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Toward a generalized model of human emotional attachment

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ABSTRACT

As artificial intelligence and robots increase in popularity, human emotional attachment to technologies has become a salient research topic. However, many studies face the challenges of lacking a clear definition of emotional attachment that is overarching to cover emotional attachment to different entities and of differentiating these types of attachment phenomena. After reviewing the classic and contemporary research on human emotional attachment to people, pets, and possessions, we propose a novel, generalized definition and model of attachment across a person's lifespan that describes the mechanism of human emotional attachment. Our literature review revealed two distinct but overlapping broad categories of research on human attachment: human-human attachments and human-nonhuman attachments. Our model integrates psychological principles and mechanisms from both classic infant-mother attachment theory and contemporary consumer behaviour research on emotional attachment to nonhuman objects. Emphasis is placed on the central role of *the self-concept* in all forms of human emotional attachments. We define human emotional attachment as a psychological phenomenon characterized by (a) perceiving the attributes of the attachment object as congruent with the self (supporting the self-concept and self-worth), (b) eliciting emotional reactions, and (c) evoking attachment behaviours. More specifically, the new model may lead to a series of new research on human emotional attachment to technologies and on its relationship to individuals' self-concept development and well-being.

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Relevance to human factors/ergonomics theory

Human emotional attachment is a critical phenomenon in human-robot relationships. A clear definition and model of human emotional attachment can advance our understanding of human attachment to all entities by positing a universal attachment process that allows us to 1) categorize various forms of attachment, 2) measure the strength of our attachments, 3) compare the results of research on attachment across studies, and 4) inform the design of technology for more effective human-robot interaction.

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Introduction

Researchers have increasingly used the term *attachment* to describe humans' emotional responses to various types of robots: service robots, such as Roomba (Sung et al. 2007); pet robots, such as AIBO dog (Friedman, Kahn Jr, and Hagman 2003; A. Weiss, Wurhofer, and Tscheligi 2009); military robots (Ackerman 2013; Barber 2013; Carpenter 2013); and future social robots (Norman 2004). However, in the context of human–robot relationships, researchers often face the challenge of lacking a clear definition and core features of attachment to categorize a psychological phenomenon as emotional attachment, and therefore, used a mix of words (E. C. Collins 2016; Huber, Weiss, and Rauhala 2016), including emotional attachment, emotional bond, emotional responses (Huang and Gillan 2014), emotional connection (Björling et al. 2020), rapport, companionship, relationship, etc. In addition, researchers who used the term emotional attachment did not justify the differentiation between human emotional attachment to a robot and the classic infant–mother attachment first introduced in developmental psychology by Bowlby (1969, 1999). The lack of a clear definition of attachment leads to the challenge of finding appropriate measures, which makes it hard to compare results across studies. These challenges hinder researchers from moving forward in HRI research area, which should have flourished in this era because humans have closer interactions with robots and non-living things more than ever in history and the trend will continue to grow.

Emotional attachments impact human development and behaviour in important ways (Bowlby 1988; Mikulincer, Shaver, and Pereg 2003). In human–robot interactions, for example, emotional attachment to a robot may adversely influence a soldier's rational decision-making in the field (Ackerman 2013; Barber 2013; Carpenter 2013). On the other hand, an attachment to companion robots used in nursing homes may help elderly people with memory loss to a healthy recovery (Wada et al. 2005). The literature on human attachment informs our understanding of the relationships between infants and their primary caregivers (Bowlby 1982) and the attachments of adolescents to other parents (Howes 1999), adults to a spouse (Hazan and Shaver 1987), humans to pets (Zilcha-Mano, Mikulincer, and Shaver 2011), consumers to products and possessions (Ball and Tasaki 1992; Norman 2004; Schifferstein and Zwartkruis-Pelgrim 2008), and people to places (Low and Altman 1992; Scannell and Gifford 2014). Across these various relationships, researchers have studied and defined human emotional attachment in unique ways, generating different concepts and mechanisms. The differences are often linked directly to the object of the attachment (Schifferstein and Zwartkruis-Pelgrim 2008), the nature of the attachment bond (Norman 2004; A. Weiss, Wurhofer, and Tscheligi 2009), or the motivation for attachment (Ball and Tasaki 1992). However, future research on human attachment could benefit greatly from a universal framework, a common language, and a shared basis for the comparison of data and research findings. Having a single, generalizable definition and conceptual framework to account for all forms of human emotional attachment is important not only for the validity and reliability of research in these various areas but also for clear communication and a more complete, shared understanding among scientists of this universal phenomenon.

The following sections consist of three parts. Part one identifies, describes, compares, contrasts, and synthesizes research on the nature of various human–human attachments (e.g. infant–mother, adolescents' attachment, and adults' attachment). Part two does the same for the research on human attachment to nonhuman objects (e.g. pets, possessions,

activities, and robots). In part three, we present a unifying definition and model of human attachment and discuss its implications for future research. The proposed model integrates three components of human attachment—the self, attachment emotions, and attachment behaviours—that appear to be shared across all forms of human emotional attachment.

Part one: human attachment to other humans

Systematic research on attachment theory in psychology started with Bowlby's (1958) work on infants' attachment to mothers in the 1950s. Bowlby and his colleagues have had a significant impact on the development of attachment research (Bretherton 1992) as infant–mother attachment has been extended and applied in later researchers' investigations of adolescents' attachment to peers and other caregivers and of adults' attachment to their spouses and children. Research on attachment covers the lifespan of human development.

Infants' attachment to mothers

The evolutionary theory of attachment suggests that children come into the world biologically pre-programmed to form attachments with others to ensure survival (Bowlby 1988, 1969, 1999; Harlow and Zimmermann 1958; Lorenz 1935). The infant produces innate 'social releaser' behaviours, such as crying and smiling, that stimulate innate caregiving responses from adults. Research on infants and monkeys suggested that attachment is determined not by the provision of food but by the provision of appropriate care, comfort, and responsiveness by the caregiver (Bowlby 1969, 1999; Harlow and Zimmermann 1958).

Bowlby suggested that a child initially forms only one primary attachment (monotropy) and that the attachment figure acts as a secure base for exploring the world. The attachment relationship acts as a prototype for all future social relationships, so disrupting the formation of the attachment relationship can have severe, life-long consequences. This theory also suggests that there is a critical period for developing an attachment (about 0–5 years). If an attachment has not developed during this period, then the child will suffer from irreversible developmental consequences, such as reduced intelligence and increased aggression (Bowlby 1969).

In attachment theory, the term *attachment* was first characterized by two infant behaviours: (a) infants' instinctive tendency to seek physical proximity (i.e. clinging) to their mothers and (b) infants' strong emotional anxiety when temporarily separated from their mothers. Proximity seeking and separation anxiety were considered indicators of an emotional bond or tie to the mother (Ainsworth 1972; Bowlby 1982). In addition to these two infant behaviours, Ainsworth later contributed two distinct functions of the mother as a *safe haven* and *secure base* (Ainsworth et al. 1978). As a *safe haven*, mothers are sensitive to infants' distress and needs and comfort them. Mothers' sensitivity and availability when infants are distressed or in need determines the infants' attachment behaviour styles. The mother is also a *secure base*, making infants more willing to explore the environment when the mother is present compared to when only strangers or no one is present.

The evidence for these four central features of infant–mother attachment was well documented in the stranger situation studies (Ainsworth et al. 1978). In one experiment, a 12-month-old infant and its mother were in a playroom, then the mother left the playroom and later returned. The infant's anxiety upon the mother's leaving the room and varied

reactions (i.e. joyful or avoidant) upon the mother's return showed evidence of the infant's attachment to its mother. The infants all displayed anxiety and distress when their mothers left the room but their reactions differ when their mothers returned: (a) some were very happy and clung to their mothers immediately, (b) some avoided their mothers, and (c) some were still distressed and swiped their mothers while clinging to them. Ainsworth et al. (1978) described these varied reactions as different attachment styles and noted that the only similarity among these styles was the infants' distress upon separation from their mothers. In these scenarios, infants were not only physically attached to their mothers by proximity but also emotionally attached. Infant-mother attachment theory also describes an infant's similar attachment to various other caregivers, such as fathers, grandparents, or older siblings (Bowlby 1982, 304; Howes 1999; Stewart and Marvin 1984; Teti and Ablard 1989).

As described above, a primary assumption of attachment theory is that humans form close emotional bonds with caregivers in the interest of survival. Another central principal of attachment theory is that these bonds facilitate the development and maintenance of 'internal working models' or mental representations of the self and others (Bowlby 1969, 1973, 1999). These mental representations help individuals understand their environment, engage in survival behaviours, and establish a psychological sense of well-being. The processes and functions of Bowlby's internal working models are consistent with Rogers' (1959) self-concept, which includes self-image, self-worth, personality, true self, and the ideal self. These internal working models also consist of expectations about the self and are believed to include detailed content about attachment objects, such as people, places, activities, and things (Bowlby 1969, 1999; Bretherton 1992; N. L. Collins and Read 1994). Working models are also believed to remain relatively stable over time, although they may change under some conditions (Bowlby 1973).

Adolescents' attachment to other humans

Attachment is 'from crib to grave' (Bowlby 2005, 129), but how and to whom attachment is expressed changes over time. When infants grow up, their attachment behaviours to mothers remain, but other people may become attachment figures of a child if they: (a) care for a child's physical and emotional needs, (b) remain present and consistent in a child's life, or (c) emotionally invest in a child (Howes 1999). According to these standards, children's attachment figures may include other family members, teachers, and peers. Attachment behaviours in adolescents depart even further from those of infants in many aspects: (a) they do not seek as much physical proximity as infants do, (b) they usually prefer to turn to peers for comfort, (c) they usually do not experience separation anxiety when their caregivers are absent temporarily (Allen and Land 1999), and (d) they even actively avoid dependency on parents when stressed (Steinberg, as cited in Allen and Land 1999, 321). Although these differences in behaviour between infants and adolescents are great, we propose that it is merely the form and level of attachment that changes. Further, we propose that this change is due to the development of the self-concept.

In Self-Determination Theory (Ryan and Deci 2000), *relatedness* is another term that can connect changing attachment behaviours to the self-concept. Like Bowlby's (1969, 1999) infant-mother attachment, which theorizes that young children feel safe to explore and experiment when they have a safe attachment toward their caregivers (Ryan, Deci, and Grolnick 1995), forming *relatedness* requires caregivers to provide autonomy support,

helping care-receivers to resolve obstacles and achieve increasing levels of competence. Similarly, individuals develop the sense of relatedness with non-human entities that support their self-concept, autonomy, and competence. However, human relatedness to objects will differ slightly from relatedness to humans in terms of their capabilities and characteristics and will be discussed in part two.

Adults' attachment to humans other than mother

When adolescents grow up, they may get attached to friends and romantic partners (Hazan and Shaver 1987). The three criteria for children's attachment figures that Howes (1999) identified—that is, caring for physical and emotional needs, maintaining a consistent presence, and emotionally investing—also seem to apply to romantic partners. Research on attachment between adults started in the early 1970s and included studies on bereavement (Bowlby and Parkes 1970) and marital separation (R. S. Weiss 1973). Romantic love is considered an attachment process, which is influenced by early child-caregiver experiences (Feeney 1999). Researchers have used the four criteria for infant-mother attachment to study adult attachment: physical proximity, safe haven, secure base, and separation anxiety (Hazan and Shaver 1987; Mikulincer and Shaver 2007; Shaver and Hazan 1988) and have found that people are comforted when they get support in emergencies and that attachment figures can serve as a safe haven (Bowlby 1982).

The idea that romantic relationships may be attachment relationships has profoundly influenced modern research on close relationships. There are at least three critical implications of this idea. First, if adult romantic relationships are attachment relationships, then we should observe the same kinds of individual differences in adult relationships that Ainsworth et al. (1978) observed in infant-caregiver relationships. We may expect some adults, for example, to be **secure** in their relationships—to feel confident that their partners will be there for them when needed and to be open to depending on others and having others depend on them. In contrast, we should also expect other adults to be insecure in their relationships. For example, some insecure adults may be **anxious-resistant**: they worry that others may not love them completely and are easily frustrated or angered when their attachment needs go unmet. Others may be **avoidant**: they may appear not to care too much about close relationships and may prefer not to be too dependent upon other people or to have others be too dependent upon them.

Second, if adult romantic relationships are attachment relationships, then the way adult relationships 'work' should be similar to the way infant-caregiver relationships work. In other words, the same kinds of factors that facilitate exploration in children (i.e. having a responsive caregiver) should facilitate exploration among adults (i.e. having a responsive partner). The kinds of things that make an attachment figure 'desirable' for infants (i.e. responsiveness, availability) are the kinds of factors adults should find desirable in romantic partners. In short, individual differences in attachment should influence relational and personal functioning in adulthood in the same way they do in childhood.

Third, an adult's security/insecurity in adult relationships may be a partial reflection of experiences with his or her primary caregivers. Bowlby believed that the mental representations or working models (i.e. expectations, beliefs, and 'rules' or 'scripts' for behaving and thinking) that a child holds regarding relationships are a function of their caregiving experiences. For example, previous experiences will tend to lead a secure child to believe that

others will be there for them. Once a child has developed such expectations, they will tend to seek relational experiences that are consistent with those expectations and will perceive others in a way that is influenced by those beliefs. According to Bowlby, this process should promote continuity in attachment patterns over the life course, although it is possible that a person's attachment pattern will change if their relational experiences are inconsistent with their expectations. In short, if adult relationships are attachment relationships (Hazan and Shaver 1987; Mikulincer and Shaver 2007; Shaver and Hazan 1988), it is possible that children who are secure will grow up to be secure in their romantic relationships.

Less research is available on parents' reciprocal attachment to children in the work of Bowlby and his followers. Bowlby wrote explicitly that the parent–child relationship is a complementary social relationship and avoided using attachment to describe the parental side of the social bond, which he called 'maternal caregiving' (Bowlby 1982, 377). Bowlby also stated that attachment–caregiving described the self-protective attachment of less-abled individuals to more-abled individuals. In a child–parent relationship, the role of a parent as the attachment figure remains stable for a long time. However, the roles may change, such as in marriage or when a child grows up to take care of an aging parent (Bowlby 1982).

Few researchers reported that parents describe themselves as being attached to their babies. Rather, research suggested that parents tend to transfer their own previous infant–mother relationship to their parenting (Mercer 2006). When children grow old enough to go to school or move away from home, many parents will experience separation anxiety, which was broadly defined as feelings of worry and discomfort associated with concern for their children's safety and well-being (Bartle-Haring, Brucker, and Hock 2002). In contrast to an infant's separation anxiety, however, parental separation anxiety is less about their own personal security and more about their self-esteem or self-concept as good caregivers. In other words, separation from a child complicates and threatens a parent's ability to perform their expected role as a parent (i.e. to protect and care for their child), which is part of the self-concept. The Parents of Adolescents Separation Anxiety Scale (PASAS) was developed to measure parents' feelings on two subscales: (a) anxiety about adolescent distancing and (b) comfort with their *secure base* role (Hock et al. 2001).

In sum, part one reviews the literature on human–human attachment, beginning with the classical theory of infant–mother attachment (Bowlby 1958), and then describes its extension and application to attachment in adolescent children, adults' attachment to other adults, and adults' attachment to children.

Part two: humans' attachment to nonhuman entities

Even though the development of attachment theory was heavily influenced by ethology and adopts an eclectic approach, the major works by attachment researchers have not included nonhuman entities, let alone non-living objects or activities (Bowlby 1973, 1980, 1982; Cassidy and Shaver 1999; Grossmann, Grossmann, and Waters 2005). Part two reviews research related to human emotional attachment to living organisms (e.g. pets and assistive animals), and non-living objects (e.g. possessions and robots). Part two concludes with a focus on human emotional attachment to robots as a special case of human attachment to nonhuman entities.

Humans' attachment to pets

The central characteristics of classic infant–mother attachment theory emphasize the child's development of an internal working model (also part of self-concept), the child's desire for physical proximity, the mother's roles as a safe haven and secure base, and the child's separation anxiety in the absence of the mother. These characteristics are believed to be linked to the caregiving attributes of the adult human and the conditions necessary for the survival, security, and healthy development of the child (Ainsworth et al. 1978; Bowlby 1969, 1999; Bretherton 1992). Some researchers have proposed that human attachment to other living creatures (e.g. pets), many with infant-like features, might result in similar behaviours and forms of emotional attachment (Zilcha-Mano, Mikulincer, and Shaver 2011). For example, characteristics of a human attachment to dogs include a (a) sense of closeness, (b) perception of companionship and care-giving desire, (c) desire to keep a close relationship, and (d) loss and separation-related stress (Archer and Ireland 2011). However, the principles of *safe haven* and *secure base* seem to have limited application in the human caregiver's attachment to their pets. Most pet owners do not rely on their pets for caregiving, nor do they expect dogs to provide the conditions necessary for the owner's survival, security, and healthy development. There exists the limited exception of service and therapy animals (e.g. diabetic alert dogs, visual assistance dogs, psychiatric service dogs, etc.). For example, many people with visual or motion disabilities rely on trained dogs to navigate or move. More than 50% of service dog owners reported intense grief over the loss of their dogs, which was consistent with a caregiving relationship (Kwong and Bartholomew 2011). Although human attachment to pets has some characteristics of a reciprocal social commitment similar to the classic infant–mother attachment, the attachments humans form with their pets are more like the caregiver attachment that parents form with their child. In other words, the human's availability and sensitivity to the pet's needs are likely an important influence on the nature of the *pet's* attachment to the human.

Human emotional attachment to non-living things

Consumer behaviours demonstrate that people develop a strong feeling of affection for non-living things. This section will review the research on human attachment to non-living things such as possessions.

Attachment to possessions

In the marketing or consumer behavior field, attachment to possessions was defined as 'the extent to which an object that is owned, expected to be owned, or previously owned by an individual is used by that individual to maintain his or her self-concept' (Ball and Tasaki 1992, 155). The more effectively an object maintains an individual's self-concept, the stronger their attachment to it. In comparing consumers' relationships with objects that had a greater or lesser role in defining the owners' identity, consumers tended to treat the former category of objects more protectively, to spend more time maintaining them, and to have stronger negative emotions in response to their deterioration and loss of the objects (Ball and Tasaki 1992). Ball and Tasaki's research showed that the significance of the object to

one's self-concept—how positively or negatively it was associated with significant events or people in the person's life—is a component of the attachment formation. Researchers on hoarding disorder also emphasized the role of self-concept in the formation of emotional attachment to possessions (Kings, Moulding, and Knight 2017). On the surface, 'you are what you own' (Kings, Moulding, and Knight 2017, 51) sounds reasonable; at the deep level, however, the meaning and identity that possessions bring to a person is the key.

Like Ball and Tasaki (1992), who attributed human attachment to objects to the self-concept, Belk (1988) suggested that individuals conceive of possessions as extensions of the self. Moreover, the degree to which the individual can freely manipulate the object by personal will (i.e. the degree of control) determines how closely the object is associated with the inner self. That is, 'the greater the control we exercise, the more closely allied with self the object should become' (Belk 1988, 141). Prelinger (1959) tested a similar hypothesis by having participants rate 0–3 (0 = nonself, 3 = self) for 160 items. In descending order, the results were (a) body parts (e.g. skin, organs), (b) psychological or intra-organismic processes (e.g. the conscience, an 'itching' on the soul), (c) personal identifying characteristics and attributes (e.g. age, occupation), (d) possessions and products (e.g. watch, perspiration, toilet articles), (e) abstract ideas (e.g. social mores, laws), (f) other people (e.g. neighbours, family members), (g) objects within the close physical environment (e.g. dirt on the hands, furniture in the room), and (h) distant physical environment. Of these categories, only the category 'other people' has some overlap with the subjects in Bowlby's attachment theory (Bowlby 1969, 1999).

Prelinger's (1959) finding that possessions were rated closer to self than other individuals may be because it is easier to make your possessions the way you like than manipulating other people's free wills the way you want (Belk, 1988; McClelland, 1951). It seems problematic applying Belk's degree of control to predict closeness to the self and the strength of an individual's attachment to another human because infant–mother attachment, adult–spouse attachment are commonly accepted relationships that normally do not employ mental or physical control over the other (Ainsworth et al. 1978; Bowlby 1969, 1999; Bretherton 1992). However, if we think about the control as an influence that supports the self-concept (e.g. mother taking care of the infant's needs when cries), then Belk's findings may support Ball and Tasaki's findings.

Schultz, Kleine, and Kernan (1989) used 'a person–material possession association' to describe human–object attachment, specifically, 'a multidimensional property of material object possession [that] represents the degree of linkage perceived by an individual between themselves and a particular object' (p. 359–360). The perceived linkage has three dimensions: individuation (how individuals differentiate self from others), integration (social connection to others), and temporal orientation (the frequency of demonstrating evidence of individuation, integration and association with the past, present, and future). In Schultz, Kleine, and Kernan (1989) work, emotions are key to forming attachment to possessions, and positive emotions are associated with a strong attachment while negative emotions (e.g. disliking) and neutrality are associated with a weak attachment.

The concepts of linkage and attachment emotions also appear in Schifferstein and Zwartkruis-Pelgrim (2008) research. They defined consumer–product attachment as the emotional bond that the consumer experiences with a durable product that is special to them. Due to the emotional bond, the person will tend to keep the product for a long time and will experience negative emotions if the attachment object is lost. Schifferstein and

Zwartkruis-Pelgrim (2008) definition focused on physical products rather than abstract objects, such as brands. Their definition also excluded temporary products, such as food. Their explanation for how consumer–product attachment is formed emphasized the significance of the four aspects of self (i.e. diffuse self, private self, public self, and collective self), the meanings of the products to the self (i.e. enjoyment, individual autonomy, group affiliation, and life vision), and the irreplaceability and indispensability of the product to the self.

An expert in field of Human Factors, Norman (2004) also discussed human attachment to products in his book *Emotional Design*, acknowledging similar processes at work in humans' attachments to people, pets, and personal belongings. Norman proposed three levels of object appreciation: *visceral* (i.e. immediate attraction to an object based on its appearance), *behavioural* (i.e. love for a product because of its function and usability, based on the quality of interaction experiences), and *reflective* (i.e. strong emotional response to an object that has special meaning to the individual). Although without explicitly defining emotional attachment, Norman implied that strong positive emotions elicited by any of these three levels of object appreciation, or by some combination of them, indicate emotional attachment. Unlike Bowlby's (1969, 1999) attachment theory, Norman only emphasized positive emotions; he did not explicitly mention separation anxiety, nor did he differentiate the strength levels of the emotions.

Norman's three-level model of emotional processes is not entirely new. Schultz, Kleine, and Kernan (1989) asserted that 'the degree of attachment is reflected through thoughts, feelings, and behaviors toward a particular object' (Schultz, Kleine, and Kernan 1989, 360). Norman's reflective level of emotions are also consistent with Ball and Tasaki (1992) findings that people become attached to things that support their self-concept and self-worth. In a passage of *Emotional Design*, Norman (2004) asserted that people become attached to objects that represent or are associated with meanings and feelings.

We become attached to things if they have a significant personal association, if they bring to mind pleasant, comforting moments.... Our attachment is really not to the thing; it is to the relationship, to the meanings and feelings the thing represents. (p. 48)

From this, it is reasonable to conclude that one meaning individuals could attach to an object, most likely at the reflective level of appreciation, could be the individual's own sense of worth or self-concept.

In addition, people have also reported strong attachments to activities, groups, institutions, and religious faiths (e.g. Christianity), possibly because these entities serve as *safe havens* and *secure bases* (Granqvist, Mikulincer, and Shaver 2010; Kirkpatrick and Shaver 1992; Rom and Mikulincer 2003). Bowlby (1969) indicated that attachment to activities and institutions would be qualitatively and quantitatively different from the classic attachment theory since attachment to most possessions have little to do with a safety-regulating system. However, such attachments may not be as different if these entities serve to maintain and support self-concept, even safety-regulation is one way to enable self-concept and self-development.

Human emotional attachment to robots: a special case of human–nonhuman attachment

Robots are somewhat unique objects due to their life-like mobility, their responsive sensors, and the vast possibilities for physical appearance. Robots can resemble humans, pets, or

objects in both their forms and functions. Norman (2004) envisioned a future in which advanced, socially intelligent robots will have physical proximity to individuals and be able to attend sensitively to humans' needs and distresses. It is quite possible that future robots may function as primary caregivers for humans and that, consequently, humans will get attached to robots as they do to human caregivers (Norman 2004). While the current technology is still far from reaching that stage, it may be helpful to study human relationships with less advanced robots. Although most current educational and service robots have limited intelligence and capabilities, Coeckelberg (2011) predicted that humans would develop potentially problematic emotional attachment to robots, such as children's intense, long-term relations with their toy robots, and adults with their pet robots.

Many researchers in the field of Human–Robot Interaction have used the term *attachment* to describe humans' emotional responses to various types of robots. For example, Weiss, Wurhofer, and Tscheligi (2009) studied children's and adults' initial reactions to AIBO, a robotic dog, at a shopping mall and found that children demonstrated positive emotions at all three appreciation levels defined by Norman (2004): visceral—being attracted to AIBO when they first saw it; behavioural—playing with it for a period of time; and reflective—expressing the wish to bring it home as a companion. Therefore, they concluded that the children had rapidly developed emotional attachment to the robot dog. However, even though the children felt reluctant to leave after a short period of time interacting with AIBO, they are unlikely to have felt long lasting separation anxiety when they had to leave it. In short, Weiss, Wurhofer, and Tscheligi (2009) research bears the flaw of Norman's (2004) definition of emotional attachment—it lacks evidence of a defining characteristic in the Bowlby's attachment theory: strong and lasting separation anxiety (Ball and Tasaki 1992; Hazan and Zeifman 1999).

An individual may experience positive emotions toward an object on several levels but still not experience separation anxiety. In such a case, Bowlby's (1958) classic attachment has not been formed. For example, when a robot fan looks at any robot, she may be attracted to it (at the visceral level); she may spend a long time observing its outside features, inside structure, and function (at the behavioural level); and she may deeply appreciate the purpose and meaning the robot has for her research, for children, or for potential users (at the reflective level). However, bearing all three levels of Norman's (2004) object appreciation, she may not necessarily feel any negative emotions about leaving the robot behind or giving it away, therefore, no attachment to the robot is formed. Similar to a child's impulse to own a toy at the first glance, the desire to have the robot as a companion is likely to pass quickly. Therefore, despite Weiss, Wurhofer, and Tscheligi (2009) conclusions, the children's emotional responses to AIBO after a short-term interaction may be quantitatively and qualitatively different from the attachment phenomenon in Bowlby's classic attachment theory (1969, 1982). Another recent study (Björling et al. 2020, 71) on teen–robot interaction claimed the teen expressed emotional attachment to the robot based on teens' one sentence, such as 'I said that I wasn't very stressed and he said he was glad to hear that, so that was nice.' This claim also would not fit the criteria of classic emotional attachment.

Roomba, a robotic vacuum machine, is another product that has been studied relative to human attachment. People treated their Roomba as a family member, assigning it a nickname and a gender (Forlizzi and DiSalvo 2006; Jones and Schmidlin 2011; Sung et al. 2007). Sung et al. (2007) studied Roomba forum postings and conducted interviews with Roomba users and concluded that this human–robot relationship was a form of *intimacy*

because it created feelings of warmth, closeness, and sharing. Sung et al.'s study added an additional dimension to Norman's (2004) three levels of emotional processing—interpersonal and social aspects. Thus, in addition to positive emotions toward the Roomba, many participants expressed grief when their robot needed repair. In this regard, humans are likely to have developed attachment toward their Roomba, but it may still be a different kind of emotional attachment from that in Bowlby's (1982) classic attachment theory.

Along similar lines, soldiers have been reported in news and research to feel frustration, anger, and sadness when their military robots are damaged or destroyed. Some have even held 21-gun funerals for their destroyed robots (Barber 2013). Such emotional connections may even influence soldiers' decision-making in the field, as when soldiers have appeared reluctant to send their robots into dangerous terrain (Ackerman 2013; Barber 2013; Carpenter 2013). Based on interviews with 23 male Explosive Ordnance Disposal (EOD) military personnel, Carpenter (2013) concluded that these soldiers had become attached to their EOD robots. Many of the interviewed soldiers experienced sadness when temporarily or permanently separated from their robots. Carpenter (2013) wrote that soldiers were aware that the field robots were merely tools but nevertheless interacted with them as though they were humans or pets. They named the robots after their wives or girlfriends and felt loss when the robots did not come back to base safely. Thus, their robots may have served as symbolic substitutes for soldiers' significant others. Another reasonable explanation is that the EOD robots have significant meaning to the soldiers (reflective appreciation) because these robots serve a safety and security function for their handlers and extended the soldiers' self. When an EOD robot is deployed by a soldier to locate, identify, and defuse a suspected explosive, it is serving to protect others, including the handler, especially when the robot is destroyed in the place of the soldier. Therefore, EOD personnel may become attached to their robots because they saved their lives, a different meaning from social exchanges.

Like humans, and pets, the robots discussed above are developed products ready for consumers to use. In contrast, educational tournament robots may have fewer capabilities. Many educational robots used in robotic tournaments are made from mechanical parts, appear as machines, and have limited sensors and frequent malfunctions. They do not have sufficient intelligence to actively provide support, affection, or protection; after all, they were not designed to function as caregivers. Would it be possible for humans to develop attachment to this type of robot? An answer to this question is suggested by an anecdote: a mother reported that her son got attached to the robot because he did not go to bed the night before a robotics tournament, choosing instead to stay with the robot in the lab (Personal communication, March 2014). The son's difficulty with separation was one of the key criteria she used to decide her son had become attached to his tournament robot. However, such attachments do not meet all the criteria for classic attachment theory. There is some evidence that robot builders will seek proximity to their robots and experience some separation anxiety but a lack of evidence that robot builders perceive their robots as safe havens or secure bases.

The robot attachment studies reviewed in this section reflect a shared understanding of *emotional attachment*, but none of them presented a definition of robot attachment that bridges to the original meaning of the term in Bowlby's theory (1969, 1982, 1999). Infants' attachment to their caregivers is quite different from human attachment to nonhuman objects (e.g. robots). In most cases, humans do not rely on robots for emotional support or protection. Robot builders' relationships with their robots seem to be more like parent-child

relationships, but Bowlby (1982) did not include maternal caregiving as an element of the attachment ‘social bond’ because caregiving is a one-directional behaviour provided by the parent. Bowlby (1982) believed that in forming a ‘social bond,’ attachment only applies to relationships that involve ‘both parties’ commitment (p. 376). If robot builders were in the parents’ role and the robots in the children’s role, robots still lack the ‘free will’ to commit to a relationship, although they can be programmed to respond to caregiving behaviours. In any case, given these significant differences between humans and robots (Melson et al., 2009), any direct application of classic definitions and descriptions of human–human attachment to human–robot relationships is problematic. This conceptual gap makes it even more critical to develop a useful, more relevant model and definition of human–robot attachment that can be applied in HRI research.

In sum, part two reviewed contemporary research on human attachment to non-human entities, including living organisms (e.g. pets and assistive animals), and nonhuman objects (e.g. possessions and robots), which are not included in Bowlby’s classical attachment theory (Bowlby 1982; Bretherton 1992). Bowlby and Ainsworth’s work and that of other major scholars (e.g. Cassidy and Shaver 1999) has primarily focused on human–human attachment (Bretherton 1992).

Part three: toward a generalized model of human emotional attachment

The literature review in parts one and two has revealed two distinct, yet overlapping, areas of research on human attachment. Furthermore, attachment researchers have proposed a variety of concepts and mechanism to describe and explain human emotional attachment to other humans, as well as to nonhumans (pets, objects, and robots). However, it is not clear how these overlapping, yet seemingly incompatible descriptions are related or how they might be integrated and applied to more fully inform our understanding of all human emotional attachments. We summarize and compare these two broad areas of research in Table 1.

Classical attachment theory was developed specifically to describe, explain, and predict infant attachment to mothers or caregivers. It was never intended to explain other forms of human attachment. Nevertheless, many attachment researchers have encouraged exploration of new directions, methods and topics in attachment theory research (e.g. Bretherton 1992; Grossmann, Grossmann, and Waters 2005). To bridge the conceptual and theoretical gap classic attachment theory for human–human attachments and contemporary research

Table 1. Summary of research on human–human and human–nonhuman attachment.

	Classic Human–Human Attachment	Human–Nonhuman Attachment
Purpose of the Attachment	Security, survival, and safety of self and development of internal working models/representations	Develop, preserve, and promote self-concept, self-worth, self-identity, ideal self, true self
Nature of the bond	Emotional association or bond	
Direction of bond	Uni- or Bi- directional (Infant–mother)	Mostly uni-directional, sometimes Bi-directional (pets)
Attachment formation	<i>Safety-regulating process</i>	<i>Self-regulating process</i>
Attachment behaviours	Proximity seeking, signalling, approaching, exploration, protective, etc.	
Key processes/concepts	Proximity, safe-haven, secure base, sensitive care and responsiveness, separation/threat anxiety, secure, anxious-resistant, avoidant attachment	Integration, individuation, and temporal orientation object appreciation (visceral, reflective, and behavioural), self-development

on human–nonhuman attachments, we propose a single, integrated and generalized definition and model of how humans become emotionally connected to people or things across the lifespan. This model will (a) use a mechanism that not only includes but also surpasses the mechanism in classic infant–mother attachment, (b) address the differences between classic infant–mother attachment and human–nonhuman attachment, and (c) position their common features.

In this model, we first identify underlying psychological concepts or phenomena present in both human–human and human–nonhuman relationships (e.g. the self-concept, emotional reactions, attachment behaviours) before appropriately integrating seemingly different natures (e.g. the infant safety-regulating process and the adolescent/adult self-regulating process) into a single concept. This integration could be reasonably done in two ways by either defining one concept, the safety-regulating process, as a *subcomponent* of the developing self-concept, or by defining the safety-regulating process as an early-life, developmental focus or stage of a single mechanism called the *self-regulating process*. However, the infant's safety-regulating process may not be a distinct system (or subsystem of the self) at all but an early stage of an evolving self-regulating process. That is, an individual's self-regulating process may have an early childhood focus on physical survival, safety, and security but later mature and shift its focus to enhancing self-esteem, self-efficacy, and the ideal- and self-identity.

By integrating these two seemingly different concepts and incorporating existing commonalities of human–human and human–nonhuman attachments, a more robust and generalizable model of human attachment emerges. The foundational concepts and principles of Bowlby's classic infant–mother attachment theory are retained and integrated with the features of contemporary attachment models into a broader, more elegant approach that could account for human emotional attachment to all things (human and nonhuman) across the lifespan.

Finding common ground to bridge the human emotional attachment across the lifespan

The literature search revealed at least three components have been observed in both human–human and human–nonhuman attachment: (a) the role of the self-concept (including the infant's safety-regulating process in order to develop a self-concept), (b) attachment emotions, and (c) attachment behaviours. [Figure 1](#) presents a generalized model of human emotional attachment showing the relationships among the central features and its iterative development process. The first element of the model is the potential attachment target (a human or non-human entity), which bears features or attributes. The second element is the individual's self-concept, which includes (among other things) self-image, self-worth, personality, an ideal-self (Rogers 1959), and a true-self (Strohming, Knobe, and Newman 2017). Then, the attributes of the target will be perceived by the individual and processed through his/her self-concept. Emotions are the third element of the model. If the perceived attributes are incongruent with the self-concept, then they are likely to generate indifference or negative emotions toward the target entity. This would probably result in a lack of attachment, rejection, or even a perceived threat. If, on the other hand, the features of the target are perceived to be congruent with (i.e. aligned, promoting, reassuring, securing, developing, or enhancing) the individual's self-concept, positive emotions are likely to be evoked. The persistence of

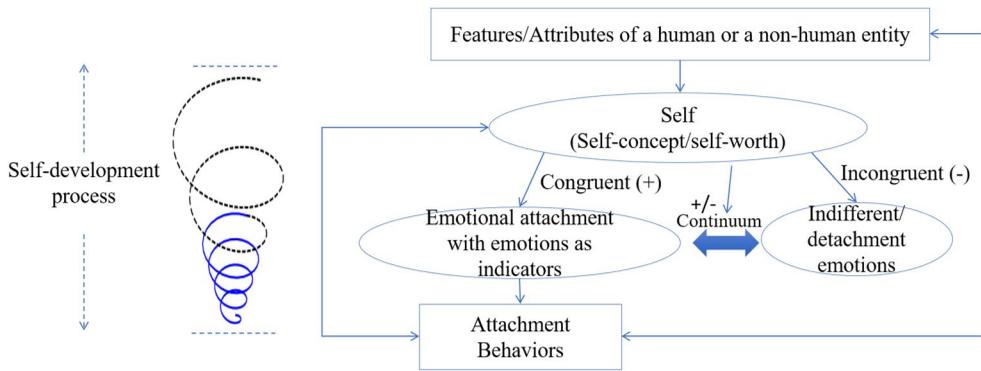


Figure 1. A generalized model of human emotional attachment through a self-development process.

these positive emotions (e.g. excitement, passion, pride, affection) indicate the formation of an emotional bond or attachment, which will be displayed through those positive emotions and by attachment behaviours (increased signalling, interaction, or proximity seeking) directed toward the target entity. The behaviours are the fourth element. Increased interactions and proximity seeking with the target entity will also influence the individual's subsequent perception of the target's features. Furthermore, separation from, loss of, or damage to the attachment target might be expressed through sadness and distress, consistent with predictions made by Bowlby's classic infant–mother attachment theory. This iterative process—perceiving, interacting, and assessing the target entity's features—contributes to the individual's self-development. The self-development process is not a linear trajectory but spiral. The solid line of the spiral refers to self-centred development and the dotted line of self-development represents outward interests and focus on something bigger than self; even sacrificial choices may be part of the self-concept as a result of maturity or growth.

The following section will further define and elucidate the three components of human emotional attachment.

The self-concept

The self-concept evolves as a lifelong process, from crib to grave (Bowlby 1969, 1999, 2005). The self has many aspects and has different priorities at different stages of human development (Kings, Moulding, and Knight 2017). In the earliest, most vulnerable life stage, an infant's evolving self is primarily focused on physical survival, security, self-awareness, and the exploration of self-capabilities through interactions with environments. In this sense, the early self-concept development may be operationally and functionally equivalent to Bowlby's (1958) innate safety-regulating process. Alternatively, the safety-regulating process may be considered an early childhood emphasis of the emerging self-concept. As the individual grows and becomes self-aware, the motivation to explore, maintain, and support the individual's self-identity, self-esteem, and self-worth becomes as important as physical safety. When conflicting goals exist, sacrificial choices also reflect their self-concept. It may be an evolutionary capability for the self-concept of adolescents and adults to recognize that attachments to other people, activities, things, and pets benefit the growth and future survival of an individual.

Ball and Tasaki (1992) definition of attachment is based on maintaining the self-concept and supporting self-worth. In research on consumer attachment to durable products, Schifferstein and Zwartkruis-Pelgrim (2008) found that the individual's memories were the most important determinant of the attachment. The researchers did not specify the nature of the memories that form attachment, but they did associate memories with gifts and other humans, all of which may have important meanings to individuals and their self-concept. Norman's (2004) three levels of emotional processes, described above, also are related to the self. This is especially true of the reflective level, which focuses on the meaning of the object to the individual and thus is part of the individual's self-concept. People also have individual differences at the visceral and behavioural levels due to their unique biology and self-concepts, senses of self-worth, and self-images. Hoarding disorder is an extreme example of emotional attachment to one's possessions, and it has deep relationships with an individual's self-concept (Kings, Moulding, and Knight 2017).

The self-concept is also related to the need for autonomy—humans' basic psychological need to exercise control over their actions and to express the authentic free will of the self—as the core component of Self-Determination Theory (Ryan and Deci 2000). When the need of autonomy is satisfied in an activity, the person's intrinsic motivation toward the activity is enhanced. The self-concept may also apply to teams by investigating the typical users on a team and their competences and preferences to make incentive customized design for the group.

Attachment emotions

Emotions are a common theme throughout all attachment research. In infant–mother attachment theory (Ainsworth 1972; Bowlby 1982), *proximity-seeking*, *safe haven*, and *secure base* are characteristics of human attachment, which maintains or results in positive emotions for the infant. In contrast, separation anxiety is associated with negative emotions that are elicited when the attachment figure is absent. In attachment theory, separation anxiety is a strong indicator that an attachment has been formed between the mother and the infant. In the study of consumers' attachment to products, researchers have found that objects that help maintain self-worth or reinforce self-concept elicit positive emotions (Ball and Tasaki 1992). Conversely, loss of or separation from the attachment object or product is likely to elicit the negative emotions of grief and sadness. In Norman's (2004) book on attachment to products and objects, he proposed three levels of object appreciation that can elicit positive emotional responses: the visceral, behavioural, and reflective levels. Positive emotions toward the object at one or more levels indicate an emotional attachment to the object. In addition, negative emotions toward separation and loss are also critical to define emotional attachment. In Schultz, Kleine, and Kernan (1989) work, strong attachment is associated with positive emotions (e.g. liking) and weak attachment is associated with negative emotions (e.g. disliking) and neutral feeling.

Attachment behaviours

Attachment behaviours are another major theme in attachment research, although the behaviours vary by case and by types of attachment. Attachment behaviours arise from

attachment emotions and may affirm the formation of an emotional bond. Bowlby (1982) described two basic types of attachment behaviours: (a) signalling behaviours to bring the mother to the child, such as crying, calling, smiling, and babbling and (b) approaching behaviours to bring child to mother, such as clinging and following. The strength of the attachment can be measured by the frequency and intensity (i.e. speed, effort) of the attachment behaviours (Bowlby 1982). These same behaviours and other attachment behaviours are expressed by adolescents and adults to develop, maintain, or strengthen attachments that are supportive of the *self*.

The iterative self-development process

The continuously evolving nature of the individual's self-concept is a process of self-development, which is represented in the model above by a feedback arrow leading from the attachment behaviours back to the features and the self-concept in the model. The evolving self is present in both the classic models of human attachment and in contemporary studies of attachment; thus, the self-development process applies to both human–human and human–nonhuman attachments. The model of the self-development process depicts how human emotional responses and related attachment behaviours can influence and subsequently change the self.

When infants are born, they do not yet have a self-concept. Initially, new-born infants perceive everything as one entity, as if they were still in their mothers' womb, where all their needs are provided for as or before they even arise. As infants grow, they begin to realize that mothers are separate from them and that mothers may disappear for a while. This kind of separation, or loss of self, causes anxiety in the child (Kegan 1982). As children grow older, they begin to realize that they are distinct and different from others. The self-development process entails exploration of one's potential capabilities and preferences as the self grows and understands its own nature. Bowlby (1982) and Ainsworth's (1978) attachment theories emphasized that children tend to explore their environment more when their mothers are present than when absent. This self-development process explains why children have the intention to explore when they feel safe. This self-development process is facilitated by the three inborn needs described in Self-Determination Theory (Ryan and Deci 2000), namely autonomy, competence, and relatedness. The internal working models record what the individual has tried and found to support their self-concept and self-worth (Bowlby 1982; Bretherton and Munholland 1999). The increasingly sophisticated exploration and development of self is reflected in the multiple layers of self that emerge (Rogers 1959) and in an individual's increasing understanding of the limitations of self and the relationship of self with the universe. The self-development process continually updates the knowledge and values of the self and re-evaluates the features of entities with whom individuals interact, making the process lifelong: from the initial recognition of self, to the exploration and growing understanding of the self, to the day life ceases.

A proposed generalized definition of human emotional attachment

Human emotional attachment is broadly defined as a psychological phenomenon characterized by the perception of features of human and nonhuman attachment entities as

congruent with the self, which evokes attachment emotions (i.e. positive emotions when interacting with the entity and negative emotions when the entity is absent or damaged) and attachment behaviours (e.g. signalling, approaching, or proximity-seeking). The strength of the attachment can be measured by the level of perceived congruence and the intensity (i.e. frequency, speed, physical or emotional exertion) of the attachment emotions and behaviours (Bowlby 1982). When the features of a human or nonhuman entity are perceived as incongruent with the self, no attachment emotions and behaviours result. This generalized model and definition of human attachment is sufficiently broad to encompass both the classic and more contemporary research findings in attachment behaviours. Furthermore, the proposed model provides a method not only to determine whether an attachment has formed but also to measure the strength of human attachment to any attachment object.

Conclusion

In summary, the literature on human–human attachment (i.e. infants’ attachment to mothers, adolescent children’s attachment to parents and peers, adults’ attachment to spouses and children) and human–nonhuman attachment (i.e. humans’ attachment to pets, assistive animals, possessions, and robots) revealed a significant conceptual gap between these two areas of study concerning the nature and underlying mechanisms of human emotional attachment. In human–human attachment, the infant’s attachment to the mother is believed to be grounded in an evolutionary biological *safety-regulating process* essential to the survival and security of the infant. Later in adolescent and adult life, the effects of this safety-regulating system continue to manifest themselves in our relatedness, connections, and attachment to others. Previous research into human–nonhuman attachments has suggested that the bond between an individual and a non-human entity is driven by an underlying psychological mechanism referred to as the *self-regulating process*, as part of a lifelong self-development process. The self-regulating process promotes human attachment to nonhuman entities when those entities are perceived to be congruent with the self (i.e. when they help develop and maintain self-worth or self-concept). Because it is unlikely that humans have evolved two separate and distinct attachment processes (one for our attachment to humans and another for our attachment to nonhuman entities), we presented a unified, more general model of human attachment that begins to integrate the *safety-regulating* principles and mechanisms of early infant–mother attachment with evidence for the existence of a *self-regulating process* of human attachment to all things across the lifespan. The three identified fundamental psychological phenomena appear to be common to all forms of human attachment: the unique self, attachment emotions, and attachment behaviours (see Figure 1). This work clarified the concept of human emotional attachment to different entities and provided its mechanism and measurement criteria. This fundamental work has broad applications in all human relationships with people, animals, and objects. Some potential applications include using emotional attachment framework to develop human-centered software (Sherkat et al. 2018), treating hoarding disorder (Kings, Moulding, and Knight 2017), and enhance human–robot teamwork effectiveness (You and Robert 2017). The next step is to apply the framework to a specific relationship between humans and technologies (e.g. AI-embedded agents, robots), develop metrics to measure the level of attachment, and apply design principles to influence human

emotional attachment to various agents (e.g. other humans, nonhuman and non-living objects) in a healthy way.

Disclosure statement

This work has no conflict of interest with any organization.

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