional criteria outlined above, we outline components of each that seem common in previous attachment work, as an attempt to answer the question of "how?" the criteria may be met. By combining those with observed attachment behaviors, we give a framework for justifying placement of human-robot bonds on the attachment spectrum.

Though, by themselves, the definitions of attachment functions and behaviors are helpful, they are not entirely precise. In order to properly classify HRI results in terms of attachment, we must ask, "What do we mean by 'secure base'?" What underlies the safe haven function? To be clear, our theorized components of these attachment criteria in no way comprehensively or rigorously define each. Rather, they set up a theoretical framework through which analysis of different attachment figure types will be facilitated. What becomes even more interesting is that an analysis of attachment criteria components makes evident the idea that some categories of attachment figures have attachment *potential* based off of these components, as distinct from actual manifestations of attachment. We should note that our choice to frame attachment in terms of these four features does not ignore other definitions such as those from Norman [75] or Huber et al. [51]. We will argue that this proposed framework actually encompasses those definitions and places them in greater context that will help unify disparate definitions.

For each attachment feature, after analyzing its components, we will comment on how different attachment figure types (humans, animals, objects, symbols, and robots) may engender the components. However, to give more nuance to our analysis of human-robot attachment potential, we choose to make clear that not all robots are created equal. Robots can functionally be quite varied, and any honest analysis should take that into consideration. Accordingly, we will comment on the most applicable robots in each situation while encouraging the reader to keep in mind that we wish to characterize each robot individually and with nuance.

3.1 Secure Base Function

We begin with the first function discussed in attachment theory: that of a secure base. While summarizing attachment literature, Zilcha-Mano et al. describe this function as providing a "sense of safety from the attachment figure which incur[s] exploration, risk taking, and self-development" [99]. Our framework must, then, have some way to account for feelings of safety, and naturally present rough heuristics that comprise "safety."

For our purposes, it seems sufficient enough to note that lack of safety produces vulnerability: we are safe when we are free from immediate or potential harm. We use Mackenzie, Rogers and Dodds' notion of "inherent" vulnerability as motivation for our framework; that which arises from corporal needs such as, "hunger, thirst, sleep deprivation, physical harm, emotional hostility, social isolation, and so forth" [70]. An other may shield us from vulnerability by providing access to resources, including material (such as shelter or physical protection), mental (including access to knowledge), and social (connection to groups, or influence) resources.

When Bowlby describes his theory of separation anxiety, he references the "strong and wise parent" – an attachment figure who is able to be strong through manipulating the world, and wise via access to mental resources [14]. These abilities of the attachment figure seem linked to notions of power – the figure can act on the world so as to secure safety for the child, so the child can in turn explore the world more courageously. Notably, as mentioned above, these abilities simply create potential for the secure base function to be performed. Our analysis will explicate the potential for attachment figure types to achieve each component of the secure base function, use those findings to motivate where robots may have potential or not, and then analyze human-robot bonds as described by HRI studies to see how those potentialities have manifested secure base functions in research.

A visual representation of the function, its components, and where different potential attachment figures fall on a spectrum of low to high degrees of fulfillment is shown in Fig. 2.

3.1.1 Potential to Meet Physical Needs

A component leading to material safety would surely be the ability to meet physical needs [70]. Imagining a human parent would perhaps conjure their tendency to procure food, shelter, money in order to buy those things, or even physical strength in order to hold us, or remove danger from our environment. Some animals also have the ability to meet our physical needs [99]. Some objects are able to meet physical needs; car transports us and protects us from elements, and a house may shield us in times of danger [8]. Symbols such as a deity, on the other hand, are less capable of providing physical resources in actuality, but *perception* of a god as omnipotent may be enough to have a god function as a secure base [42,61].

Robots have the potential to do all of the above. One thing that robots are particularly good at is physical manipulation of resources, with strength that even surpasses humans. Robots such as the PackBots described by Garreau indeed serve a function of physical safety by detonating IEDs to protect soldiers [38]. There are many studies in nursing where robots assist with relevant tasks; including assistive robots to aid people with disabilities, service robots to aid the elderly in their daily lives [43,73], mobility robots to help people with navigation, serving and feeding assistance robots which range from bringing food on trays to actual support in feeding [37,11], and carrier robots which transfer patients from beds to wheelchairs [69]. Ivanov additionally summarizes roles that robots have presently taken in service and hospitality: as delivery agents, vacuums, servers, and more [52]. While many robots have been developed to meet physical needs in the service and care industries, it still remains that these robots are specialized. It appears that robots in general have the potential to meet many different physical needs, as their combination of sophisticated artificial cognition and physical embodiment allow complex tasks to be accomplished, but present technical limitations limit actual manufactured robots to serve a specialized role and perhaps meet only a few needs within that umbrella.

3.1.2 Potential to Meet Intellectual Needs

In the view of Bowlby's "strong and wise parent," a key component of a secure base seems to be wisdom, or generally, mental power [14]. A human caregiver has a decent amount of knowledge accrued over their lifetime, providing intellectual resources. Note that in order to later place mental comfort under the safe haven function, we are leaving meeting emotional needs out of this component. Animals are less able to provide intellectual resources [99]. Some objects, however, such as smartphones or books, have the ability to provide a broad or deep amount of intellectual resources. Even deities can be perceived to be wise and offer intellectual support through their associated parables and lessons.

Similarly to objects, robots have the potential to provide a host of intellectual resources. One that is connected to the internet and equipped with searching features may prove to be more intellectually resourceful than even a human or deity. However, limitations in sophistication – e.g. not being able to communicate information as compellingly as in a parable, or not as tailored to your mind as would be from a human – prevent current robots from rivaling humans or deities in some ways. In the HRI space, it seems that a prevalent line of robots that meet intellectual needs are those which serve as education assistants. Social tutor robots have been shown to lead to affective and cognitive outcomes [10,80,67]. Moreover, robots have been shown to encourage curiosity and creativity in children [40,5].

3.1.3 Potential to Connect to Others to Meet Needs

While perhaps non-obvious, a seemingly crucial element of safety garnered through power in the world is that secured through social means [70].

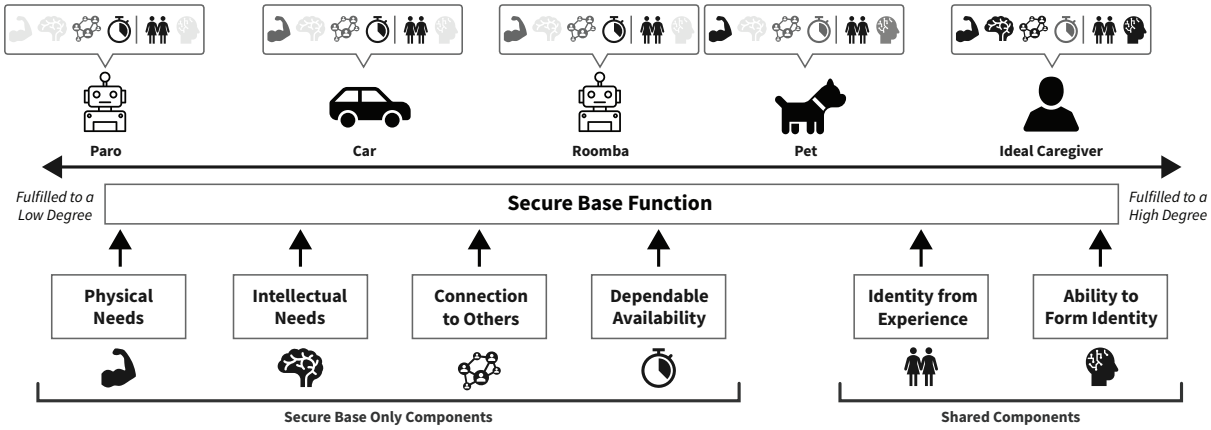

Fig. 2: Components of the secure base function – as fulfilled by different attachment figures – on a spectrum from low to high fulfillment

Upon reflection, we can see this is true as people who are well-connected, socially influential, or generally of some social prestige, are able to secure resources that can lead to safety [25,47]. In the eyes of a child, a human attachment figure such as a parent may have a magical ability to call on friends, acquaintances, or professionals to overcome or address vulnerabilities. This component of security, then, seems very dependent on the ability to encourage connection between people. It may be tempting to argue that a human attachment figure's inherent sociability – their ability to socialize with us – should be part of the equation. However, we will contend that this lies more in a component of the safe haven function. We strictly limit this socially-driven security as being able to connect to others. Given this working definition, a pet could meet social needs by encouraging the meeting of other people with pets, or promoting pro-social behavior through meeting people on walks [98]. Technological devices like a phone similarly connect us with each other to meet our social needs [20].

In the sense of encouraging social connection with other humans, robots could potentially do so in a variety of ways. While robots may not have other humans friends of their own to connect us with, they could be a topic of conversation, lead us to other robot users, or have similar telephonic capabilities as our smart devices [35]. There are some cases in the HRI literature, which we will explicate below, that indicate instances where some robots have served as social bridges between otherwise socially distant people. Therapy robots like Paro certainly accomplish this [94,85,28]. It seems that other robots that follow suit, such as those described by Shiomi et al., which encourage prosocial behavior through a robotic teddy bear [87]. Social robots have also been theorized to be able to serve a role as social mediators – facilitating our interactions in a way that promotes sociability [24].

3.1.4 Potential for Dependable Availability

A crucial piece of security additionally seems to be the reliability of the provider of security [13,14,16, 17]. After all, it would not make much sense to seek safety from an other that is sporadic in its protection against vulnerabilities. An attachment figure which is not available would not be able to be returned to for safety after a bout of distress sets in. In this sense, humans tend to be less reliable unless they are structurally set up to be present in our lives. Logically, our main attachment figures tend to be family members and significant others – those who are frequently available [1,2]. While pets have similar agency to humans, the structural role that they play via normative treatment of animals also renders them quite available [99]. Confined to the house or area close by, they may even be more present than humans, who are out and about. This is an aspect of security for which objects and symbols shine. Objects lack any autonomy, and are therefore as present as necessary as long as they are within grasp. Symbols such as deities, however, are the most present – omnipresent, in fact – and are available to be called upon for security at any moment, for any duration [42,61].

Robots again take a position that is somewhat a combination of multiple other attachment figure types. Some robots may be totally sedentary, and therefore always available within the home [71,85, 94]. Other robots may roam as autonomously as humans, and be likewise often unavailable. However, most robots at present seem to be limited to the confines of their user's environment [28,36, 43,56,88,95], and therefore highly available. Due

to currently low levels of sophistication and autonomy, social robot availability appears to range between that of objects and pets.

3.1.5 Robotic Secure Bases

In total, all attachment figure types studied thus far fill some aspects of the secure base function for people. Predictably, humans appear to be the most capable of providing such a function, as they are adept at securing safety in the physical, intellectual, and social realm – albeit perhaps being less dependable than other, less autonomous attachment figures. Pets appear to be less able to fulfill a variety of physical needs, barring perhaps offering physical safety, and likewise fall shorter regarding intellectual and social resources [99]. Pets, however, can be fairly available as many owners, indeed, *own* their pets and exercise control to make them physically available. Symbols are an interesting case as they can certainly be rationalized to have fulfilled physical or intellectual needs – especially in the case of an omnipotent and omniscient god having had a hand in any beneficial outcomes in life. Symbols also bring people together in community through worship [61,42]. Further, they are entirely available as their representations lie in our minds, which – in most cases – never leave us. Finally, objects may provide physical or intellectual resources, potentially even connection to others, but are often limited by intended function. They are, though, often very available as they have no autonomy, but are not so available as a mental representation.

Robots have the potential to bridge and move between these categories to achieve aspects of a secure base function, but, as is the case with objects, are largely differentiated based on functional design. Across the HRI literature, different robots take different qualities and inspiration from their human [56], pet [94,95], symbol, or object [43] counterparts, and subsequently achieve different degrees of secure base functions. Studies show hints of the secure base function being achieved by robots, but not quite as much as other attachment figure types.

There are notable studies investigating the popular service robot, Roomba. In a longitudinal study, Forlizzi and DiSalvo ran an ecological study in which they provided participants with Roombas for three to six weeks, then interviewed them about the robot [36]. Most participants responded fondly, and many described their pleasure with it in terms of its usefulness. Some cited its accessibility for elderly users, others described how it did a better job of cleaning than their old vacuum, or mentioned its ease of use. Sung et al. infamously described users' interactions with Roomba on an online forum, and noted that their outlook on vacuuming changed from "drudgery to a happy thought" [88]. Sung's study also describes users' distress when their Roomba broke down or had to be sent off for repairs. However, it does not seem apparent that Roomba served the full secure base function for its users. Rather, it seems to meet some specific physical needs, with high availability, potentially foster some social connections for users on the Roomba forum, but forgo meeting any intellectual needs.

Other robots seem to have been shown to meet intellectual needs, but be incapable or otherwise not compelled to meet physical or social needs. Chen, Park, and Breazeal document studies with tutoring or educational robots that help foster vocabulary acquisition, and affect expression [22]. Other social robots have been shown to be able to encourage creativity and growth mindset in participants [79,3,4,55]. These are strong examples of providing intellectual resources, but in a contained and short-lived manner. In a longer-term study, Gross et al. had their robot integrated into the daily lives of 9 seniors [43]. The robot could remind participants about medications, appointments, or engage in physical fitness coaching with them. In Gross et al.'s case, their robot seemed to certainly meet intellectual needs while also developing some social relationship over time.

Then there are robots like Paro, which are purposely designed to be therapeutic, and have been shown to elicit social behavior. Wada and Shibata provide qualitative evidence that residents in an elder-care facility where the robot Paro was deployed used the robot as a communication anchor [94,85]. For example, a particular resident who previously was avoiding others started to voluntarily join the interaction when she found someone else playing with Paro. In these instances, Paro is facilitating human social connections as would a real pet, is quite available, but does not have the capability to meet physical or intellectual needs.

It seems that robots that have been studied in the HRI literature can meet a few of the secure base function components, but no robot has met all of them. Functional design determines whether any robot can obviously meet physical, intellectual, or social needs. As of yet, no robot we have found in the literature even has the capability to fulfill all components of the function, regardless of whether or not they actually do. This seems to leave the robots with the highest secure base function potential more toward the pet end of both capability and actual role fulfilment – heavily de-

pendent on functional design, and time spent with the robot.

3.2 Safe Haven Function

The second important attachment figure function that appears to engender attachment phenomena is that of the "safe haven." Again, in their summary of psychological attachment theory research, Zilcha-Mano et al. describe this function as when someone gets a "sense of removing distress and receiving comfort, encouragement, and support from the attachment figure" [99].

For our purposes, it was important to distinguish this from the secure base function; specifying that secure base is *strictly* concerned with removing vulnerabilities, while a safe haven is less about security but rather concerned with soothing, healing, and comforting. The mental aspect of secure base is perhaps the best example of this: it is important to distinguish providing mental resources in the form of ideas or wisdom, which may create conditions for comfort, from the direct creation of mental comfort via emotional support or encouragement. While this line may be fine, we attempt to outline important, though by no means comprehensive, components of the safe haven function.

A visual representation of this function, its components, and where different potential attachment figures fall on a spectrum of low to high degrees of fulfillment is shown in Fig. 3.

3.2.1 Potential to Palliate Physical Distress

Chief to any safe haven function that we may associate with attachment figures is some ability to soothe in a physical manner [93]. As children, if lucky enough, we look to our primary caregivers when faced with cuts, scrapes, bruises, aching muscles, or other bodily distress. A kind and loving parent may, then, be associated with the warm feeling we get from their hugs, careful band-aid application techniques, and kisses. However, as is evident from further attachment research, others such as close friends or partners also become associated with such physical stress relief [21]. In this sense, humans are quite adept at being physically comforting. Pets tend to achieve great success in this arena as well, and one may argue that over time they have been artificially selected to be more successful [53]. Symbols, similarly to their role in the secure base function, may likely be associated with their ability to soothe us when we think of them, and a visceral, physical feeling may also accompany the thoughts. Finally, some objects are functionally designed to remove physical aches and pains from our bodies, and thus may be candidates for safe haven formation.

To their benefit, robots can pick and choose from these categories in order to achieve certain measures of physical comfort: they can be functionally designed to alleviate pain while also being materially crafted to be soft, huggable, or otherwise physically soothing [85]. Perhaps some robots may even return the hugs [86]. Though, as became clear through our analysis of robots regarding the secure base function, the present lack of mechanical sophistication of robots would likely hamper any attempts at recreating nuanced human touches or embraces. The whirring of gears and hydraulics as your robotic companion stiltedly attempts to hug you may also have a high likelihood of killing the comforting mood, so to speak. Limited to small touches, some robot touch has been shown to decrease physiological stress in participants as they were watching a scary movie [96], and has led to longer engagement time as participants completed a monotonous task [86, 74]. Though, some studies have shown no such effect [12]. Conversely, people touching a robot have reported perceived friendship with it, and emotional stability as higher than those who did not touch the robot [78].

3.2.2 Potential to Palliate Mental/Emotional Distress

On the flip side of the physical, we often experience mental and emotional distress that can be equally painful as it manifests though psychosomatic means [9]. Humans clearly stand at the apex of ability to soothe mental and emotional distress (and, ironically, in their ability to cause it). Through words of affirmation, gestures of solidarity, or simple listening and validation, a human attachment figure has a plethora of tools at their disposal to interact with our mental and emotional distress. Even their presence as a social other may soothe distress based on loneliness or lack of community. Pets, though not equipped with human-level linguistic capabilities, do serve as emotional support for a vast number of people. If the proliferation of emotional support animals is any indication, it appears to be evident that people feel that their pets understand them, and do offer substantial mental comfort [18]. Symbols and deities are frequently cited as providing emotional comfort in times of distress [77, 61, 42]. Simply imagining an icon may be enough to bring about such comfort. Moreover, deities offer comfort in the sense of bestowing purpose and mean-

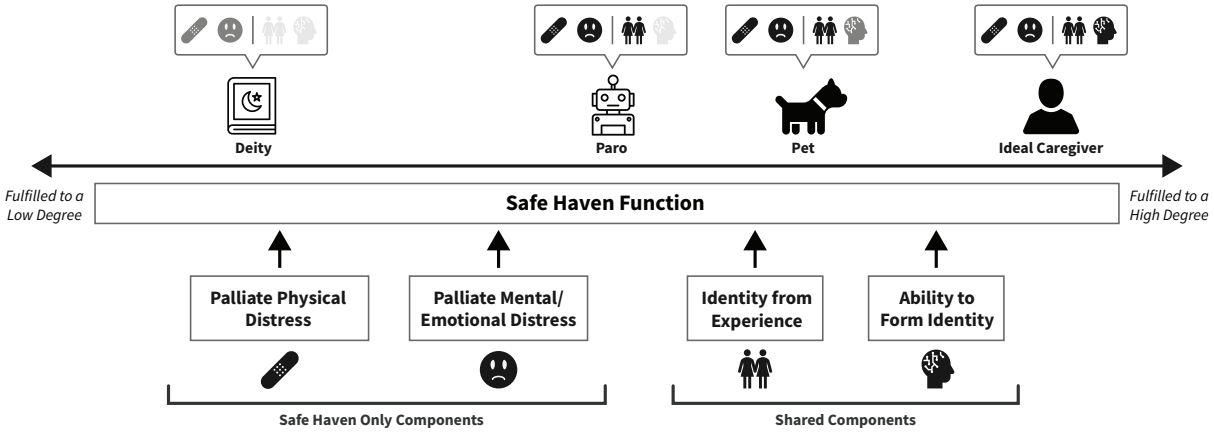

Fig. 3: Components of the safe haven function – as fulfilled by different attachment figures – on a spectrum from low to high fulfillment

ing to people; providing existential comfort. Additionally, some objects may even provide mental encouragement. Certainly, books which contain encouraging words can do so, but even well-designed objects resonate personally with their owners to bring about emotional response simply by their form alone. Norman's conception of attachment also addresses an object's ability to be associated with memories which, upon recall, may also provide emotional comfort [75].

An important aspect of mental soothing seems to be the ability to be generative, and provide novel soothing thoughts or behaviors. Our emotional and mental distress, by nature of our mental complexity, can manifest in a variety of ways that likely changes as we grow older, learn more, and mature. However, this must be importantly contrasted with novelty as it pertains to infatuation, which Bowlby is quick to dismiss as a different phenomenon altogether from attachment [13]. It is most evident in the case of objects that we often become bored or less stimulated by them as time goes on; their form is fixed and therefore cannot adapt to new distress. More complex creatures, such as humans or pets, certainly have the ability to be novel and generative, but to varying degrees. Perhaps humans are so frequently our primary attachment figures because they, by virtue of their equally complex mental and emotional systems, are the only ones who can commensurately match our distress. Surprisingly, through stories or records such as films, music, etc., symbols and icons may also embody a degree of novelty. In holy texts, there are so many stories that one is likely to find new meaning and comfort in them even as time marches on.

Robots present an interesting case, as some may be able to somewhat address mental or emotional distress, but in a limited capacity. Some specifically therapeutic robots, specifically designed for cognitive interventions via natural language, have been shown to increase positive affect and mood in participants [92,28]. But while those which engage with language often, at first, appear to give off the impression that they understand our mental anguish – as is famous in the anecdotes of people chatting with systems like ELIZA [84] – their lack of generative novelty may reveal them to be shallow over time [29]. This may be the opposite effect of what was observed in regards to secure base social connection being fostered over longer periods of time spent with the robot. The current level of sophistication thus hinders robots' ability to soothe us emotionally as compared to how humans can. However, there are some studies that appear to indicate that a social robot's mere presence can also alleviate feelings of loneliness or social distress – something that may not attenuate with time [43]. Children particularly seem to bond emotionally with a variety of robots, and view them as potential friends, or avenues to seek comfort when sad, by the end of the experiment [56,95]. Further, robots which aim to emulate pets, which soothe emotionally without any linguistic endowment, seem poised to be the best case of providing mental comfort, especially over longer time spans [94,85,71].

3.2.3 Robotic Safe Havens

Different attachment figure types again appear to interact with safe haven components to various degrees, and therefore allow for achievement of the safe haven function to varying degrees. Humans are the most apt to be capable of this function as some are adept at providing both physical comfort and emotional or mental comfort. They are also the most mentally complex and therefore gen-

erative and capable of novel comforting provisions over time. Other animals – specifically, pets – are also capable of high degrees of physical and emotional comforting behavior. Though not equipped with linguistic faculties, our tendency to infer intention enables us to receive mental support from them. Symbols may not be able to provide as much physical comfort, though may engender psychosomatic feelings, but can flexibly address emotional distress. And objects may be functionally designed to bring about physical relief, or designed in a manner that evokes an emotional response, but largely suffer from lack of variety and novelty over time, and can thus have less ability to become a safe haven. However, objects do have the capacity to become safe havens through means of association with memory and identity, which we will discuss more while analyzing shared components.

Again, robots, based on their class of design, strike different chords in terms of safe haven function fulfillment. While some simple, non-social robots have little capability to evoke soothing sensations, others may be explicitly designed to do so. Moreover, social robots, and their perceived autonomy, may play into our social systems as we ascribe levels of intention to them and feel comforted by their presence alone [91]. But despite a multitude of robots which palliate physical distress, and many which do so for emotional distress, it seems rare for robots to do both.

Logan et al. have shown that social robots in the pediatric care setting have been able to both soothe children's perception of pain and engender positive affect [68]. Other therapy robots have been able to positively affect the moods and behaviors of dementia patients [28]. Additionally, Paro seems to address both physical and emotional soothing due to its soft form factor and its emotionally therapeutic effect [94,85,71]. These types of caring, therapeutic interactions seems to be the closest to achieving the full function of safe haven. Further, in the vein of Norman's characterization of emotional soothing by associated memory, any robot seems to be able to be the subject of such memory formation [75]. A therapy robot which stays with a user could benefit from this additional mental representation of being comforting upon recollection. Someone who receives this type of long-term care from a robot, soothing both physical and emotional distress, may be nudged to form weak attachment bonds with the robot the way some may with therapy animals.

Though, the bonds may be even weaker as these robots do not appear to be able to *actively* provide physical relief. Contrasting the robots whose touch was studied [86,87,74], many simply stand as passive recipients of touch and embrace, which does have a soothing effect of its own. However, the lines seem blurry, and it becomes confusing to attempt to distinguish between active versus passive soothing, what counts as physical soothing as opposed to psychosomatic, and so forth.

In total, despite potential to scrutinize and draw fine lines between forms of soothing, there do at least appear to be some robots in the HRI literature which fulfill criteria for the safe haven function.

3.3 Components Common to Secure Base and Safe Haven

Rather than duplicating analysis of some components of both secure base and safe haven functions, we wish to address some that are common across both. These are such that they inform both perceived ability to provide safety and ability to soothe. In particular, we wish to point out the effect of identity formation through shared experience, and *ability* to form identity. It will be important to sharply distinguish the two. These considerations will address Norman's [75] popular formulation of attachment.

3.3.1 Identity from Shared Experience

We are more than our present selves: our history and future intentions contribute to the construction of our Internal Working Models of self, and the case is no different with others [13,16]. Thus, attachment figures must also enjoy some degree of identity-formation based on some aspects of history as well.

Norman eloquently describes what we mean by identity from shared experience [75]. He writes that, "True, long-lasting emotional feelings take time to develop: they come from sustained interaction... what matters is the history of interaction, the associations that people have with objects, and the memories they evoke." We can recognize that this notion need not solely apply to objects, it easily maps to humans, pets, symbols, and robots. Norman continues to remark that this type of memory-driven attachment also informs our, "attachment to places: favorite corners of our homes, favorite locations, favorite views." The word *favorite* is important because it implies some hierarchy: a favorite is one that stands eminent above others, and is therefore unique in its identity.

It is not, however, a requirement that something must be a favorite to play into attachment; it must simply be part of shared, positive experiences. It is then clear that this notion of identity

from shared experience can apply to every category: humans, pets, symbols, objects, or robots. Some potential attachment figures, then, may have more distinct positive identities and therefore may in turn give rise to more significant secure base or safe haven functions in our lives [2]. It is as if the functions are amplified because of the attachment figure's unique status. Some people have best friends, preferred pets, or cherished mementos, where the "favorite" here may simply indicate a stronger bond based off of unique experiences.

In this sense of identity built from shared experience, any robot is subject to these effects. Norman discusses this phenomenon in the context of completely inanimate objects, so even the most simple robots, such as Roomba [88], would be a candidate. The onus is on the human in this case, as our tendency to form positive associations with any other to whom we endow meaning will certainly apply to any robots.

3.3.2 Ability to Form Identity

Contrasting identity formed purely from the standpoint of an attached person's collection of memories, an identity constituted by the *attachment figure's* ability to learn, remember, adapt, and mold itself to a human is completely distinct. Here, different attachment figures clearly have different capacities to form identities based off of experiences. Humans are obviously very capable of this barring some exceptions with the elderly or cognitively impaired. Pets also appear to grow with us; as they learn owner tendencies, personality, and adapt accordingly [99]. Symbols such as deities or otherwise, on the other hand, do not appear to have any ability to change and adapt to any given attached person. Perhaps there are so many wide-ranging stories in religious texts that a god may appear to be relevant in different ways as people's lives change, but there is no agency in these changes except on the part of the attached human. Similarly, most objects do not have as much facility as humans in shaping their interactions and composition along with an attached human. However, it would be important to note that the phenomena of objects wearing down with time, or being able to bear old cracks or chips may be considered an ability to form identity [75]. A baseball glove or pair of shoes being "broken in" is one example of this notion. Further, some technologies like smartphones also have capabilities that bestow identity such as being able to be customized; different app icon configurations, saved preferences, or shortcuts make one device special to a user over others, and would more likely be the object of attachment formation.

Distinctly from identity constructed in the human mind from shared experience, some robots may, indeed, have capabilities to adapt to their user's behavior and form a sort of identity (e.g., [65]). Social robots, particularly, may have the ability to recognize faces [27,89], to learn user preferences or speech patterns [81,64], and generally adapt themselves to appear more socially capable. As educational robots are some of the most prevalent in child HRI literature, personalization seems to be a particularly useful skill for tutoring robots to have. One study found that a robot whose learned a student's particular skill proficiencies and adapted its curriculum appropriately resulted in students who performed better than those who chose random lessons [67]. Another tutoring robot personalized its motivational methods based on children's affective states; over a long-term study, children showed more positive valence towards this robot as compared to one at did not personalize behavior [41]. In a non-tutoring longitudinal context, people developed more rapport and were more engaged with a delivery robot that personalized its behavior with each person's usage and interaction pattern than one that did not [66]. Some studies have even reported that the ability for users to physically customize robots may be beneficial to tailor them to circumstantial needs [73].

In line with the philosophical notion of the "type-token distinction," a robot that becomes a token through personalization, memory, or shared history, may be subject to greater attachment than a robot that remains a replaceable type [7]. However, current robotics capabilities are not so great that social robots are as generative and adaptive as humans or pets. After a while, a robot's speech patterns, responses, and social "tricks" may be discovered [76], and the novelty effect will wear off to reveal the robot as less flexible [29]. Simpler robots, such as Roomba, are not as capable of these tricks at all (yet, they sometimes seem to achieve "token" status with their users [88]). They are explicitly non-social, and therefore may be no more adaptable than their ability to discover a more efficient vacuuming route after a software update.

3.4 Proximity Maintenance and Separation Distress

On the other side of an attachment figure's functional roles are subsequent behaviors, exhibited by the attached person, made manifest when attach-

ment relationships are formed [13,14,1,16]. We choose to group these together because they both seem to be driven by the same sub-components: the strength of both the secure base and safe haven functions. In contrast to our analysis of attachment functions, where distinct robot capabilities led to differing ability to engender attachment bonds, these behaviors are not brought about simply by the robot itself. For example, Roomba's lesser functional range as compared to Robovie's broader functional range do not solely play into the degree to which an attached user would suffer separation distress upon losing the robot. While the robots' functions do determine *to what degree* the robots can achieve secure base or safe haven functionality, it is not as if the effect is instantaneous. As became evident from the identity-related components, time and experience contribute to the formation of attachment bonds [43,28,29]. We will instead argue that attachment behaviors are dependent on the degree to which the attachment figure functions as a secure base and safe haven – not the theoretical capability of the attachment figure to do so.

Thus, we will use this section to briefly discuss each behavior and point to relevant literature to describe where it may be observed or not. In HRI research, we believe that these behaviors should be used as a sort of test or measurement to gauge the degree to which a participant has grown to use that robot for secure base or safe haven functionality. Beyond theorizing *if* a given robot is capable of engendering such cognitive representations based on its abilities, there must be qualitative analytic frameworks to determine whether a robot *actually does* induce these attachment bonds. We must note, however, that just as the components we described for the attachment functions were by no means comprehensive or intended as definitions, neither are these behaviors the sole indicators of attachment. We reject behaviorist notions that all can be gleaned from simply observing external behavior, and that internal cognitive analysis is unimportant. We simply wish to offer these behavioral patterns deduced by social psychologists as tools to be used by HRI researchers.

3.4.1 Proximity Maintenance Behavior when Distressed

In summary of relevant attachment ideas, Zilcha-Mano et al. summarize one such behavior, proximity maintenance, as "physical closeness to the attachment figure, especially in need or stress" [99]. As we acknowledged previously, we believe this behavior to be driven by the degree to which secure base and safe haven functionality is present in the relationship to the attachment figure. Differing patterns of proximity seeking behavior, such as incessant seeking, or lack of seeking, can also be analyzed in the context of maladaptive anxious or avoidant attachments. We will not explicate what that would look like, and instead refer readers to the relevant psychological literature [1].

There are some notable cases of proximity maintenance behavior in the HRI literature that could potentially point to attachment formation during studies. Notably, most studies do not take place over a sufficiently long span of time so as to produce meaningful attachment between users and robots. However, some studies do occur over a longer duration, and results may indicate markers of attachment [94,34]. Moreover, almost all of the studies are devoid of conditions involving human distress. As such, these examples of proximity seeking and maintenance may be thought to be precursors to habits that may transfer into situations where the human is distressed – though, that is not guaranteed.

In a study by Tung and Au, hotel guests who had opportunities to interact with robots reportedly went out of their way to create new experiences with the robot [90]. Children, in particularly, had positive experiences with the robots, and continued to talk about those experiences after the study was over. Wada and Shibata additionally noted, in their studies of Paro, that there was a dramatic increase in the time residents spent in the area where Paro was located [94]. Paro also encouraged more communication and social interactions between the residents. It is unclear whether people spent more time in the area seeking proximity with others – encouraged by the presence of Paro – or whether they were seeking the robot itself. Feingold Polak and Levy-Tzdek reported that participants in their stroke rehabilitation study came to see the robot even when they did not have scheduled sessions [34]. In a study with the social robot Robovie, Kahn et al. showed from a structured interview following an interaction that 84% of 9-15 year olds said they would spend time with the robot if they felt lonely, and that 55% of them said they would seek comfort from the robot if they felt sad [56].

3.4.2 Separation Distress Behavior

As the final significant pillar in attachment relationships, Zilcha-Mano et al. describe separation distress behavior as "[a] sense of separation distress when the attachment figure is temporarily or permanently unavailable" [99]. This fundamen-

tally gets at the vulnerability and anxiety brought about by losing something that, in one's life, serves a strong secure base and safe haven function. It is understandable that through loss of those we are attached to, we feel a distinct *lack* of the security and comfort brought about by the attachment figure. We may further worry about the future and our newfound vulnerabilities, with endless "What if?" questions, or remember the past and mourn the comfort that once felt so readily available. This is why we are led to believe that the strength of secure base and safe haven functions would be linked to separation distress behaviors.

Separation distress behavior is not very present in the HRI literature, except in some notable edge-cases. While robots' greater ability to personalize identity through learning or physical alteration may set them up to be subject to separation distress [7], this does not seem to be a common case. Perhaps, as noted with proximity maintenance behavior, the short duration of most HRI studies does not allow requisite time for strong attachments to form. Regardless, there are some notable HRI studies which exhibit separation distress-like behavior that may indicate attachment relationships having formed.

Gross et al. reported that out of participants who lived with their home-dwelling robot, Max, eight out of nine participants were sad when they had to leave the robot [43]. This perhaps gives some weight to the idea that longer-duration studies engender higher chances of attachment, as the Gross et al. study lasted three days. Perhaps more infamously, in a journalistic report, Garreau described soldiers' sorrow after losing the valuable robotic member of their team, PackBot [38]. No doubt under distress from the traumas of warfare, one of the interviewed explosives technicians is described as being, "visibly upset... insist[ing] he did not want a new robot." Finally, Sung et al. briefly mention indications of separation anxiety in Roomba owners [88]. They write that when Roomba broke down or needed repairs, people were surprised at the grief brought up by sending it away to be repaired. They even mention that some described Roomba as, "dead, sick, or hospitalized."

In contrast to the above participants' distress, there are some HRI studies that explicitly note that participants had no separation distress, despite prolonged or personal interactions with robots. Huang et al. found that although students – who built robots over the course of a semester – developed strong positive emotions towards their robots, they also experienced no negative feelings from separation [50]. They only noted feeling sad having to dismantle their robots.

4 Spectrum of Attachment

We now wish to end our analysis by distinguishing between degrees of attachment as will be relevant for future HRI research. This is meant to directly address the many ways that attachment is referenced in the literature – as the same word is sometimes meant in very different ways or simply ill-defined – and provide a unified, theoretical framework for HRI researchers to use when judging potential attachment formation throughout studies.

Based off of the above analysis, we wish to finally distinguish what may be called *strong attachment* from *weak attachment*. What we mean by strong attachment is, generally, the presence of attachment functions as defined by psychological attachment theory, presence of relevant proximity seeking or separation distress behaviors – and moreover, presence in a significant sense. Because the two attachment behavior criteria are largely dependent on the two functional criteria, it seems logical to claim that the overall strength of attachment is largely dependent on the degree to which these two functions are met by a robot. It may not be enough to simply observe participants occasionally finding reprieve in a robot, or sometimes seeking proximity to it. Strong attachment would be the systematic seeking of proximity when distressed, the robot's frequent fulfilling of security or comfort needs, and potentially a high degree of distress present upon an event of separation. We know these feelings to be present when we interact with or lose beloved family members, significant others, or cherished pets. It is then the place of weak attachment to describe relationships which are less significant: including those described by Norman which are solely formed by cumulative positive experience, or those deemed "secondary attachments" – i.e. ones which fill in gaps otherwise left by primary attachment figures. This type of weaker attachment is often referenced in HRI literature simply as "attachment," which can be misleading and give the impression that study participants are bonding with robots as they would with other humans. Most of the time, this does not appear to be the case.

Moreover, it is not solely the case that attachment can be evaluated as it presently exists, it is equally relevant and important to note the *potential* of robots in our HRI studies to engender attachment bonds. Here, the components of the two functional attachment criteria – secure base and safe haven – are key; each describes a more fine-grained view of what it would mean to meet part of the attachment function. As such, a robot's

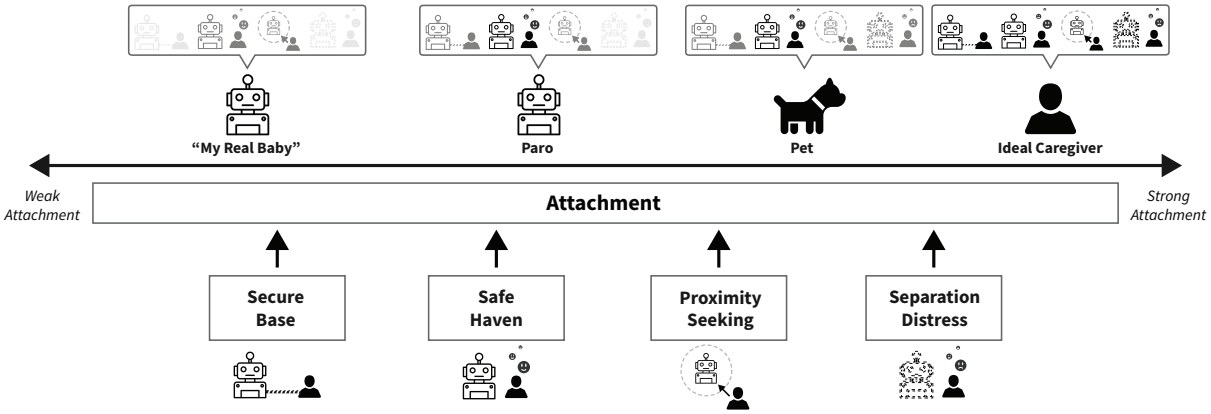

Fig. 4: Our spectrum of attachment, from *weak* to *strong* attachment

functional capabilities become key in determining whether or not the robot could ever meet such criteria in a strong manner, let alone if the signs are present. This notion was not necessary to analyze for the humans of classical attachment psychology, because most human caregivers already have the ability to meet these functional needs. Robots, however, as we illustrated above, are not as omnifunctional as humans, and are often designed for more narrow tasks that may prohibit meeting some components of attachment criteria functions.

We will thus present operational definitions of strong and weak attachment, and place some notable HRI studies on a spectrum between the two points on the spectrum. We acknowledge that our labeling and placement of studies may be contested, but hope that regardless of outcome, the analysis makes clear the need to parse such study results carefully and with nuance.

A visual representation of the entire attachment spectrum, its components, and where different potential attachment figures fall on a spectrum of weak to strong attachment is shown in Fig. 4.

4.1 Strong Attachment

Strong attachment should be thought of as that which we classically witness in the social psychological literature. When infants bond to their caregivers, the ensuing attachment relationship is one that bears markers of both the secure base and safe haven functions, as well as exhibitions of proximity maintenance and separation distress behavior. Further, these four criteria are present to a high degree, as it would be easy to argue that in the case of infant-caregiver relationships, the caregiver fulfils the components of each criteria that we outlined above.

On the attachment spectrum that we lay out, as more of the attachment criteria are present, the attachment should be characterized as stronger. Moreover, as each criteria is present to a more significant degree – in the sense that more of the components of each are present – the attachment bonds should move toward the strong end of the spectrum. We can thus observe a gradation form between what we analyzed in regards to human-human, human-pet, human-symbol, and human-object attachment. Human-human attachment bonds seem to be the strongest, as caregivers or relationship partners serve significant secure base and safe haven functions, and subsequent behaviors of proximity maintenance and separation distress are observed [13,1,2]. Pets may rival humans in some cases, as studies have demonstrated owners do attach to their pets significantly enough to elicit attachment behaviors [99]. Symbols have been described as so-called "secondary attachments," as study participants have close parasocial relationships with a god or television personality, but they often arise in response to a lack of tangible attachment figures [42,61]. We can argue that secondary attachment figures may be deemed so because they do not meet as many components of the criteria as physical counterparts; failing to truly meet physical or intellectual needs, and lacking any means of physical soothing. These attachment bonds would fall farther away from the strong side of the attachment spectrum; rather describing weaker attachments. We will also argue below that human-object attachment bonds lean in a similar weak direction.

Consequently, stronger attachment would also necessitate stronger maladaptive behaviors elicited by anxious or avoidant attachment patterns. If stronger attachment bonds were present, the patterns described by Bowlby's Internal Working Models would manifest no matter what or who the attachment figure is [13]. This would be of particular interest to HRI study because robotics re-

searchers and developers should be concerned with potential adverse effects from strong attachment patterns [6]. These worries are in line with earlier HRI attachment theory as written by Turkle [91] and Sharkey, Sharkey [84]. If at all, we argue that concerns along these lines should only be brought up if sufficient criteria as described above exist in the robot itself, and have been observed its interactions with humans.

Throughout our investigation into HRI attachment literature, we hardly found any studies which indicated human-robot bonds that were of the strong attachment variety. As we touched on above, Paro seems to be one of the few robots which elicits precursors to stronger attachment bonds [85,94,71]. Paro was shown to be available and create social connection – components of the secure base function – and provide physical and emotional comfort – components of the safe haven function. It is unclear whether participants who interacted with Paro over a long period of time developed markers of identity; including, but not limited to, forming positive memories of Paro, or viewing an individual Paro as being distinct from any other. But it seems fairly clear that Paro did not meet physical or intellectual resource needs, nor did it seem to engender strong proximity maintenance or separation distress behavior. In total, we could argue that Paro is more similar to the type of attachment garnered by pets, but still not quite as strong because Paro does not have as rich of physical capabilities, or mental capabilities to adapt to its owner and present uniqueness.

Some of the other robots we touched on in the above attachment criteria categories, such as Roomba [88], do not come as close as Paro to meeting our attachment criteria. Though Roomba meets aspects of the secure base function such as specific cleaning-related physical needs, high availability, and some social connection facilitation, its design does not lend itself at all to a safe haven functionality. This pattern seems to be the case for almost all other robots included in our analysis: each serves such specific functions that it does not meet enough of both attachment functions to foster strong attachment bonds. As expected, study of their interaction with human participants does not seem to engender proximity seeking and separation distress behaviors.

In light of this tendency to meet some criteria but not others, and those met to varying degrees, we propose that those bonds be categorized under weak attachments.

4.2 Weak Attachment

Contrasting strong attachment, weak attachment should be thought of as describing bonds that do not meet all the criteria of attachment bonds, or meet the criteria to a lesser degree by meeting fewer components of each. Here we find Norman's description of human-object attachment encompassed in this idea of weak attachment: it is solely based off of the identity components of the secure base and safe haven functions, and does not address any other components of each [75]. It thus seems natural to accept that the word "attachment" can be used in this case, but insist that it should be qualified with the label of weak attachment.

Secondary attachments, as noted above, are also perfect candidates for weak attachment. Human-symbol attachment such as that described by Granqvist and Kirkpatrick appear to systematically meet only some components of the secure base and safe haven functions, and thus not lead to strong exhibition of attachment behaviors [42, 61]. Indeed, Granqvist even goes so far as to label these bonds "attachment-like," clearly distinguishing them from the strong attachments engendered by human-human bonds. Moreover, human-object attachment as described by Keefer at al. seems to fit the same pattern as participants turned toward objects to compensate for the perceived unreliability of close others [57].

Logically, weaker attachments should also lead attached humans to exhibit fewer signs of the proximity seeking and separation distress attachment behaviors present with strong attachment. Contrasting ethical concerns brought about by strong attachment, weak attachments to robots would likely engender no such thing. Anxious and avoidant maladaptive attachment paradigms would also likely be less present if not invisible in weak attachment bonds. These consequences of weak attachment may be of use to HRI researchers and robot designers, as robots could be intentionally designed to bring about the best aspects of attachment relationships, while avoiding the challenges [6]. Though, with the exception of Paro, it appears that most human-robot pairs do not come close to attaining such a strong level of attachment.

We believe that most HRI studies which describe some form of attachment are describing weak attachment. As noted above, there are a few exceptions which seem to get close to strong attachment, which leaves the vast remainder closer to the weak attachment end of the spectrum. Most robots in HRI literature are not demonstrated to

meet many components of attachment criteria at all, which makes sense because they are often not designed to do so. Though, even explicitly social robots only appear to meet few components of the criteria because their design is narrowly focused. Some may meet physical needs [88], some foster creativity or learning [79,56], and others provide physical or emotional soothing [68]. However, the key is that no one robot does it all.

4.3 Potential versus Actual Attachment

We would finally like to acknowledge that some factors may be less dependent on specific robot design as they are on study design. There is a sharp distinction between what any attachment figure type *could* do to form attachment bonds, and what they actually do. The spectrum can therefore be applied in either the case of determining potential attachment strength, or actual attachment strength.

What we have described above illustrates actual attachment. Based off of evidence gathered by HRI study, a researcher could classify any given robot as garnering strong or weak attachment. Many empirical HRI studies touch on this concept without explicitly framing it as attachment. For instance, Gross et al. note at the conclusion of their study that some participants were somewhat sad to see their robot, Max, go at the end of the study [43]. Sung et al. note Roomba users' reporting that they had pleasant feelings brought about by its making vacuuming more enjoyable [88]. However, some HRI studies report empirical evidence, but then use it as an extrapolation to indicate that systematic attachment is possible. Sharkey and Sharkey take a situation where a child interacts with a social Hello Kitty robot, and follow its logical conclusion to warn of robots becoming caregivers for children – bringing about complicated attachment relationships [84]. Turkle likewise uses evidence from interactions with the My Real Baby robot to conclude that robots may become relational artifacts that cause attachment-like responses in people [91]. These are important and motivating conclusions, but can be examined with a more granular framework so as to conclude that, while some attachment-like behavior may have been observed in these interactions, they did not meet the criteria for strong attachment. Further, they mix actual and potential attachment; extrapolating the former into the latter without qualifying with a more nuanced look at attachment.

Attachment potential should be viewed through a functional lens: What are the capabilities of this potential attachment figure such that it could fulfill components of attachment function criteria and engender attachment bonds? Humans are so functionally diverse that they can meet physical, intellectual, or social needs, provide physical and emotional comfort, and form identity through learning about an attached person. Most humans therefore have strong attachment potential. Many robots, however, have at most neutral attachment potential (neither weak nor strong), and at least weak attachment potential. Robots are, at present, functionally designed for specific tasks – even when they are designed as social robots. This may alleviate the worries of Sharkey & Sharkey, and Turkle as a functional analysis of the Hello Kitty and My Real Baby robots would reveal that they do not have any potential to meet physical or intellectual needs, may have potential to soothe physically or emotionally, but likely do not have potential to form identity as their social behaviors become very predictable and replaceable [84,91]. Any extrapolation of robotic attachment potential must include an analysis in this vein, or run the risk of bringing about potentially inflated worry among the community and greater public regarding the current state of robotics.

5 Conclusion

Through a thorough investigation of attachment literature describing human attachment to other humans [13,1], pets [99], objects [58], symbols [42, 61], and robots [26], we were able to construct a framework to gauge attachment potential, and actual engendered levels of attachment, in human-robot interaction study. Inspired by Collins et al.'s initial call for such a framework [26], we utilized the well-verified attachment theory framework from social psychology, and deconstructed the secure base and safe haven functions to motivate components of each that could be used to more specifically describe what it means to serve those functions [46]. This framework attempts to subsume both psychological attachment theory, and theories describing attachment to objects or technology in HCI, such as Norman's [75]. While the list of components we described is not perfectly comprehensive, they give what we argued to be a sufficient framework to begin deepening HRI attachment research and analysis. Further, we included proximity seeking and separation distress behaviors as described by social psychological at-

tachment theory, as engendered behaviors in this framework.

Using the framework, we analyzed a host of HRI studies which included commentary on human-robot attachment, and gauged which components – including to what degree – each attachment bond seemed to meet our component criteria. In sum, most robots we analyzed do not come close to fulfilling all of the components of each attachment criteria. Notably, Paro, the therapeutic seal-like companion robot, seemed to come the closest to serving a secure base, and safe haven function for the elderly people whom it is designed for [94, 85]. Subsequently, participants were observed acting out, to a degree, proximity-seeking behaviors. Even stranger cases of supposed-attachment, such as Sung's descriptions of users' bonds to their Roombas, are captured by the framework: sheer amount of time spent with Roomba, formation of identity, and it meeting some physical needs, was enough for a purposefully non-social robot to engender a bond [88]. Other robots appeared to fulfill some components of attachment criteria, but to a lesser extent. The qualitative descriptions of how human participants in those studies felt about their robots matched with what the framework would predict, and participants did not seem to strongly attach to any of those robots; the robots did not meet attachment function criteria, and the participants did not exhibit any attachment behaviors.

Currently, the field of attachment in HRI has numerous gaps, including notably the lack of longitudinal studies and ways to evaluate attachment to robots. While our framework attempts the latter, the framework itself needs to be evaluated as well. Though here we analyzed past HRI studies, we encourage researchers to use our attachment framework in real time when they run their own studies to further validate it. By specifically testing the framework through new studies, we will be able to see how well experimental results fit into or are predicted by the framework, and where the framework might break down in the face of new results. This will allow us to form new research questions about attachment in HRI. Though the current trend of attachment studies in HRI seems to be focused on the development of specific robotic capabilities that may lead to attachment (i.e., emotion detection [23], dialogue-based interaction [82], facial character analysis [39], etc.), perhaps in parallel we need to ask how these capabilities will affect the attachment that does form. What roles do we want robots to have in our world of attachment figures?

The framework allowed us to motivate a spectrum from *weak attachment* to *strong attachment*. We argued that HRI studies that investigate potential or actualized human-robot attachment should use the notion of attachment on a spectrum, with justifications provided by the framework, to disambiguate different strengths of bonds which otherwise become conflated as simply, "attachment." By distinguishing weak from strong attachment, important theoretical inquiries like those of Sharkey & Sharkey [84, 83], or Turkle [91], can be placed in context and evaluate potential human-robot attachment risks with stronger backing. Thinking of human-robot attachment on this spectrum will ideally lead to stronger motivations for future HRI methodological tools – like questionnaires – from disciplines like social psychology and HCI, and work towards a deep understanding of how human-robot attachment fits into the greater picture.

6 Declarations

Funding: This work was partially supported by NSF IIS grant 43520050.
Conflict of Interests: The authors declare that they have no conflict of interest.

References

1. Mary DS Ainsworth, Mary Blehar, Everett Waters, Sally Wall, et al. Patterns of attachment, 1978.
2. Mary S Ainsworth. Attachments beyond infancy. *American psychologist*, 44(4):709, 1989.
3. Safinah Ali, Tyler Moroso, and Cynthia Breazeal. Can children learn creativity from a social robot? In *Proceedings of the 2019 on Creativity and Cognition*, pages 359–368. 2019.
4. Patrícia Alves-Oliveira, Patrícia Arriaga, Matthew A Cronin, and Ana Paiva. Creativity encounters between children and robots. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 379–388, 2020.
5. Patrícia Alves-Oliveira, Samuel Gomes, Ankita Chandak, Patrícia Arriaga, Guy Hoffman, and Ana Paiva. Software architecture for yolo, a creativity-stimulating robot. *SoftwareX*, 11:100461, 2020.
6. Anon. In Review.
7. Thomas Arnold and Matthias Scheutz. Hri ethics and type-token ambiguity: what kind of robotic identity is most responsible? *Ethics and Information Technology*, pages 1–10, 2018.
8. Gaston Bachelard. *The poetics of space*. Penguin Classics, 2014.
9. Lisa Feldman Barrett. *How emotions are made: The secret life of the brain*. Houghton Mifflin Harcourt, 2017.
10. Tony Belpaeme, James Kennedy, Aditi Ramachandran, Brian Scassellati, and Fumihide Tanaka. Social robots for education: A review. *Science robotics*, 3(21), 2018.

11. Tapomayukh Bhattacharjee, Ethan K Gordon, Rosario Scalise, Maria E Cabrera, Anat Caspi, Maya Cakmak, and Siddhartha S Srinivasa. Is more autonomy always better? exploring preferences of users with mobility impairments in robot-assisted feeding. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 181–190, 2020.
12. Nikolai Bock, Laura Hoffmann, and Astrid Rosenthal-vd Pütten. Your touch leaves me cold, robot. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*, pages 71–72. ACM, 2018.
13. John Bowlby. Separation anxiety. *International Journal of Psycho-Analysis*, 41:89–113, 1960.
14. John Bowlby. Attachment and loss: retrospect and prospect. *American journal of Orthopsychiatry*, 52(4):664, 1982.
15. Cynthia Breazeal. Emotion and sociable humanoid robots. *International journal of human-computer studies*, 59(1-2):119–155, 2003.
16. Inge Bretherton. Attachment theory: Retrospect and prospect. *Monographs of the society for research in child development*, pages 3–35, 1985.
17. Inge Bretherton. The origins of attachment theory: John bowlby and mary ainsworth. *Developmental psychology*, 28(5):759, 1992.
18. Helen Louise Brooks, Kelly Rushton, Karina Lovell, Penny Bee, Lauren Walker, Laura Grant, and Anne Rogers. The power of support from companion animals for people living with mental health problems: a systematic review and narrative synthesis of the evidence. *BMC psychiatry*, 18(1):1–12, 2018.
19. Lola CaÑAmero, Arnaud J Blanchard, and Jacqueline Nadel. Attachment bonds for human-like robots. *International Journal of Humanoid Robotics*, 3(03):301–320, 2006.
20. Michael Chan. Mobile phones and the good life: Examining the relationships among mobile use, social capital and subjective well-being. *New Media & Society*, 17(1):96–113, 2015.
21. Xianwei Che, Robin Cash, Sin Ki Ng, Paul Fitzgerald, and Bernadette M Fitzgibbon. A systematic review of the processes underlying the main and the buffering effect of social support on the experience of pain. *The Clinical journal of pain*, 34(11):1061–1076, 2018.
22. Huili Chen, Hae Won Park, and Cynthia Breazeal. Teaching and learning with children: Impact of reciprocal peer learning with a social robot on children's learning and emotive engagement. *Computers & Education*, 150:103836, 2020.
23. Luefeng Chen, Mengtian Zhou, Wanjuan Su, Min Wu, Jinhua She, and Kaoru Hirota. Softmax regression based deep sparse autoencoder network for facial emotion recognition in human-robot interaction. *Information Sciences*, 428:49–61, 2018.
24. Meia Chita-Tegmark and Matthias Scheutz. Assistive robots for the social management of health: A framework for robot design and human–robot interaction research. *International Journal of Social Robotics*, pages 1–21, 2020.
25. James S Coleman. Social capital in the creation of human capital. *American journal of sociology*, 94:S95–S120, 1988.
26. Emily C Collins, Abigail Millings, and Tony J Prescott. Attachment to assistive technology: A new conceptualisation. In *Proceedings of the 12th European AAATE conference (Association for the advancement of assistive technology in Europe)*, volume 6, page 74, 2013.
27. Claudia Cruz, L Enrique Sucar, and Eduardo F Morales. Real-time face recognition for human-robot interaction. In *2008 8th IEEE International Conference on Automatic Face & Gesture Recognition*, pages 1–6. IEEE, 2008.
28. Dagoberto Cruz-Sandoval, Arturo Morales-Tellez, Eduardo Benitez Sandoval, and Jesus Favela. A social robot as therapy facilitator in interventions to deal with dementia-related behavioral symptoms. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 161–169, 2020.
29. Daniel P Davison, Frances M Wijnen, Vicky Charisi, Jan van der Meij, Vanessa Evers, and Dennis Reidsma. Working with a social robot in school: a long-term real-world unsupervised deployment. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 63–72, 2020.
30. Maartje MA de Graaf, Somaya Ben Allouch, and Jan AGM van Dijk. A phased framework for long-term user acceptance of interactive technology in domestic environments. *new media & society*, 20(7):2582–2603, 2018.
31. Carl F DiSalvo, Francine Gemperle, Jodi Forlizzi, and Sara Kiesler. All robots are not created equal: the design and perception of humanoid robot heads. In *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques*, pages 321–326, 2002.
32. Nicholas Epley, Adam Waytz, and John T Cacioppo. On seeing human: a three-factor theory of anthropomorphism. *Psychological review*, 114(4):864, 2007.
33. Damien Erceau and Nicolas Guéguen. Tactile contact and evaluation of the toucher. *The Journal of social psychology*, 147(4):441–444, 2007.
34. Ronit Feingold Polak and Shelly Levy Tzedek. Social robot for rehabilitation: Expert clinicians and post-stroke patients' evaluation following a long-term intervention. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 151–160, 2020.
35. Naomi T Fitter, Luke Rush, Elizabeth Cha, Thomas Groechel, Maja J Matarić, and Leila Takayama. Closeness is key over long distances: Effects of interpersonal closeness on telepresence experience. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 499–507, 2020.
36. Jodi Forlizzi and Carl DiSalvo. Service robots in the domestic environment: a study of the roomba vacuum in the home. In *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, pages 258–265, 2006.
37. Daniel Gallenberger, Tapomayukh Bhattacharjee, Youngsun Kim, and Siddhartha S Srinivasa. Transfer depends on acquisition: Analyzing manipulation strategies for robotic feeding. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 267–276. IEEE, 2019.
38. Joel Garreau. Bots on the ground. *Washington Post*, 6, 2007.
39. Fatma Göngör and Önder Tutsoy. Design and implementation of a facial character analysis algorithm for humanoid robots. *Robotica*, 37(11):1850–1866, 2019.
40. Goren Gordon, Cynthia Breazeal, and Susan Engel. Can children catch curiosity from a social robot? In

Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction, pages 91–98, 2015.
41. Goren Gordon, Samuel Spaulding, Jacqueline Kory Westlund, Jin Joo Lee, Luke Plummer, Marayna Martinez, Madhurima Das, and Cynthia Breazeal. Affective personalization of a social robot tutor for children's second language skills. In *Proceedings of the AAAI conference on artificial intelligence*, volume 30, 2016.
42. Pehr Granqvist, Mario Mikulincer, and Phillip R Shaver. Religion as attachment: Normative processes and individual differences. *Personality and Social Psychology Review*, 14(1):49–59, 2010.
43. Horst-Michael Gross, Steffen Mueller, Christof Schroeter, Michael Volkhardt, Andrea Scheidig, Klaus Debes, Katja Richter, and Nicola Doering. Robot companion for domestic health assistance: Implementation, test and case study under everyday conditions in private apartments. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 5992–5999. IEEE, 2015.
44. C Hazan and D Zeifman. Sex and the psychological tether. w: K. bartholomew, d. perlman (red.), attachment processes in adulthood. advances in personal relationships (s. 151-178), 1994.
45. C Hazan and D Zeifman. Pair bonds as attachments: Evaluating the evidence, handbook of attachment: Theory, research, and clinical applications, 1999.
46. Cindy Hazan and Phillip Shaver. Romantic love conceptualized as an attachment process. *Journal of personality and social psychology*, 52(3):511, 1987.
47. John F Helliwell and Robert D Putnam. The social context of well–being. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 359(1449):1435–1446, 2004.
48. Damith C Herath, Christian Kroos, Catherine Stevens, and Denis Burnham. Adopt-a-robot: a story of attachment (or the lack thereof). In *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 135–136. IEEE, 2013.
49. Antoine Hiolle, Lola Cañamero, Marina Davila-Ross, and Kim A Bard. Eliciting caregiving behavior in dyadic human-robot attachment-like interactions. *ACM Transactions on Interactive Intelligent Systems (TiiS)*, 2(1):1–24, 2012.
50. Lixiao Huang, Terri Varnado, and Douglas Gillan. An exploration of robot builders' attachment to their lego robots. In *Proceedings of the Human Factors and Ergonomics Society annual meeting*, volume 57, pages 1825–1829. SAGE Publications Sage CA: Los Angeles, CA, 2013.
51. Andreas Huber, Astrid Weiss, and Marjo Rauhala. The ethical risk of attachment how to identify, investigate and predict potential ethical risks in the development of social companion robots. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 367–374. IEEE, 2016.
52. Stanislav Hristov Ivanov, Craig Webster, and Katerina Berezina. Adoption of robots and service automation by tourism and hospitality companies. *Revista Turismo & Desenvolvimento*, 27(28):1501–1517, 2017.
53. Mary R Janevic, Varick Shute, Cathleen M Connell, John D Piette, Jenna Goesling, and Julie Fynke. The role of pets in supporting cognitive-behavioral chronic pain self-management: Perspectives of older adults. *Journal of Applied Gerontology*, 39(10):1088–1096, 2020.
54. Henri Julius, Andrea Beetz, Kurt Kotrschal, Dennis Turner, and Kerstin Uvnäs-Moberg. *Attachment to pets: An integrative view of human-animal relationships with implications for therapeutic practice*. Hogrefe Publishing, 2012.
55. Peter H Kahn, Takayuki Kanda, Hiroshi Ishiguro, Brian T Gill, Solace Shen, Jolina H Ruckert, and Heather E Gary. Human creativity can be facilitated through interacting with a social robot. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 173–180. IEEE, 2016.
56. Peter H Kahn Jr, Takayuki Kanda, Hiroshi Ishiguro, Nathan G Freier, Rachel L Severson, Brian T Gill, Jolina H Ruckert, and Solace Shen. "robovie, you'll have to go into the closet now": Children's social and moral relationships with a humanoid robot. *Developmental psychology*, 48(2):303, 2012.
57. Lucas A Keefer, Mark J Landau, Zachary K Rothschild, and Daniel Sullivan. Attachment to objects as compensation for close others' perceived unreliability. *Journal of Experimental Social Psychology*, 48(4):912–917, 2012.
58. Lucas A Keefer, Mark J Landau, and Daniel Sullivan. Non-human support: Broadening the scope of attachment theory. *Social and Personality Psychology Compass*, 8(9):524–535, 2014.
59. Lucas Allen Keefer. *The use of material objects as a secure base*. PhD thesis, University of Kansas, 2014.
60. Cory D Kidd, Will Taggart, and Sherry Turkle. A sociable robot to encourage social interaction among the elderly. In *Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006.*, pages 3972–3976. IEEE, 2006.
61. Lee A Kirkpatrick. An attachment-theory approach psychology of religion. *The International Journal for the Psychology of Religion*, 2(1):3–28, 1992.
62. Veronika Konok, Beáta Korcsok, Ádám Miklósi, and Márta Gácsi. Should we love robots?–the most liked qualities of companion dogs and how they can be implemented in social robots. *Computers in Human Behavior*, 80:132–142, 2018.
63. Virginia SY Kwan, Samuel D Gosling, and Oliver P John. Anthropomorphism as a special case of social perception: A cross–species social relations model analysis of humans and dogs. *Social Cognition*, 26(2):129–142, 2008.
64. Minae Kwon, Erdem Biyik, Aditi Talati, Karan Bhasin, Dylan P Losey, and Dorsa Sadigh. When humans aren't optimal: Robots that collaborate with risk-aware humans. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 43–52, 2020.
65. Kwan Min Lee, Namkee Park, and Hayeon Song. Can a robot be perceived as a developing creature? effects of a robot's long-term cognitive developments on its social presence and people's social responses toward it. *Human communication research*, 31(4):538–563, 2005.
66. Min Kyung Lee, Jodi Forlizzi, Sara Kiesler, Paul Rybski, John Antanitis, and Sarun Savetsila. Personalization in hri: A longitudinal field experiment. In *2012 7th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 319–326. IEEE, 2012.
67. Daniel Leyzberg, Aditi Ramachandran, and Brian Scassellati. The effect of personalization in longer-term robot tutoring. *ACM Transactions on Human-Robot Interaction (THRI)*, 7(3):1–19, 2018.

68. Deirdre E Logan, Cynthia Breazeal, Matthew S Goodwin, Sooyeon Jeong, Brianna O'Connell, Duncan Smith-Freedman, James Heathers, and Peter Weinstock. Social robots for hospitalized children. *Pediatrics*, 144(1):e20181511, 2019.
69. Noel Maalouf, Abbas Sidaoui, Imad H Elhajj, and Daniel Asmar. Robotics in nursing: a scoping review. *Journal of Nursing Scholarship*, 50(6):590–600, 2018.
70. Catriona Mackenzie, Wendy Rogers, and Susan Dodds. *Vulnerability: New essays in ethics and feminist philosophy*. Oxford University Press, 2014.
71. Sean A McGlynn, Denise Geiskkovitch, Tracy L Mitzner, and Wendy A Rogers. Paro's stress-reduction potential for older adults. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 60, pages 1799–1803. SAGE Publications Sage CA: Los Angeles, CA, 2016.
72. Gail F Melson, Peter H Kahn, Jr, Alan Beck, and Batya Friedman. Robotic pets in human lives: Implications for the human–animal bond and for human relationships with personified technologies. *Journal of Social Issues*, 65(3):545–567, 2009.
73. Sanika Moharana, Alejandro E Panduro, Hee Rin Lee, and Laurel D Riek. Robots for joy, robots for sorrow: community based robot design for dementia caregivers. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 458–467. IEEE, 2019.
74. Kayako Nakagawa, Masahiro Shiomi, Kazuhiko Shinozawa, Reo Matsumura, Hiroshi Ishiguro, and Norihiro Hagita. Effect of robot's active touch on people's motivation. In *Proceedings of the 6th international conference on Human-robot interaction*, pages 465–472. ACM, 2011.
75. Donald A Norman. *Emotional design: Why we love (or hate) everyday things*. Basic Civitas Books, 2004.
76. Maike Paetzel, Giulia Perugia, and Ginevra Castellano. The persistence of first impressions: The effect of repeated interactions on the perception of a social robot. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, pages 73–82, 2020.
77. Stacy C Parenteau, Katrina Hurd, Haibo Wu, and Cassie Feck. Attachment to god and psychological adjustment: God's responses and our coping strategies. *Journal of religion and health*, 58(4):1286–1306, 2019.
78. Eunil Park and Jaeryoung Lee. I am a warm robot: the effects of temperature in physical human–robot interaction. *Robotica*, 32(1):133–142, 2014.
79. Hae Won Park, Rinat Rosenberg-Kima, Maor Rosenberg, Goren Gordon, and Cynthia Breazeal. Growing growth mindset with a social robot peer. In *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*, pages 137–145, 2017.
80. Aditi Ramachandran, Chien-Ming Huang, Edward Gartland, and Brian Scassellati. Thinking aloud with a tutoring robot to enhance learning. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*, pages 59–68, 2018.
81. Hannes Ritschel, Ilhan Aslan, Silvan Mertes, Andreas Seiderer, and Elisabeth André. Personalized synthesis of intentional and emotional non-verbal sounds for social robots. In *2019 8th International Conference on Affective Computing and Intelligent Interaction (ACII)*, pages 1–7. IEEE, 2019.
82. Alessandro Russo, Grazia D'Onofrio, Aldo Gangemi, Francesco Giuliani, Misael Mongiovi, Francesco Ricciardi, Francesca Greco, Filippo Cavallo, Paolo Dario, Daniele Sancarlo, et al. Dialogue systems and conversational agents for patients with dementia: The human–robot interaction. *Rejuvenation research*, 22(2):109–120, 2019.
83. Amanda Sharkey and Noel Sharkey. Granny and the robots: ethical issues in robot care for the elderly. *Ethics and information technology*, 14(1):27–40, 2012.
84. Noel Sharkey and Amanda Sharkey. The crying shame of robot nannies: an ethical appraisal. *Interaction Studies*, 11(2):161–190, 2010.
85. Takanori Shibata and Kazuyoshi Wada. Robot therapy: a new approach for mental healthcare of the elderly–a mini-review. *Gerontology*, 57(4):378–386, 2011.
86. Masahiro Shiomi, Kayako Nakagawa, Kazuhiko Shinozawa, Reo Matsumura, Hiroshi Ishiguro, and Norihiro Hagita. Does a robot's touch encourage human effort? *International Journal of Social Robotics*, 9(1):5–15, 2017.
87. Masahiro Shiomi, Aya Nakata, Masayuki Kanbara, and Norihiro Hagita. A hug from a robot encourages prosocial behavior. In *2017 26th IEEE international symposium on robot and human interactive communication (RO-MAN)*, pages 418–423. IEEE, 2017.
88. Ja-Young Sung, Lan Guo, Rebecca E Grinter, and Henrik I Christensen. "my roomba is rambo": intimate home appliances. In *International conference on ubiquitous computing*, pages 145–162. Springer, 2007.
89. Murat Taskiran, Nihan Kahraman, and Cigdem Eroglu Erdem. Face recognition: Past, present and future (a review). *Digital Signal Processing*, page 102809, 2020.
90. Vincent Wing Sun Tung and Norman Au. Exploring customer experiences with robotics in hospitality. *International Journal of Contemporary Hospitality Management*, 2018.
91. Sherry Turkle. A nascent robotics culture: New complicities for companionship. *American Association for Artificial Intelligence Technical Report Series AAAI*, 2006.
92. Dina Utami and Timothy Bickmore. Collaborative user responses in multiparty interaction with a couples counselor robot. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 294–303. IEEE, 2019.
93. Mariana von Mohr, Louise P Kirsch, and Aikaterini Fotopoulou. The soothing function of touch: affective touch reduces feelings of social exclusion. *Scientific reports*, 7(1):1–9, 2017.
94. Kazuyoshi Wada and Takanori Shibata. Living with seal robots—its sociopsychological and physiological influences on the elderly at a care house. *IEEE transactions on robotics*, 23(5):972–980, 2007.
95. Astrid Weiss, Daniela Wurhofer, and Manfred Tscheligi. "i love this dog"—children's emotional attachment to the robotic dog aibo. *International Journal of Social Robotics*, 1(3):243–248, 2009.
96. Christian JAM Willemse and Jan BF van Erp. Social touch in human–robot interaction: Robot-initiated touches can induce positive responses without extensive prior bonding. *International journal of social robotics*, 11(2):285–304, 2019.
97. W Winnicott, D. Transitional objects and transitional phenomena—a study of the first not-me possession. *International journal of psycho-analysis*, 34:89–97, 1953.

98. Lisa Wood and Hayley Christian. Dog walking as a catalyst for strengthening the social fabric of the community. *The Health Benefits of Dog Walking for Pets and People*, pages 51–74, 2011.
99. Sigal Zilcha-Mano, Mario Mikulincer, and Phillip R Shaver. An attachment perspective on human–pet relationships: Conceptualization and assessment of pet attachment orientations. *Journal of Research in Personality*, 45(4):345–357, 2011.