The Journal of Mind and Behavior
Spring 2016, Volume 37, Number 2
Pages 71–98
ISSN 0271–0137

Robotic Alloparenting: A New Solution to an Old Problem?

Richard T. McClelland

Nanaimo, British Columbia, Canada

Recent science fiction films portray autonomous social robots as able to fulfill parental roles with human offspring and thus display a form of "alloparenting." Alloparenting is widespread in the animal world, and involves care of the young by individuals not themselves their biological parents. Such parenting by proxy affords substantial fitness benefits to the young and also to those who alloparent them, and is almost certainly an adaptive form of behavior. Review of developments in current robotic technology suggest very strongly that actual robots may well be capable of alloparenting in the near future. The paper goes on to suggest a view of human culture (as information) and its evolution that can explain how fictional treatments of robots and scientific robotics might converge on such a hypothesis. Robotic alloparenting, finally, is presented as an extension of basic human capacities for cooperative and intelligent tool use, albeit by means of a non-biological platform.

Keywords: alloparenting, culture, evolution, robotics

In the second Terminator film, *Terminator 2: Judgment Day* (Cameron, 1991), there is a poignant scene in the desert. Sarah Connor (played by Linda Hamilton) and her son John (Edward Furlong) have escaped the depredations of the T-1000 terminator (Robert Patrick) for the time being, thanks to the intervention of the T-800 terminator (Arnold Schwarzenegger) which has been sent back in time to protect especially the life of John Connor. Sarah is gearing up for her attempt to assassinate the computer scientist Miles Dyson (Joe Morton) who is about to be responsible for designing the (ultimately) evil Skynet computer system. Sarah has collected weapons and other gear from a stash kept by her friend Enrique Salceda (Castulo Guerra). The assassination will not succeed, as it happens, because John and the T-800 will intervene. During our scene John is shown playing with the terminator as Sarah looks on. In voice-over we hear her thoughts about what she is seeing:

An anonymous reader and the Editor of JMB have provided valuable advice regarding both content and style of this paper. The author thanks them warmly. Correspondence concerning this article should be addressed to Prof. Richard T. McClelland, Ph.D., 4513 Sheridan Ridge Road, Nanaimo, BC, V9T 6G3, Canada. Email: richmcc999@gmail.com.

> Watching John with the machine, it was suddenly so clear. The terminator would never stop. It would never leave him, and it would never hurt him, never shout at him, or get drunk and hit him, or say it was too busy to spend time with him. It would always be there. And it would die to protect him. Of all the would-be fathers who came and went over the years, this thing, this machine, was the only one who measured up. In an insane world, it was the sanest choice. (Cameron, 1991)

It is a short scene (barely 1% of the whole film), but a moving one. In it Sarah Connor imagines the terminator (an autonomous robot) as John's pseudo-father, protector, mentor, and even playmate. In the security of knowing this about him, she leaves the scene suddenly and with little prospect of surviving her mission. It is this supposition of a paternal role for the robot that interests me in this paper. That supposition comes to fuller fruition in the most recent of the Terminator series.

In *Terminator Genisys* (Ellison, Goldberg, and Taylor, 2015) the T-800 terminator, still played by Arnold Schwarzenegger, is now cast explicitly as the Guardian of the young Sarah Connor. Indeed, we are told that the terminator has raised her on its own from the age of six years (the young Sarah is played by Willa Taylor). This element of their relationship runs like a small "red thread" through the film, including speculation (and confirmation thereof) about a rich emotional relationship between Sarah and her Guardian, a relationship that will prove to be a barrier for Kyle Reese at the end of the film, even though the vicissitudes of time travel plus parallel universe creation destine him to be the real father of John Connor. In this new version of the history of the Connor family, the terminator itself is now cast in a much fuller parental role. Indeed, what we have here is a fuller exposition of the theme introduced in *Terminator 2*: the robot as alloparent. Moreover, the alloparenting function of the T-800 has evidently been carried out with signal success, for the adult Sarah Connor (Emilia Clarke) is quite evidently a well-adapted adult member of our species, someone in whom psychosocial maturity, emotional maturity, and intellectual maturity, all combine in a very attractive and effective way. Whatever the trauma of her first six years and whatever the potentially maladaptive effects of those trauma might have been, it is evident that she and her Guardian have formed a most resilient dyad, capable of surmounting those early traumatic events and producing a successful human adult, one who is about to make a momentous and (as we know) successful choice of a mate. It is this notion of the robot as alloparent that I wish to address most directly in this essay. Just how plausible is it to suppose that a social robot, even one so sophisticated as the T-800, could serve as an alloparent? My thesis is that the two films together posit an affirmative answer to that question. Recent scientific evidence, I will argue, also tends to support the plausibility of both films' hypothesis. As such, then, that hypothesis may very well predict our own future, a future that may be rapidly approaching.

It may be objected that a mere fictive device such as a popular film ought not be a source of serious scientific and philosophical theses. However, as I will argue in greater detail in the last section of this paper, a certain view of the nature of human culture (as forms of information) and of cultural evolutionary dynamics will suggest that convergence between fictive imaginative creations and the underlying science of an emerging technology such as robotics is not only plausible but expectable. And, as we will see, the relevance of science fiction films to the actual direction of contemporary robotics is more extensive than just this thesis about possible robotic alloparenting. But we should first consider more carefully just what alloparenting involves.

Alloparenting

Alloparenting is, to put it roughly, care of the young by other individuals who are not the children's biological parents. (The whole topic is often bound up with the concept of "cooperative breeding," but need not be: see Bogin, Bragg, and Kuzawa, 2014, for the more successful concept of "bio-cultural reproduction.") These individuals may include close biological relatives such as older siblings, aunts and uncles, grandparents (especially grandmothers: see Gibson and Mace, 2005), cousins, and the like. They may also include others who are not direct kin of the offspring in question (for surveys see Bentley and Mace, 2012; Briga, Pen, and Wright, 2012; Burkart, Hrdy, and Van Schaik, 2009; Choe and Crespi, 1997; Crespi, 2014; Fletcher, Simpson, Campbell, and Overall, 2015; Hrdy, 2009a; Sear and Mace, 2008; alloparenting social spiders are described in Samuk and Aviles, 2013). Care of the young by non-parents is found widely in the animal world, including approximately 9% of the 10,000 species of birds and 3% of mammalian species, about 50% of primates, some fish, some social insects, and social spiders. Hrdy (2009a) argues that alloparenting was probably found in our ancient *homo erectus/ergaster* ancestors as far back as 1.8 million years (cf. DeSilva, 2011). Tamarins and marmosets also practice widespread and sophisticated forms of alloparenting. We had a common ancestor with those species 35 million years ago; the last common ancestor of hominins and spiders was a sponge-like creature some 500-600 million years ago. We are thus looking at behavior that is extraordinarily ancient in its biological origins. It includes such things as provision of food for the young, actual feeding (including lactation) of the young, protection from predators, thermo-regulation, carrying the young from place to place (which saves their mothers large quantities of calories and time), and incubation of eggs (where relevant, e.g., among birds and fish).

In a justly famous essay, Kaplan (1994) calculated that human children in modern hunter–gatherer societies prior to the age of 18 years normally consume significantly more calories per day than they are able to produce by foraging on their own. The deficit has to be made up from contributions by adults, including parents and any alloparents that may be involved. Kaplan estimates the deficit from birth to 18 years as 13 million calories per child, far more above their own needs than the average mated pair of adults can produce on their own. Provision of food is thus a key ingredient in alloparenting. The bioenergetics of raising multiple children makes assistance from alloparents virtually imperative for humans (Sear and Mace, 2008). Teaching of vital skills and knowledge, mentoring, affective support and general social support are also benefits extending to the young from alloparents (see Sterelny, 2012; Whiten and Erdal, 2012 for expositions of the importance of pedagogy to human evolution, both cultural and biological). Successful alloparenting can make the difference between offspring surviving or not (in some cases, at least doubling the odds of surviving at least to age five years). Such survival benefits include improved immune system functioning that can help stave off infections, while mothers who enjoy alloparental assistance are much less likely to abandon their young, especially during periods of high dietary stress. Similarly, children's height, weight, and overall nutritional quality are significantly improved by alloparenting (Gibson and Mace, 2005). The general point can be put this way: "Offspring are nature's vehicles for gene replication across generations. From an evolutionary perspective nothing matters more than ensuring the success of offspring" (Geher, 2011, p. 27).

Benefits to alloparents themselves include practicing childcare (for older siblings, especially) prior to actual childbearing, direct social benefits of enhanced status in the group or even territorial gains, future breeding position, grooming and other affective gains. There may also be substantial cognitive benefits for alloparents as they practice and extend their own skills and knowledge in the service of the young. Such cognitive gains may also be the groundwork for gains in a sense of competence and autonomy in sibling alloparents. As one recent review has put it: ". . . early experience caring for someone else's infants is critical to becoming competent parents" (Snowdon and Ziegler, 2007, pp. 52–53; cf. Weisner, 1987). As we will see later, such gains in autonomy are intrinsically valuable and serve to justify the practices of alloparenting from an ethical point of view.

From the perspective of groups themselves, alloparenting encourages the development of social tolerance and general prosociality (Burkart, 2015), and thus may well make such groups more effective in their own striving for survival and flourishing. *Alloparenting is thus almost certainly an adaptive form of behavior.* Accordingly, it is no surprise to learn that it has arisen repeatedly across animal taxa and has sometimes appeared and disappeared repeatedly in single species over evolutionary time. Neither is it surprising that alloparenting behavior is commonly transmitted across generations, and that there is more than one biological mechanism for such transfers, including epigenetic transmission (see Curley, Mashoodh, and Champagne, 2011 on epigenetic transmission; Ginther and Snowdon, 2009; Perkeybile, Delaney–Busch, Hartman, Grimm, and Bales, 2015 on intergenerational transmission).

It is further apparent that in the human lineage, adults are well adapted to respond to infants and young children in ways that encourage alloparenting.

Adult humans are predisposed to respond to infant human faces with positive affect and caring motivation. Such attention and care is automatic, independent of experience and cultural setting, and shows none of the in-group bias commonly found for adults' responses to the faces (and the voices) of other adults (Cardenas, Harris, and Becker, 2013; Caria, de Falco, Venuti, Lee, Esposito, Rigo et al., 2012; Esposito, Nakazawa, Ogawa, Kawashima, Putnick et al., 2014). Such differentiated responses to infant faces (and voices) include a wide range of physiological reaction, such as increases in heart rate, skin conductance, skin temperature, blood pressure and changes in respiratory sinus arrhythmia. Neural signals also show specific differences in response to infant cries compared to responses to adult cries, and these responses begin to appear as early as 90 ms post stimulus, much faster than conscious awareness (Kringelbach, Lehtonen, Squire, Harvey, Craske, Holliday et al., 2008; Parsons, Young, Parsons, Stein, and Kringelbach, 2012; Young, Parsons, Elmholdt, Woolrich, Van Hartevelt, Stevner et al., 2016). It is not difficult to see how such mechanisms would have been highly adaptive in the early evolution of our species. Even at the level of neurophysiology, the role of oxytocin, prolactin, and the glycol-protein CD38 have been shown to strengthen the predisposition for alloparenting of human young, encouraging parental behavior in a wide range of mammals (Akther, Korshnova, Zhong, Liang, Cherepanov, Lopatina et al., 2013; Keebaugh and Young, 2011; Snowdon and Ziegler, 2015). The human hand, moreover, is adapted for the specific action of caressing, which promotes positive social bonds both with children and other adults (Campagnoli, Krutman, Vargas, Lobo, Oliveira, Oliveira et al., 2015). It thus appears certain that we are hard-wired for alloparenting. Sarah Hrdy has articulated this point very clearly:

> Our benevolence towards children is not just because we are "civilized" acculturated creatures, but also because primates generally, and especially humans, descend from a long line of intensely social creatures, innately predisposed to help vulnerable immatures whether they be foundlings or kin born into their group. (Hrdy, 2009b, p. xiv)

In a recent study, Piantadosi and Kidd (2016) have similarly argued that there is a self-reinforcing cycle in human evolution between altriciality of neonates and high intelligence in parents. A further consequence of this cycle, according to their analysis, is selection pressure in favor of alloparenting.

It further follows from all this that human children are well-adapted to receive alloparenting from others, including non-kin. Indeed, such a capacity is part of human resilience, which can be analyzed in terms of capacities to navigate towards valuable social resources and to successfully negotiate with those resources to secure relevant benefits. (The literature on psycho-biological resilience in humans is now immense. Representatives include Charney, 2004; Masten, 2011; Oken, Chamine, and Wakeland, 2015. The language of navigation and negotiation is drawn from Unger, 2005, 2011. The neurobiology of resilience is illuminated by Kalisch, Mueller, and Tuescher, 2015.) Without such capacities, alloparenting would simply be wasted and natural selection would have extinguished it in our ancient ancestry.

All of this is by way of positing the following sub-hypothesis: that the *Terminator* films considered here progress to the point of treating the T-800 terminator robot as an alloparent of Sarah Connor. We have thus to ask whether it is at all plausible to suppose that a robot could function in the role of an alloparent. The answer is surprising, but entails a consideration of the current state of play in actual social robotics and the interactions of humans (including young human children) with social robots.

Robotic Soundings

Films engaging apparently sentient (and sometimes even highly intelligent) robots abound, as we all know. Most of them cheat in one or other of three characteristic ways. The first form of cheating is to build the robot around something that is remarkably similar to a human (or humanoid) brain. Isaac Asimov lead the way here with his "positronic brain," which made the entire *I, Robot* series of novels work (and was copied somewhat by the recent film by that name). No one, of course, has any idea what a positronic brain is like or how to build one. Another way to cheat is to stick with the software (programming) and imagine a real artificial intelligence, regardless of the hardware that instantiates it. Think of VICKI in *I, Robot* (Mark, Davis, Dow, Godfrey, and Proyas, 2004), or Skynet in the *Terminator* films, or the little boy in *A. I. Artificial Intelligence* (Kennedy, Spielberg, Curtis, and Spielberg, 2001). A third common cheat (of similar ilk) is to suppose that consciousness itself is a kind of program that can be shifted from one hardware platform to another without loss of functionality, content or continuity of personal identity, even when embodied in a robot. *Chappie* (Kinberg and Blomkamp, 2015) is a splendid example of this. All of these strategies are cheats because we have, so far at least, not the least idea of how to accomplish these things (and the third is almost certainly impossible metaphysically). This is only to acknowledge that what the *Terminator* films imagine in terms of the abilities of the T-800 robot is vastly beyond our current capabilities. We cannot produce robots with anything approaching the sophistication of those cognitive abilities and action potentials. However, that said, the development of so-called "social robots" in the current period is instructive. I will suggest here that we have good reason to think that very rudimentary forms of the abilities of the T-800, and notably those abilities that would be engaged by its alloparenting of Sarah Connor, are already available in some advanced social robots. The whole subject deserves a more comprehensive (and more expert) treatment than I can perform here, but we can take at least some suggestive "soundings" in the robotic world. They will lead us to an interesting conclusion.

Actual parenting of human offspring could not occur as it does without a capacity in both child and caretakers for "joint attention," that is, the capacity of both to attend to the same things, events or circumstances at the same time. It is joint attention that enables us to construct a common "space" within which to carry out cooperative endeavors, social communication of all kinds, and so on (the whole issue is reviewed thoroughly in Seemann, 2011). Joint attention in the normal case depends on a capacity to track and coordinate eye gaze, an ability that includes following another's gaze to attain common perceptual experience, manipulating another's gaze to share an experience, and monitoring another's gaze to verify that joint attention has been reached and is being maintained. Recent experimental work shows that robots can carry out all three of these functions, thanks both to advances in software and hardware (Huang and Thomaz, 2011; Mehlmann, Janowski, Baur, Haering, Andre, and Gebhard, 2014; Mutlu, Kanda, Forlizzi, Hodgins, and Ishiguro, 2012; Skantze, Hjalmarsson, and Oertel, 2014). Joint attention between robot and human is, at it were, the *pons asinorum* of alloparenting. For without this there can be no collaboration between robotic agent and human agent, and alloparenting is a form of collaboration and not merely something that is done by one agent to the other.

In human–human interactions, gaze also helps insure various other features of cooperative action, including "presence," checking back on the status of the situation, paying attention (as above), attending to elements of the scene and so on. Use of gaze (including orienting movements of both eyes and head) by robots can also aid and support human attempts to carry out cooperative tasks. Using the social robot iCub, which is the size of a 3–4 year old child and has a body with 53 degrees of freedom of movement, experiments have shown that humans interacting with the robot are more effective in cooperative tasks than they would otherwise be (Boucher, Pattacini, Lelong, Bailly, Elisei, Fagel et al., 2012; and cf. Ernest–Jones, Nettle, and Bateson, 2011). The cooperative tasks in question are relatively simple, to be sure, but they afford the possibility of creating a social space shared between the human and robotic agents. This is a necessary (but not sufficient) condition for alloparenting.

Humans and robots can also deliberate together, where such deliberation includes engaging the robot in argumentation by citing evidence and investigating what went wrong (in a previous social interaction, e.g., adjudicating winners and losers in a social game). In one study of social human–robot interaction, as many as 68% of participants engaged in mutual deliberation with the robot (Kahn, Ruckert, Kanda, Ishiguro, Shen, and Gary, 2014). Here the shared social space is also a cognitive space, and such capacity brings us a significant step closer to sufficient conditions for alloparenting. Of course, mutual deliberation is not characteristic of parenting in its earliest stages, for no neonate is capable of deliberation. But even neonates are cognitive agents and thus a shared cognitive space in some form or other is also a necessary condition of alloparenting. (The whole issue rests on studies of human psycho-social development and is much too large to be explored here. For general treatments of the issue, with special emphasis on the emotional character of early shared cognitive spaces, see Cozolino, 2014; Hobson, 2004; Legerstee, Haley, and Bornstein, 2013; Narvaez, Panksepp, Schore, and Gleason, 2013; Schore, 1994; Tronick, 2007. Of special interest and value to philosophers is Reddy, 2008, for its resolute anti-Cartesianism.)

Robots have been designed and built to respond to the regulatory behavior of their human "caretakers," to which behavior the robot can adapt its own behavior as a function of the varying responsiveness of the caretaker. This can extend to exploratory behavior, learning, resolution of conflicts (as above), heightening of affiliation, and robotic equivalents of valence and arousal (Hiolle, Lewis, and Canamero, 2014; and cf. Baxter, Wood, Baroni, Kennedy, Nalin, and Belpaeme, 2013; for more on learning mechanisms in social robots see Jiang and Zhang, 2015; Morse, Benitez, Belpaeme, Cangelosi, and Smith, 2015). Alloparenting, of course, is a process of co-adaptation in which caregivers and child adapt their behavior to each other, and most notably to the regulatory behaviors of the other (it will not surprise any parents to learn that very young children are capable of regulating the behavior of their adult caretakers).

The "social facilitation effect" is one of the most secure findings in modern social psychology. It has two components: performance of an easy or well-learned cognitive task is facilitated by the presence of another human being as opposed to carrying it out in isolation; and performance of a complex or new cognitive task is impaired by the presence of another human being as compared with performance while being alone. Recent experiments with social robots found that the social facilitation effect was found in human–robot interactions just as it is in human–human interactions (Riether, Hegel, Wrede, and Horstmann, 2012; Stanton and Stevens, 2014). Such human–robot interactions show how profoundly the human agents assimilate their understanding of their robotic companions to norms of agency usually experienced only with other humans (see further Sciutti, Bisio, Nori, Metta, Fadiga, and Sandini, 2014). This is also a necessary but not sufficient condition for alloparenting, for without such a capacity it would not be possible for alloparent and child to be fully responsive to the presence (or absence) of the other. And alloparenting is, among much else, a certain form of social presence.

Even very young children (as young as two months old) can detect and respond to social contingencies (the dependence of one event or set of events on another event or set of events, including causal relationships) in adult–child interactions (Nadel, Carchon, Kervella, Marcelli, and Reserbat–Plantey, 1999). A recent study of 2–3 year old children interacting with social robots found that such contingency detection and appropriate responses to that detection occurred in these interactions also (Yamamoto, Tanaka, Kobayashi, Kozima, and Hashiya, 2009). Children readily attribute goals and social agency to robots, especially if the robots are emotionally responsive to them and if the robotic voices are clear and intelligible to the child. Attributing intentions and other mental states to robots is a form of anthropomorphizing, of course (see Gary, 2014; Kupferberg, Glasauer, and Burkart, 2013; Lakatos, Gasci, Konok, Bruder, Bereczky, Korondi et al., 2014; Urquiza–Haas and Kotrschal, 2015). An especially interesting example of this has to do with cheating. Using the NAO social robot developed by Aldebaran Robotics, a group of experimenters were able to model cheating behavior in the robot during play of a game of Battleship and to compare the response of human adults to robotic cheating to their response to human cheating in similar circumstances. Both humans and robots were rated less trustworthy in the dishonest condition than in the honest condition. No surprise there. The robot, however, was also rated more intelligent when cheating than when honest, while humans who cheated were rated as less intelligent than honest players. Both humans and robots were taken to be more intentional in their actions when cheating than when playing honestly, but robots were held to be less accountable for their cheating than were humans (Ullman, Leite, Phillips, Kim–Cohen, and Scassellati, 2014; cf. Litoiu, Ullman, Kim, and Scassellati, 2015). We are now in the realm of fairly sophisticated social interactions and the cognitions that normally accompany them. And thus we are closer to a sufficient condition for alloparenting by robotic agents.

Children not only readily attribute mental states to robots (i.e., anthropomorphize them), but also will readily exhibit care-taking behavior towards social robots, especially when they perceive that the robot is in trouble or has been frustrated or perhaps even harmed (Ioannou, Andreou, and Christofi, 2015). The situation is not always so positive: children also abuse robots, especially when no adult is looking, and it appears that they abuse robots for the same reasons they abuse other children (Nomura, Uratani, Matsumoto, Kanda, Kidokoro, Suehiro et al., 2015; cf. Brscic, Kidokoro, Suehiro, and Kanda, 2015 for ways robots can escape such abuse). The human children thus assimilated their robotic companions to even destructive social norms familiar to the humans from their ordinary social interactions with other children. The whole field of child–robot interaction is currently in great ferment, with a wide range of robotic platforms, programs, and types of interaction under intense scrutiny. Throughout these studies runs a connecting thread: children (like adults) readily take robots to be genuine agents and to attribute to them a wide range of intentional states. Without this, of course, robotic alloparenting would not be possible. But there is more, much more. For successful alloparenting also depends on emotion, emotional communication, and empathy — capacities which social robots are increasingly able to exercise.

The whole field of emotional detection, recognition, and expression in robots rests heavily (and very ironically) on the experience of Frank Thomas and Ollie Johnston who shared 60 years of work in the Walt Disney Animation Studios, experience they cast in their 1981 book *The Illusion of Life*. In this book they lay out Disney's Twelve Principles of Animation. Those principles aim to create a "believable character," described by another researcher who followed these principles as "not an honest or reliable character, but one that provides the illusion of life and thus permits the audience's suspension of disbelief" (Bates, 1994, p. 122). The illusion of life is accomplished by such things as emotionally expressive eyes with actuated pupils, use of exaggerated motions or movements and gestures to communicate emotion, exaggerated mouth parts and movements, and so on. (Certain kinds of exaggerated motion have also been found to significantly increase the fluency of robot–human collaboration, namely, movements that are "legible" in so far as they make clear what is the robot's intention: see Dragan and Srinivasa, 2013; Dragan, Bauman, Forlizzi, and Srinivasa, 2015.) The eyes and the mouth are the most emotionally expressive parts of the human face, and this can to some extent be replicated in robotic faces. The Disney animators' principles have been appropriated by many roboticists, who thus extend and continue the influence of Walt Disney and his studio throughout the world (Bates, 1994; Bennett and Sabanovic, 2013; Pavia, Leite, and Ribeiro, 2014). Robotocists have also used to good effect the work of so-called "method" actors, including Stanislavski's methods, to enhance the emotional expressivity of social robots (Greer, 2014). Cynthia Breazeal at the MIT Media Lab has, for decades, worked on the development of emotionally expressive robots. Her Kismet, for example, is a splendid example of the application of the Thomas and Johnston principles (see Brazeal's 2002 book as well as Breazeal, 2009 for extended discussions of the issues and illustrations of Kismet). Using Aldebaran's NAO humanoid robot, experimenters have been able to develop its capacities to communicate emotions through voice, posture, gestures, whole body poses, eye color, though not facial expressions as it has an immovable face.

With internal valence and arousal functions, an adaptive capacity (noted above), it is possible for NAO to develop genuine social bonds with children (tested at a mean age of nine years by Tielman, Neerincx, Meyer, and Looije, 2014). NAO can carry out elaborate conversations with children, can both give and take multiple-choice tests with children, can teach the children dance sequences, can teach a series of simple arm poses that the child partner memorizes and imitates, and has 60 communicative goals included in its programming (Kruijff–Korbayova, Cuayahuitl, Kiefer, Schroeder, Cosi, Paci et al., 2012). Children, generally, show a rich capacity to perceive and interpret the emotional body language of social robots (Beck, Canamero, Hiolle, Damiano, Cosi, Tesser, and Sommavilla, 2013). The KOBIAN social robot is capable of some 600 emotionally expressive faces and recognizes emotions in its users about as accurately and reliably as do humans (Trovato, Kishi, Endo, Hashimoto, and Takanishi, 2012). In a related development, Nilani Sarkar and his colleagues at Vanderbilt University have created robotic systems capable of detecting stress in human interlocutors (Rani, Sarkar, Smith, and Kirby, 2004; Rani, Sims, Brackin, and Sarkar, 2002). A team at the University of Washington and ATR of Kyoto, Japan has even successfully modeled four kinds of humor on Robovie, a social robot. They found that such expressions of humor (including corny jokes, dry humor, and self-deprecation) enhance sociality in human–robot interactions (Kahn, Ruckert, Kanda, Ishiguro, Gary, and Shen, 2014; for shared humor between human and robot see Jo, Han, Chung, and Lee, 2013). The T-800 in *Terminator Genisys* engages in just these kinds of humor. Alloparenting, like actual parenting, is very much a matter of emotional communication. Indeed it is more fundamentally emotional than it is focused on verbal content or rational processes. (Like many others I take it that emotions are a form of cognition [though not only so], and that any sharp dichotomy between cognitive and affective processes is misplaced. The literature is enormous, but notable contributions are: Clore, Gasper, and Garvin, 2001; Gratch and Reisenzein, 2009; Helm, 2001; Pessoa, 2013; Prinz, 2004; Roberts, 2003. Appraisal theories of emotions are especially attractive in this context and are reviewed in Ellsworth, 2013; Moors, Ellsworth, Scherer, and Frijda, 2013; Roseman, 2013; Scherer, 2005, 2009.) Only social bonds that include vital emotional connections and inter-responsivity have any chance of serving as a foundation for robotic alloparenting. But such is already on our horizon. (*Terminator Genisys* makes much of the emotional bond between the Guardian and Sarah Connor, and rightly so, given its emphasis on alloparenting.)

Touch is the earliest developing sensory platform in the human embryo, and touch remains a sensory modality that is critical for the healthy psycho-social development of mammals (not just humans) throughout their lifespans. It is similarly one of the earliest media of communication between any human infant and its caretakers, especially for affective communication. Touch serves to amplify affective communication by means of the face or voice. Touch can elicit emotions and also modulate them. It can influence people's attitudes towards other persons, places, or events. And it can modulate behavior arising from those attitudes (bonding, alliance formation, mentoring, and so on). Touch can also serve for humans as a substitute for grooming, with consequent benefits to the immune systems of both child and caretaker. Haptic communication is now readily available on robotic platforms, greatly aided by the development of artificial skin and appropriate underlying sensors (see especially Cooney, Nishio, and Ishiguro, 2014; Silvera–Tawil, Rye, and Velonaki, 2015; cf. Van Erp and Toet, 2015). This adds tremendously to robots' capacity for emotional communication and social bonding. Here, too, then, we have a robotic capacity that could facilitate alloparenting. But there is one more functionality of contemporary social robots to consider in this connection: empathy.

Empathy plays an enormous role in alloparenting, as it does in actual parenting, at least in humans (and almost certainly in some other animals as well, and very widely across the mammalian species). Its importance for successful psychosocial development cannot be exaggerated, in our case (for surveys see Coplan and Goldie, 2011; Decety, 2012; Decety and Ickes, 2009). Today there are no fully empathic robots available (Leite, 2015, notwithstanding). However, that said, there are robots with capacities that are foundational for empathy: emotional recognition and responsivity (using vision, speech, gesture, and physiological cues), emotional expression, regulatory capacities, capacity for learning and adaptation to a human's emotional moods or condition. Existing social robots can display forms of social interaction with humans that are foundational for empathy, especially by changing their behavior according to (and thus either in tune with or out of tune with) the affective state of their user. Robots can also imitate or mimic those states and their corresponding actions in their users. Robots can take the perspective of their user (in relatively limited ways and circumstances, as of yet).

There are no fully empathic robots, but they are not far off. It is fair to say that today we have proto-empathic robots (see Castellanos, Leite, Pereira, Martinho, Paiva, and McOwan, 2013; Leite, Castellanos, Pereira, Martinho, and Paiva, 2014; Leite, Pereira, Mascarenhas, Martinho, Prada, and Paiva, 2013; Rosenthal–van der Puetten, Schulte, Eimler, Sobieraj, Hoffmann, Maderwald et al., 2014). To suppose that such abilities will grow exponentially more sophisticated in coming years, enough to support genuine alloparenting, is entirely plausible. Moreover, we now have very good evidence that humans can and do respond empathically to robots. Thus, one recent investigation shows that human empathy is more readily induced for real robots than it is for merely computer-simulated robots (Seo, Geiskovitch, Nakane, King, and Young, 2015). This same team found a way, using standard psychological conceptions of empathy, to measure human empathic responses to robots. Humans are also liable to keep the secret of a robot, and keeping the secret of another agent is often motivated by a form of empathy, namely "perspective taking." We keep the secrets of others because we can imagine the impact on them of telling the secret. Such imagining makes use of our capacity for "theory of mind" and is close to the heart of empathy (see Kahn, Kanda, Ishiguro, Gill, Shen, Gary, and Ruckert, 2015 for keeping robots' secrets; Misch, Over, and Carpenter, 2016; Peskin and Ardino, 2003 for the underlying psychology). It is now also common to analyze and evaluate empirically our trust in robots (Hancock, Billings, Schaefer, Chen, de Visser, and Parasuraman, 2011; Salem, Lakatos, Amirabdollahian, and Dautenhahn, 2015). Such trust is certainly a form of psychological intimacy and arguably a function of empathy. So, human empathy is readily elicited towards robots and in response to robotic behavior. And robots can reliably exhibit at least an analogue of that same empathic responding. Such two-way or reciprocal empathic responding is foundational for alloparenting.

Study of so-called "motor resonance" between robots and humans probably belongs to this wider discussion of empathy. Some researchers have argued that such resonance depends on the operation of the mirror neuron system: e.g., Bisio, Sciutti, Nori, Metta, Fadiga, Sandini, and Pozzo, 2014; Gazzola, Rizzolati, Wicker, and Keysers, 2007; Oberman, McCleery, Ramachandran, and Pineda, 2007; Press, Bird, Flack, and Heyes, 2005; Sciutti, Bisio, Nori, Metta, Fadiga, Pozzo, and Sandini, 2012; Sciutti, Bisio, Nori, Metta, Fadiga, and Sandini, 2014.

Others soft-pedal the role of mirror neurons in such phenomena: e.g., Cross, Liepelt, Hamilton, Parkinson, Ramsey, and Stadler, 2012; De Lange, Spronk, Willems, Toni, and Bekkering, 2008. The entire subject needs further review in the light of more recent critiques of the common conception of mirror neurons and their functions (in e.g., Filimon, Rieth, Sereno, and Cottrell, 2014; Hickok, 2014; and Savaki, 2010). But now it is time to draw this section of the present essay to a close.

There are no robotic alloparents available to us . . . as of yet. But it is entirely plausible to suppose that robotic science in the not-distant future will produce an autonomous social robot capable of full alloparenting. Such an alloparenting robot is not likely to be the T-800, nor anything quite similar to it. Indeed, it is possible that alloparenting may not be the function of singleton robots at all, but rather the function of groups of deeply interacting and coordinated robots. Similar groups have already proven to have emergent capabilities for sensing and acting that are not available to their singleton members (Mathews, Christensen, O'Grady, and Dorigo, 2015). Alloparenting may prove to be an emergent capacity of networks of robots. Howsoever it may be instantiated, whether in one robotic agent or in a group of them, an alloparenting functionality seems likely to be available within the next few decades. We can already see the outline of that functionality emerging in current technology. The alloparenting hypothesis of the Terminator films, then, limns a trajectory that can be found in actual robotic technology today. This brings us, then, to some of the larger issues that arise in connection with the alloparenting hypothesis of *Terminator 2* and *Terminator Genisys*.

Consilience

So, our two films manage between them to conjecture that sophisticated autonomous social robots might engage in alloparenting. The current state of actual robotic technology suggests, as I have argued, that they are correct in this conjecture: it is likely that there will come a time when robots can serve as alloparents to human children (alternatively that a group of inter-connected robots might so serve . . . the robotic village it might take to raise a child). The conjecture is, of course, only tangential to the main thrust of the two films. Let us suppose that the films are correct. At least three substantial broader issues then arise almost immediately: one is ethical and two are epistemic.

The ethical issue is the obvious one: could it ever be morally correct or permissible to alloparent a human child by use of, or with the assistance of, robotic agents? We may suppose that such agents are, *ex hypothesi*, fully capable of carrying out their alloparenting responsibilities. We do not need to suppose that they are in any way deficient, or at least no more deficient in this regard than other human alloparents might be (bearing in mind that adult or older sibling alloparents might themselves suffer from one or more relevant defects). In alloparenting as well as parenting itself, good enough is good enough. Is there any good reason to suppose that having robots alloparent human children would be morally wrong? I do not think so. If the robots were fully capable of the necessary affective, empathic, cognitive, social, and physical tasks of alloparenting, and if human children were appropriately responsive to those alloparenting robots, there is not likely to be any harm done in allowing robotic agents to play a full role in the developmental support and acculturation of human offspring. It seems even permissible that a sufficiently capable robotic agent should replace biological parents entirely in the care of human offspring (as the Guardian does in *Terminator Genisys*).

That said, however, there are nonetheless some objections to be met. One is that we do not yet have any idea how it would appear to a human child to be parented by a robot. Alloparenting robots, more particularly, will lack some of the characteristics of humans that actually play important roles in their intereactions with human children. Notably, they lack guts, viscera, and thus interoception of visceral bodily states. And interoception of visceral bodily states is a very important part of affective/cognitive equipment of adult humans beings. Indeed, it is arguable that interoception is more fundamental to both self-perception and understanding, and also empathic connection with other human persons, than is exteroception. Indeed, it seems likely that in order for humans actually to have a self at all requires extensive integration of both interoception and exteroception, but that the first is phylogenetically and ontogenetically prior to the second (Craig, 2004; Critchley, Eccles, and Garfinkel, 2013; Critchley and Harrison, 2013; Garfinkel, Seth, Barrett, Suzuki, and Critchley, 2015; Murray, 2015; Ondobaka, Kilner, and Friston, in press; Seth, 2013; Suzuki, Garfinkel, Critchley, and Seth, 2013). It is possible, of course, especially in view of recent inventions of robotic programs representing internal states of valence and salience, that future developments in robotics will generate analogues of human interoception and its integration with exteroceptive sensory systems in such a fashion as to make full genuine empathic communication between robotic alloparents and human offspring reliable and effective. But we do not have a pathway there just yet. And we do not know whether the putative analogue of interoceptive cognition will be adequate to its alloparenting purpose. This is not yet, however, a good reason to reject the possibility of robotic alloparenting.

It may be objected that robotic alloparenting constitutes a form of social experimentation and that it should be outlawed just for that reason, since experimentation on the young is at least often morally objectionable. However, we do not have in mind here alloparenting by ineffective or socially impaired robots. Rather, we suppose that robotic parenting will be the function of robots with adequate "socio-emotional intelligence" (Vitale, Williams, and Johnston, 2014). Moreover, even biological parenting is a form of experimentation, especially when it is done for the first time. We do not routinely forbid human parents from engaging in such experiments merely because the outcome is uncertain or fraught with the possibility of grave harm to the young. *Ceteris paribus* and *mutatis mutandis*, then, we may argue that robotic alloparents of sufficiently sophisticated capability be allowed to function as assistants or surrogates in the care of human offspring.

In a recent study of ethical issues arising from the use of "carebots" in the homes of elderly persons, Sorrell and Draper (2014) have focused especially on the possibilities for enhanced autonomy for those who are able to benefit from the presence of such social robots in their homes. Enhanced autonomy overrides some other values in this ethical equation, in their view, as also in mine. Autonomy is one of the primary objectives of human psycho-social development, and thus of successful alloparenting. If social robots can be made capable of supporting and enhancing the autonomy of human offspring, they thus far help to fulfill an important moral objective of such caretaking. This point is worth dwelling on.

Whether considered as a condition of persons or as a property of persons, one very common way of thinking about autonomy is to think of it as self-government, including "properties such as authenticity, self-determination and self-possession . . . it means being an authentic person who makes his own choices and leads his life in accordance with his own goals and values" (Schermer, 2015, p. 207 cf. Bublitz and Markel, 2009). This definition is offered in the context of discussion of neuro-enhancements for human beings. In a related discussion of brain implants, Gilbert treats autonomy in terms of control: implants can supplement and enhance a patient's sense of control over his actions in the light of his intentions (Gilbert, 2015). Good alloparenting carried out by biological agents can be justified in so far as it contributes to enhanced autonomy by individuals so parented. We have already seen some evidence for this, in so far as alloparenting by biological agents is known to enhance the competence and autonomy of both alloparenting agents and their subjects.

It seems to me that promoting autonomy is the most important of the ethical principles commonly adduced in discussions of biomedical interventions, biomedical enhancements, and the like. And robotic alloparenting is a kind of enhancement. The other principles commonly invoked are the principle of beneficence (broadly, doing good for the subject of the intervention, contributing to the subject's flourishing), the principle of non-maleficence (refraining from doing harm or curtailing flourishing), the principle of distributive justice (insuring roughly equal access to needed resources), and the principle of respect for the integrity or dignity of the individual (the standard treatment is Beauchamp and Childress, 2012; and see discussions in Earp, Sandberg, Kahane, and Savulescu, 2014; Ebbesen, Andersen, and Besenbacher, 2006). Autonomy looms large here, in my view, because it gives point to the other principles and their application, i.e., it tells us something basic about why they matter to human flourishing. Thus, beneficence and non-malefiscence both matter in so far as they help to insure no loss or diminishment of autonomy. Distributive justice also acts to protect autonomy, as does respect for integrity or dignity. It could thus be argued that promoting autonomy is the most fundamental of these principles commonly used in defenses of biomedical interventions or enhancements. It is my contention that the likely consequences of robotic alloparenting that will matter to resolution of the ethical problem are to be sought along these lines. Robotic alloparenting, then, does not present an entirely new ethical issue, nor does its moral justification require new principles. If robotic alloparenting is capable of enhancing human flourishing and our capacity to live a good life, then it can be morally defensible. What, then, does the available relevant empirical evidence show?

Just here is the first of our epistemic problems. For available empirical tests relevant to robotic alloparenting, while suggestive and broadly positive with regard to the ethical principles mentioned above, tend to suffer from several deficiencies. Thus, sample sizes may be small, the research designs may be unclear, and randomized clinical trials are lacking (Mordoch, Osterreicher, Guse, Roger, and Thompson, 2013; cf. Ferrari, Coenen, and Grumwald, 2012). It must be acknowledged, then, that the available evidence is not definitive for answering the ethical problem. But it is nonetheless very suggestive.

Patients suffering from Parkinson's disease, for example, were as willing to discuss their health status with a robotic interviewer as they were with a human interviewer. These patients also judged that the robotic interviewer was as effective as the human in maintaining the dignity of the patients (Briggs, Scheutz, and Tickle–Degnen, 2015). Robotic touch, in another study, encouraged and enhanced human motivation to perform a variety of tasks (akin to the social facilitation effect discussed earlier: see Shiomi, Nakagawa, Shinozawa, Matsumura, Ishiguor, and Hagita, 2016). Elderly patients given access to a social robot were found to have substantial improvement of their hypertension (Robinson, MacDonald, and Broadbent, 2015). Roger, Guse, Mordoch, and Osterreicher (2012) found enough evidence for cognitive and behavioral improvement in dementia patients given sustained exposure to social robots to warrant continued study of the effect and extended application of the method. But perhaps the most indicative evidence concerns use of robots in various psychotherapeutic applications, especially with children suffering from autism.

Robot-enhanced psychotherapy with autistic children showed significantly positive effects in terms of improved cognitive, behavioral, and subjective outcomes (Costescu, Vanderborght, and David, 2014). In another study ASD children from age four to age 12 years interacted socially as effectively with a another human paired with a robot (robot–human dyad) as they did with another human paired with a third human (human–human dyad: see Kim, Berkovits, Bernier, Leyzberg, Shic, Paul, and Scassellati, 2013). Moreover, inception of positive response to robots in this therapeutic setting was much faster than in traditional therapy with only a human adult therapist. Autistic children commonly show deficits in their ability to achieve joint attention with others, and robots have also been shown to effectively enhance those skills in autistic children (Warren, Zheng, Swanson, Bekele, Zhang, Crittendon, Weitlauf, and Sarkar, 2013). Similarly, the capacity of autistic children to imitate the behavior of others can be significantly improved by means of autonomous robot interventions (Zheng, Das, Young, Swanson, Warren, and Sarkar, 2014; Zheng, Young, Swanson, Weitlauf, Warren, and Sarkar, 2015). These are remarkable achievements, the epistemic complaints notwithstanding. They bode well for the possibility that robotic alloparenting might also prove capable of supporting human flourishing. That being so, robotic alloparenting could be morally justified. And this brings us, then, to the second epistemic issue.

Once again, suppose our main hypothesis, as posited in *Terminator 2* and *Terminator Genisys*, is true: it is possible to have a well-adapted and fully functional human adult, like Sarah Connor, who is the developmental result of biological parenting aided and assisted very substantially (and solely from age six years onward) by robotic alloparenting. This accords with the findings of modern evolutionary biology, psychology, and neuroscience. It also accords with the emerging technology of modern robotics and cybernetics. It is this accord that concerns me. For here we have a convergence of two streams of human culture: the imaginative worlds of the film-makers (akin to narrative fiction of all kinds) and contemporary science. What makes such convergence possible? How shall we explain it? It might, of course, simply be an accident. But that seems wildly improbable. Moreover, thinking of this convergence as accidental doesn't really explain anything. The best alternative known to me is to consider the evolution of human culture itself under a very particular definition of what constitutes culture in the first place.

I will suppose here that culture is primarily a variety of forms of *information*. In what follows I draw heavily on the work of Grant Ramsey, but the view is now widespread (Acerbi, Tennie, and Nunn, 2011; Alvard, 2003; Call and Carpenter, 2002; De Block and Ramsey, 2016; Ehn and Laland, 2012; Flinn, 1997; Haidle, Bolus, Collard, Conard, Garofoli, Lombard et al., 2015; Ramsey, 2013; Tennie, Call, and Tomasello, 2009). Here is Ramsey's definition of culture in full:

> Culture is information transmitted between individuals or groups, where this information flows through and brings about the reproduction of, and a lasting change in, [a relevant] behavioral trait. (Ramsey, 2013, p. 466)

On this view of it, culture is, further, best understood as something that undergoes its own evolutionary development, depending on the relative "cultural fitness" of the information that constitutes it. Culture, as we know independently of these issues, is transmitted by a wide range of devices, including pedagogical devices such as social learning, mentoring, and the like. I shall suppose it is also best understood from the point of view of organisms, rather than "memes." That is, culture is among the properties of individuals who are thus undergoing a variety of selection mechanisms, among them those that affect the information those individuals are exposed to, may (or may not) adopt and make their own, and may (or may not) transmit to future generations. It is not surprising, then, that we meet culture in such a bewilderingly rich variety of streams or traditions. Traditions themselves arise from culture and are caused by it: "Culture is best seen as what engenders tradition. Traditions are patterns of behavior, similarities between individuals or groups over generational time, that are caused by culture" (Ramsey, 2013, p. 469). There are a myriad of such cultural patterns.

Information may, of course, be true or it may be false. It may be true now but not later or earlier, false now but not later or earlier. An evolutionarily sensitive epistemology will demand that true information should have a particularly high claim to cultural fitness, where cultural fitness has to do primarily with the tendency of such information to be represented in later time periods (Henrich, 2004; Ramsey and de Block, in press). This is not to suggest that the durable is also of necessity the true, but rather that cultural selection and evolution will have in it an essential dynamic that aims to preserve and extend true information and to extinguish false information. (It does not follow that we are somehow ourselves, as cultural agents and symbolic organisms, inevitably aimed towards ever greater and greater truth-gathering. For all we know, our evolutionary path is already headed for extinction, aided and abetted by our tendency to embrace what is finally false and misleading, often in the service of self-deception: see Trivers, 2011.)

What should surprise no one, on this view of culture, is that several major streams of culture might converge on the same truths. Literature and film both are imaginative productions of humans. Joseph Carroll has argued that "modern humans cannot choose not to live in and through their own imaginative structures" (2006, p. 41). Our imaginative and artistic constructions furnish us with emotionally charged and motivationally powerful guides to behavior, serving to orient us in our attitudes, emotional responses, values and beliefs, as also our purposes and our goals. "By entering an author's imaginative universe, readers participate vicariously in the author's realized act of motivational orientation" (Carroll, ibid.). We may readily extend a similar claim to films. And also to science, for science also is an imaginative construction of the world. That films and science might intersect, just as novels and science can intersect, is, I submit, built into their common cultural evolutionary dynamics. Indeed, for them to fail to converge at any point whatsoever would be truly astonishing. For then we would have no explanation for the universality of imaginative verbal constructs in human culture and history. We would also have no explanation for the ontogeny of imaginative narratives in young children, and we could not explain the myriad and diverse ways that "literature enters into the total motivational life of individuals, shaping and directing their belief systems and their behaviors" (Carroll, 2006, p. 44). It would likewise be difficult to account for the appearance of culture among non-human animals (for which see Coelho, Falotico, Izar, Mannu, Resende, Siqueira, and Ottoni, 2015; Gruber, Muller, Strimling, Wrangham, and Zuberbuehler, 2009; Gruber, Zuberbuehler, Clement, and Van Schaik, 2015; Laland and Galef, 2009; McCabe, Reader, and Nunn, 2015).

When it comes to robotics, it is increasingly more widely discussed that fictional treatments of robots and human–robot interactions can and frequently do enter into creative tension with emerging scientific and technological developments in robotics. If the view of human culture outlined above is plausible, this is to be expected. And finding what we expect to find is a certain kind of confirmation of the originating hypothesis (here that a pair of science fiction movies might hit upon an important new paradigm of alloparenting). Of course, there are plenty of ways in which fictional treatments of robots miss the mark in terms of what actual robots can and cannot do. But even such a mismatch can motivate improvements in human–robot interaction design that can overcome the mismatch (Sandoval, Mubin, and Obaid, 2014). Some investigators in robotics have analyzed scenes from science fiction films with a view to generating data bases to aid in advancing “human-centered design” of robots and to improve designs supporting human–robot interaction (Iio, Iizuka, and Matsubara, 2014; Kriz, Ferro, Damera, and Porter, 2010). Parallel use of science fiction films to suggest ways to improve human–computer interaction design have likewise been undertaken (Bates, Goldsmith, Berne, Summet, and Veilleux, 2012; Schmitz, Endres, and Butz, 2008). These studies find three broad results: (1) that models of human social behavior can be very fruitfully synthesized with robotic designs and that the future of those designs depends partly on further development of those models; (2) that study of our perception of robots as social agents can usefully inform how robot–human interactions work and how they can be made more fluent and efficient; and (3) that mass media presentations of robots can shape wider societal attitudes towards real robots as they take their place in society (see Bartneck, 2004; Bruckenberger, Weiss, Mirnig, Strasser, Stadler, and Tscheligi, 2013). One recent investigation of such creative exchange between fiction and real robotics concludes: “The design of humanoid robots is at times inspired by fictional robots; intentionally or unintentionally, scientists try to design robots and acquire as much knowledge and inspiration as possible from fiction in their experiments” (Sandoval, Mubin, and Obaid, 2014, p. 60). Daniel H. Wilson is both a widely published novelist (of robot fiction) and a highly trained robotics engineer. He recently argued at a robotics conference that the connection between science fiction and robotics is “integral,” and that this should not surprise us, for “ . . . every piece of science fiction is a simulation of the future” (Wilson, 2015, p. 11). My point here is that none of this is merely accidental or merely incidental. Rather, it is a function of the inherent dynamics of cultural evolution.

Even otherwise mediocre cultural products like *Terminator 2* and *Terminator Genisys* might, then, succeed in stumbling upon and developing an interesting set of truths about the bio-cultural phenomenon of alloparenting. And among these truths might be a simple prediction about how the technology will develop, a prediction that constitutes a genuinely new paradigm of that phenomenon: the emergence of a non-biological platform (autonomous social robots) capable of carrying out a biological function (alloparenting). We may expect such robotic alloparenting to include carrying of infants, protecting infants from predators and other environmental dangers, feeding infants, interacting socially with infants, assistance in emotional regulation, stress relief, and even medical care (compare recent advances in robotic surgery discussed in Shademan, Decker, Opfermann, Leonard, Krieger, and Kim, 2016). Just as natural selection often results in biological systems converging on similar solutions to reoccurring adaptive problems, and just as a given species might hit upon an effective solution to an adaptive problem more than once in its history, so also cultural traditions, as if they too were species or populations of individuals, might converge on similar contents that represent a common future, one predicted in the purely imaginative exercises of films and the other predicted by science. Humans are, after all, often at a sharp disadvantage when it comes to survival in the natural world: we cannot run very fast, we have no sharp claws or over-developed canine teeth, we have no bunchy fur to help protect vital organs from attack. But we do something superbly well: we use tools in a co-operative fashion to intelligently and efficiently solve practical problems (including remarkably efficient prosecution of warfare). We also preserve and transmit such knowledge across generations and across cultures (Morgan, Uomini, Rendell, Chouinard–Thuly, Street, Lewis et al., 2015; cf. Sterelny, 2012; Whiten and Erdal, 2012). That combination has caused us to rise to the top of the food chain. It may well turn out to be the case the social robots, working in an alloparental capacity, prove to be yet another valuable tool to promote the cultural and biological fitness of our species.

References

Acerbi, A., Tennie, C., and Nunn, C. (2011). Modeling imitation and emulation in constrained search spaces. *Learning and Behavior, 39,* 104–114.

Akther, S., Korshnova, N., Zhong, J., Liang, M., Cherepanov, S., Lopatina, O., et al. (2013). CD38 in the nucleus accumbens and oxytocin are related to paternal behavior in mice. *Molecular Brain, 6,* Article 41.

Alvard, M. (2003). The adaptive nature of culture. *Evolutionary Anthropology*, 12, 136–149.

Bartneck, C. (2004, April 25). *From fiction to science — a cultural reflection on social robotics.* Paper presented at the CHI2004 Workshop on Shaping Human–Robot Interaction. Vienna.

Bates, J. (1994). The role of emotion in believable agents. *Communications of the ACM, 37*, 122–125.

Bates, R., Goldsmith, J., Berne, R., Summet, V., and Veilleux, N. (2012). Science fiction in computer science education. *Proceedings of the 43rd ACM technical symposium on computer science education (*pp. 161–162*).* New York: Association for Computing Machinery.

Baxter, P., Wood, R., Baroni, I., Kennedy, J., Nalin, M., and Belpaeme, T. (2013). Emergence of turn-taking in unstructured child–robot social interaction. *Proceedings of the 8th ACM/IEEE International Conference on Human–Robot Interaction* (pp. 77–78). Piscataway, New Jersey: IEEE Press.

Beauchamp, T., and Childress, J. (2012). *Principles of biomedical ethics*. New York: Oxford University Press.

Beck, A., Canamero, L., Hiolle, A., Damiano, L., Cosi, P., Tesser F., and Sommavilla, G. (2013). Interpretation of emotional body language displayed by a humanoid robot: A case study with children. *International Journal of Social Robotics, 5*, 325–334.

Bennett, C., and Sabanovic, S. (2013, March 3–6). *Perception of affective expression in a minimalist robotic face*. Paper given at the International Conference on Human–Robot Interaction '13. Tokyo.
Bentley, G., and Mace, R. (Eds.). (2009). *Substitute parents: Biological and social perspectives on alloparenting in human societies.* New York: Berghahn Books.
Bisio, A., Sciutti, A., Nori, F., Metta, G., Fadiga, L., Sandini, G., and Pozzo, T. (2014). Motor contagion during human–human and human–robot interaction. *PLoS One, 9,* e106172.
Bogin, B., Bragg, J., and Kuzawa, C. (2014). Humans are not cooperative breeders but practice bio-cultural reproduction. *Annals of Human Biology, 41,* 368–380.
Boucher, J-D., Pattacini, U., Lelong, A., Bailly, G., Elisei, F., Fagel, S., et al. (2012). I reach faster when I see you look: Gaze effects in human–human and human–robot face-to-face cooperation. *Frontiers in Neurorobotics, 6,* Article 3.
Breazeal, C. (2002). *Designing sociable robots*. Cambridge, Massachusetts: MIT Press.
Breazeal, C. (2009). Role of expressive behavior for robots that learn from people. *Philosophical Transactions of the Royal Society B, 364,* 3527–3538.
Briga, M., Pen, I., and Wright, J. (2012). Care for kin: Within-group relatedness and allomaternal care are positively correlated and conserved throughout the mammalian phylogeny. *Biological Letters, 8*, 533–536.
Briggs, P., Scheutz, M., and Tickle–Degnen, L. (2015, March 2–5). *Are robots ready for administering health status surveys? First results from an HRI study with subjects with Parkinson's Disease.* Paper given at the International Conference on Human–Robot Interaction '15. Portland, Oregon.
Brscic, D., Kidokoro, H., Suehiro, Y., and Kanda, T. (2015, March 2–5). *Escaping from children's abuse of social robots*. Paper given at International Conference on Human–Robot Interaction '15. Portland, Oregon.
Bruckenberger, U. Weiss, A. Mirnig, N., Strasser, E., Stadler, S., and Tscheligi, M. (2013). The good, the bad, the weird: Audience evaluation of a real robot in relation to science fiction and mass media. In M. Beetz, B. Johnston, and M.-A. Williams (Eds.), *Social Robotics: Proceedings of the 6th International Conference on Social Robotics, ICSR 2014* (pp. 301–310). Heidelberg: Springer.
Bublitz, J., and Merkel, R. (2009). Autonomy and authenticity of enhanced personality traits. *Bioethics, 23,* 360–374.
Burkart, J. (2015). Opposite effects of male and female helpers on social tolerance and proactive prosociality in callitrichid family groups. *Scientific Reports, 5,* Article 9622.
Burkart, J., Hrdy, S., and Van Schaik, C. (2009). Cooperative breeding and human cognitive evolution. *Evolutionary Anthropology, 18,* 175–186.
Call, J., and Carpenter, M. (2002). Three sources of information in social learning. In C. Nehaniv and K. Dautenhahn (Eds.), *Imitation in animals and artifacts* (pp. 211–228). Cambridge, Massachusetts: MIT Press.
Cameron, J. (Producer and Director). (1991). *Terminator 2: Judgment Day* [Motion Picture]. USA: TriStar.
Campagnoli, R., Krutman, L., Vargas, C., Lobo, I., Oliveira, J., Oliveira, L., et al. (2015). Preparing to caress: A neural signature of social bonding. *Frontiers in Psychology, 6,* Article 16.
Cardenas, R., Harris, L., and Becker, M. (2013). Sex differences in visual attention toward infant faces. *Evolution and Human Behavior, 34,* 280–287.
Caria, A., de Falco, S., Venuti, P., Lee, S., Esposito, G., Rigo, P., et al. (2012). Species-specific response to human infant faces in the premotor cortex. *NeuroImage, 60,* 884–893.
Carroll, J. (2006). The human revolution and the adaptive function of literature. *Philosophy and Literature, 30,* 33–49.
Castellanos, G., Leite, I., Pereira, A., Martinho, C., Paiva, A., and McOwan, P. (2013). Multimodal affect modeling and recognition for empathic robot companions. *International Journal of Humanoid Robotics, 10,* Article 1350010.
Charney, D. (2004). Psychobiological mechanisms of resilience and vulnerability: Implications for successful adaptation to extreme stress. *American Journal of Psychiatry, 161,* 195–216.
Choe, J., and Crespi, B. (Eds.). (1997). *The evolution of social behavior in insects and arachnids.* Cambridge: Cambridge University Press.
Clore, G., Gasper, K., and Garvin, E. (2001). Affect as information. In J. Forgas (Ed.), *Handbook of affect and social cognition* (pp. 121–144). Mahwah, New Jersey: Erlbaum.

Coelho, C., Falotico, T., Izar, P., Mannu, M., Resende, B., Siqueira, J., and Ottoni, E. (2015). Social learning strategies for nut-cracking by tufted capuchin monkeys (*Sapajus* spp). *Animal Cognition, 18,* 911–919.

Cooney, M., Nishio, S., and Ishiguro, H. (2014). Affectionate interaction with a small humanoid robot capable of recognizing social touch behavior. *ACM Transactions on Interactive Intelligent Systems, 4,* Article 19.

Coplan, A., and Goldie, P. (Eds.). (2011). *Empathy: Philosophical and psychological perspectives.* New York: Oxford University Press.

Costescu, C., Vanderborght, B., and David, D. (2014). The effects of robot-enhanced psychotherapy: A meta-analysis. *Review of General Psychology, 18,* 127–136.

Cozolino, L. (2014). *The neuroscience of human relationships: Attachment and the developing social brain* (second edition). New York: W. W. Norton.

Craig, A. (2004). Human feelings: Why are some more aware than others? *Trends in Cognitive Sciences*, *8,* 239–241.

Crespi, B. (2014). The insectan ape. *Human Nature*, *25,* 6–27.

Critchley, H., Eccles, J., and Garfinkel, S. (2013). Interaction between cognition, emotion, and the autonomic nervous system. *Handbook of Clinical Neurology*, *117,* 59–77.

Critchley, H., and Harrison, N. (2013). Visceral influences on brain and behavior. *Neuron*, *77,* 624–638.

Cross, E., Liepelt, R., Hamilton, A., Parkinson, J., Ramsey, R., Stadler, W., and Prinz, W. (2012). Robotic movement preferentially engages the action observation network. *Human Brain Mapping, 33,* 2238–2254.

Curley, J., Mashoodh, R., and Champagne, F. (2011). Epigenetics and the origins of paternal effects. *Hormones and Behavior* , *59,* 306–314.

De Block, A., and Ramsey, G. (2016). The organism-centered approach to cultural evolution. *Topoi, 35,* 281–290.

De Lange, F., Spronk, M., Willems, R., Toni, I., and Bekkering, H. (2008). Complementary systems for understanding action intentions. *Current Biology, 18,* 454–457.

Decety, J. (Ed.) (2012). *Empathy: From bench to bedside*. Cambridge, Massachusetts: MIT Press.

Decety, J., and Ickes, W. (Eds.). (2009). *The social neuroscience of empathy.* Cambridge, Massachusetts: MIT Press.

DeSilva, J. (2011). A shift towards birthing relatively large infants early in human evolution. *Proceedings of the National Academy of Sciences, 108,* 1022–1027.

Dragan, A., and Srinivasa, S. (2013, March 3–6). *Legibility and predictability in robot motion.* Paper given at the International Conference on Human–Robot Interaction ’13. Tokyo.

Dragan, A., Bauman, S., Forlizzi, J., and Srinivasa, S. (2015, March 2–5). *Effects of robot motion on human–robot collaboration*. Paper given at the International Conference on Human–Robot Interaction ’15. Portland, Oregon.

Earp, B., Sandberg, A., Kahane, G., and Savulescu, J. (2014). When is diminishment a form of enhancement? Rethinking the enhancement debate in biomedical ethics. *Frontiers in Systems Neuroscience, 9,* Article 12.

Ebbesen, M., Andersen, S., and Besenbacher, F. (2006). Ethics in nanao-technology: Starting from scratch? *Bulletin of Science, Technology and Society, 26,* 451–462.

Ehn, M., and Laland, K. (2012). Adaptive strategies for cumulative cultural learning. *Journal of Theoretical Biology*, *301,* 103–111.

Ellison, D., and Goldberg, D. (Producers). Taylor, A. (Director). (2015). *Terminator Genisys* [Motion Picture]. USA: Paramount Pictures.

Ellsworth, P. (2013). Appraisal theory: Old and new questions. *Emotion Review, 5,* 125–131.

Ernest–Jones, M., Nettle, D., and Bateson, M. (2011). Effects of eye images on everyday cooperative behavior: A field experiment. *Evolution and Human Behavior*, *32,* 172–178.

Esposito, G., Nakazawa, J., Ogawa, S., Kawashima, A., Putnick, D., et al. (2014). Baby, you light-up my face: Culture-general physiological responses to infants and culture-specific cognitive judgments of adults. *PLoS One*, *9,* e106705.

Ferrari, A., Coenen, C., and Grunwald, A. (2012). Vision and ethics in current discourse on human enhancement. *Nanoethics, 6,* 215–229.

Filimon, F., Rieth, C., Sereno, M., and Cottrell, G. (2014). Observed, executed, and imagined action representations can be decoded from ventral and dorsal areas. *Cerebral Cortex, 25,* 3144–3158.

Flinn, M. (1997). Culture and the evolution of social learning. *Evolution and Human Behavior*, *18,* 23–67.
Fletcher, G., Simpson, J., Campbell, L., and Overall, N. (2015). Pair-bonding, romantic love and evolution: The curious case of *Homo sapiens*. *Perspectives on Psychological Science*, *10,* 20–36.
Garfinkel, S., Seth, A., Barrett, A., Suzuki, K., and Critchley, H. (2015). Knowing your own heart: Distinguishing interoceptive accuracy from interoceptive awareness. *Biological Psychology*, *104,* 65–74.
Gary, H. (2014). *Adults' attribution of psychological agency, credit, and fairness to a humanoid robot.* Unpublished doctoral dissertation, Psychology Department, University of Washington, Seattle, Washington.
Gazzola, V., Rizzolatti, G., Wicker, B., and Keysers, C. (2007). The anthropomorphic brain: The mirror neuron system responds to human and robotic actions. *NeuroImage, 35,* 1674–1684.
Geher, G. (2011). Evolutionarily informed parenting: A ripe area for scholarship in evolutionary studies. *EvoS Journal*, *3,* 26–36.
Gibson, M., and Mace, R. (2005). Helpful grandmothers in rural Ethiopia: A study of the effect of kin on child survival and growth. *Evolution and Human Behavior, 26,* 469–482.
Gilbert, F. (2015). A threat to autonomy? The intrusion of predictive brain implants. *AJOB Neuroscience, 6,* 4–11.
Ginther, A., and Snowdon, C. (2009). Expectant parents groom adult sons according to previous alloparenting in a biparental cooperatively breeding primate. *Animal Behaviour*, *78,* 287–297.
Gratch, J., and Reisenzein, R. (2009). Emotions as metarepresentative states of mind: Naturalizing the belief–desire theory of emotion. *Cognitive Systems Research, 10,* 6–20.
Greer, J. (2014, October 27–29). *Building emotional authenticity between humans and robots.* Workshop at the Sixth International Conference on Social Robotics: Social Intelligence. Sydney, Australia.
Gruber, T., Muller, M., Strimling, P., Wrangham, R., and Zuberbuehler, K. (2009). Wild chimpanzees rely on cultural knowledge to solve an experimental honey acquisition task. *Current Biology, 19,* 1806–1810.
Gruber, T., Zuberbuehler, K., Clement, F., and Van Schaik, C. (2015). Apes have culture but may not know that they do. *Frontiers in Psychology, 6,* Article 91.
Haidle, M., Bolus, M., Collard, M. Conard, N., Garofoli, D., Lombard, M., et al. (2015). The nature of culture: An eighth-grade model for the evolution and expansion of cultural capacities for hominins and other animals. *Journal of Anthropological Sciences*, *93,* 43–70.
Hancock, P., Billings, D., Schaefer, K., Chen, J., de Visser, E., and Parasuraman, R. (2011). A meta-analysis of factors affecting trust in human–robot interaction. *Human Factors, 53,* 517–527.
Helm, B. (2001). *Emotional reason: Deliberation, motivation, and the nature of value.* Cambridge: Cambridge University Press.
Henrich, J. (2004). Cultural group selection, co-evolutionary processes and large-scale cooperation. *Journal of Economic Behavior and Organization, 53,* 3–35.
Heyes, C. (1993). Imitation, culture and cognition. *Animal Behaviour*, *46,* 999–1010.
Hickok, G. (2014). *The myth of mirror neurons: The real neuroscience of communication and cognition.* New York: W. W. Norton.
Hiolle, A., Lewis, M., and Canamero, L. (2014). Arousal regulation and affective adaptation to human responsiveness by a robot that explores and learns a novel environment. *Frontiers in Neurorobotics*, *8,* Article 17.
Hobson, P. (2004). *The cradle of thought: Exploring the origins of thinking.* New York: Oxford University Press.
Hrdy, S. (2009a). *Mothers and others: The evolutionary origins of mutual understanding.* Cambridge, Massachusetts: The Belknap Press.
Hrdy, S. (2009b). Allomothers across species, across cultures, and through time. In G. Bentley and R. Mace (Eds.), *Substitute parents: Biological and social perspectives on alloparenting in human societies* (pp. xi–xviii). New York: Berghahn Books.
Huang, C-M., and Thomaz, A. (2011, July 31–August 3). *Effects of responding to, initiating, and ensuring joint attention in human–robot interaction.* Paper given at the 20th IEEE International Symposium on Robot and Human Interactive Communication. Atlanta, Georgia.
Iio, J., Iizuka, S., and Matsubara, H. (2014). The database on near-future technologies for user interface design from science fiction movies. In A. Marcus (Ed.), *Design, user experience and usability: Theories, methods and tools for designing the user experience* (pp. 572–579). Heidelberg: Springer.
Ioannou, A., Andreou, E., and Christofi, M. (2015). Preschoolers' interest and caring behavior around a humanoid robot. *Tech Trends, 59,* 23–26.
Jiang, M., and Zhang, L. (2015). Big data analytics as a service for affective humanoid service robots. *Procedia Computer Science, 53,* 141–148.

Jo, D., Han, J., Chung, K., and Lee, S. (2013, March 3-6). *Empathy between human and robot?* Paper given at the International Conference on Human–Robot Interaction '13. Tokyo, Japan.

Kahn, P., Kanda, T., Ishiguro, H., Gill, B., Shen, S., Gary, H., and Ruckert, J. (2015, March 2–5). *Will people keep the secret of a humanoid robot? — psychological intimacy in human–robot interaction.* Paper given at the International Conference on Human–Robot Interaction '15. Portland, Oregon.

Kahn, P., Ruckert, J., Kanda, T., Ishiguro, H., Shen, S., and Gary, H. (2014, March 3–6). *Will humans mutually deliberate with social robots?* Paper given at the International Conference on Human–Robot Interaction '14. Bielefeld, Germany.

Kahn, P., Ruckert, J., Kanda, T., Ishiguro, H., Gary, H., and Shen, S. (2014, March 3–6). *No joking aside: Using humor to establish sociality in human–robot interactions.* Paper given at the International Conference on Human–Robot Interaction '14. Bielefeld, Germany.

Kalisch, R., Mueller, M., and Tuescher, O. (2015). A conceptual framework for the neurobiological study of resilience. *Behavior and Brain Sciences, 38,* Article e91.

Kaplan, H. (1994). Evolutionary and wealth flows theories of fertility: Empirical tests and new models. *Population and Development Review, 20,* 753–791.

Keebaugh, A., and Young, L. (2011). Increasing oxytocin receptor expression in the nucleus accumbens of pre-pubertal female prairie voles enhances alloparental formation as adults. *Hormones and Behavior, 60,* 498–504.

Kennedy, K., Spielberg, S., and Curtis, B. (Producers). Spielberg, S. (Director). (2001). *A. I. Artificial Intelligence* [Motion Picture]. USA: Warner Brothers.

Kim, E., Berkovits, L., Bernier, E., Leyzberg, D., Shic, F., Paul, R., and Scassellati, B. (2013). Social robots as embedded reinforcers of social behavior in children with autism. *Journal of Autism and Developmental Disorders, 43,* 1038–1049.

Kinberg, S. (Producer). Blomkamp, N. (Director). (2015). *Chappie* [Motion Picture]. USA: Columbia Pictures.

Kringelbach, A., Lehtonen, A., Squire, S., Harvey, A., Craske, M., Holliday, I., et al. (2008). A specific and rapid neural signature for parental instinct. *PLoS One, 3*, e1664.

Kriz, S. Ferro, T., Damera, P., and Porter, J. (2010). Fictional robots as a data source in HRI research: Exploring the link between science fiction and interactional expectations. In *19th IEEE International Symposium on Robot and Human Interactive Communication,* pp. 458–463. New York: IEEE.

Kruijff–Korbayova, I., Cuayahuitl, H., Kiefer, B., Schroeder, M., Cosi, P., Paci, G., et al. (2012, September 14–15). *Spoken language processing in a conversational system for child–robot interaction.* Paper given at the Third Workshop on Child, Computer, and Interaction (WOCCI 2012). Portland, Oregon.

Kupferberg, A., Glasauer, S., and Burkart, J. (2013). Do robots have goals? How agent cues influence action understanding in non-human primates. *Behavioural Brain Research, 246,* 47–54.

Lakatos, G., Gasci, M., Konok, V., Bruder, I., Bereczky, B., Korondi, P., et al. (2014). Emotion attribution to a non-humanoid robot in different social situations. *PLoS One, 9,* e114207.

Laland, K., and Galef, B. (Eds.). (2009). *The question of animal culture*. Cambridge, Massachusetts: Harvard University Press.

Legerstee, M., Haley, D., and Bornstein, M. (Eds.). (2013). *The infant mind: Origins of the social brain.* New York: The Guilford Press.

Leite, I. (2015). Long-term interactions with empathic social robots. *AI Matters, 1,* 13–15.

Leite, I., Pereira, A., Mascarenhas, S., Martinho, C., Prada, R., and Paiva, A. (2013). The influence of empathy in human-robot relations. *International Journal of Human-Computer Studies, 71,* 250–260.

Leite, I., Castellano, G., Pereira, A., Martinho, C., and Paiva, A. (2014). Empathic robots for long-term interaction: Evaluating social presence, engagement and perceived support in children. *International Journal of Social Robotics, 6,* 329–341.

Litoiu, A., Ullman, D., Kim, J., and Scassellati, B. (2015, March 2–5). *Evidence that robots trigger a cheating detector in humans*. Paper given at the International Conference on Human–Robot Interaction '15. Portland, Oregon.

Liu, C., Conn, K., Sarkar, N., and Stone, W. (2007, August 26–29). *Online affect detection and adaptation in robot assisted rehabilitation for children with autism.* Paper given at the 16th IEEE International Conference on Robot and Human Interactive Communication. Jeju, Republic of Korea.

Mark, L., Davis, J. Dow, T., and Godfrey, W. (Producers). Proyas, A. (Director). (2004). *I, Robot* [Motion Picture]. USA: Twentieth Century Fox Film Corporation.

Masten, A. (2011). Resilience in children threatened by extreme adversity: Frameworks for research, practice, and translational synergy. *Development and Psychopathology, 23,* 493–506.
Mathews, N., Christensen, A., O'Grady, R., and Dorigo, M. (2015). Virtual nervous systems for self-assembling robots — a preliminary report. *arXiv preprint arXiv: 1505.07050*.
McCabe, C., Reader, S., and Nunn, C. (2015). Infectious disease, behavioural flexibility, and the evolution of culture in primates. *Proceedings of the Royal Society B, 282,* Article 20140862.
Mehlmann, G., Janowski, K., Baur, T., Haering, M., Andre, E., and Gebhard, P. (2014, August 18–22). *Modeling gaze mechanisms for grounding in human–robot interaction.* Paper given at the European Conference on Artificial Intelligence. Praque, Czech Republic.
Misch, A., Over, H., and Carpenter, M. (2016). I won't tell: Young children show loyalty to their group by keeping group secrets. Unpublished paper at www.eprints.whiterose.ac.uk/90403/1/Olo_final.pdf. Retrieved January 9, 2016.
Moors, A., Ellsworth, P., Scherer, K., and Frijda, N. (2013). Appraisal theories of emotion: State of the art and future developments. *Emotion Review, 5,* 119–124.
Mordoch, E., Osterreicher, A., Guse, L., Roger, K., and Thompson, G. (2013). Use of social commitment robots in the care of elderly people with dementia: A literature review. *Maturitas, 74*, 14–20.
Morgan, T., Uomini, N., Rendell, L., Chouinard–Thuly, L., Street, S., Lewis, H., et al. (2015). Experimental evidence for the co-evolution of hominin tool-making teaching and language. *Nature Communications, 6,* 6029. DOI: 10.1038/ncomms7029.
Morse, A., Benitez, V., Belpaeme, T., Cangelosi, A., Smith, L. (2015). Posture affects how robots and infants map words to objects. *PLoS One, 10,* e0116012.
Murray, R. (2015). Functional connectivity mapping of regions associated with self- and other-processing. *Human Brain Mapping, 36,* 1304–1324.
Mutlu, B., Kanda, T., Forlizzi, J., Hodgins, J., and Ishiguro, H. (2012). Conversational gaze mechanisms for human-like robots. *ACM Transactions on Interactive Intelligent Systems, 1,* Article 12.
Nadel, J., Carchon, I., Kervella, C., Marcelli, D., and Reserbat–Plantey, D. (1999). Expectancies for social contingency in 2-month-olds. *Developmental Science*, *2,* 164–173.
Narvaez, D., Panksepp, J., Schore, A., and Gleason, T. (Eds.). (2013). *Evolution, early experience and human development: From research to practice and policy.* New York: Oxford University Press.
Nomura, T., Uratani, T., Matsumoto, K., Kanda, T., Kidokoro, H., Suehiro, Y., et al. (2015, March 2–5). *Why do children abuse robots?* Paper given at the International Conference on Human–Robot Interaction '15. Portland, Oregon.
Oberman, L., McCleery, J., Ramachandran, V., and Pineda, J. (2007). EEG evidence for mirror neuron activity during the observation of human and robot action: Toward an analysis of the human qualities of interactive robots. *Neurocomputing, 70,* 2194–2203.
Oken, B., Chamine, I., and Wakeland, W. (2015). A systems approach to stress, stressors, and resilience in humans. *Behavior and Brain Research*, *282,* 144–154.
Ondobaka, S., Kilner, J., and Friston, K. (in press). The role of interoceptive inference in theory of mind. *Brain and Cognition*. Published online 12 August, 2015. DOI: 10.1016/j.bandc.2015.08.002.
Parsons, C., Young, K., Parsons, E., Stein, A., and Kringelbach, M. (2012). Listening to infant distress vocalizations enhances effortful motor performance. *Acta Paediatrica, 101,* e189.
Pavia, A., Leite, I., and Ribeiro, T. (2014). Emotion modeling for social robots. In R. Calvo, S. D'Mello, J. Gratch, and A. Kappas (Eds.), *The Oxford handbook of affective computing* (pp. 296–308). New York: Oxford University Press.
Perkeybile, A., Delaney–Busch, N., Hartman, S., Grimm, K., and Bales, K. (2015). Intergenerational transmission of alloparenting behavior and oxytocin and vasopressin receptor distribution in the prairie vole. *Frontiers in Behavioral Neuroscience, 9,* Article 191.
Peskin, J., and Ardino, V. (2003). Representing the mental world in children's social behavior: Playing hide-and-seek and keeping a secret. *Social Development, 12,* 496–512.
Pessoa, L. (2013). *The cognitive–emotional brain: From interactions to integration.* Cambridge, Massachusetts: MIT Press.
Piantadosi, S., and Kidd, C. (2016). Extraordinary intelligence and the care of infants. *Proceedings of the National Academy of Sciences*. Published online May 23.
Press, C., Bird, G., Flack, R., and Heyes, C. (2005). Robotic movement elicits automatic imitation. *Cognitive Brain Research, 25,* 632–640.

Prinz, J. (2004). *Gut reactions: A perceptual theory of emotion*. New York: Oxford University Press.
Ramsey, G. (2013). Culture in humans and animals. *Biology and Philosophy, 28,* 457–479.
Ramsey, G., and de Block, A. (in press). Is cultural fitness hopelessly confused? *British Journal for the Philosophy of Science*. Published online October 21, 2015. DOI: 10.1093/bjps/axv047.
Rani, P., Sarkar, N., Smith, C., and Kirby, L. (2004). Anxiety detecting robotic system — towards implicit human–robot collaboration. *Robotica, 22*, 85–95.
Rani, P., Sims, J., Brackin, R., and Sarkar, N. (2002). Online stress detection using psycho-physiological signals for implicit human–robot cooperation. *Robotica, 20,* 673–685.
Reddy, V. (2008). *How infants know minds.* Cambridge: Harvard University Press.
Riether, N., Hegel, F., Wrede, B., and Horstmann, G. (2012, March 5–8). *Social facilitation with social robots?* Paper given at the International Conference on Human–Robot Interaction '12. Boston.
Roberts, R. (2003). *Emotions: An essay in aid of moral psychology*. New York: Cambridge University Press.
Robinson, H., MacDonald, B., and Broadbent, E. (2015). Physiological effects of a companion robot on blood pressure of older people in residential care facility: A pilot study. *Australasian Journal of Ageing, 34,* 27–32.
Roger, K., Guse, L, Mordoch, E., and Osterreicher, E. (2012). Social commitment robots and dementia. *Canadian Journal of Aging, 31,* 87–94.
Roseman, I. (2013). Appraisal in the emotion system: Coherence in strategies for coping. *Emotion Review, 5,* 141–149.
Rosenthal–van der Puetten, A., Schulte, F., Eimler, S., Sobieraj, S., Hoffmann, L., Maderwald, S., et al. (2014). Investigations on empathy towards humans and robots using fMRI. *Computers in Human Behavior, 33,* 201–212.
Salem, M., Lakatos, G., Amirabdollahian, F., and Dautenhahn, K. (2015, March 2–5). *Would you trust a (faulty) robot? Effects of error, task type and personality on human–robot cooperation and trust.* Paper given at the International Conference on Human–Robot Interaction '15. Portland, Oregon.
Samuk, K., and Aviles, L. (2013). Indiscriminate care of offspring predates the evolution of sociality in alloparenting social spiders. *Behavior, Ecology and Sociobiology, 67,* 1275–1284.
Sandoval, E., Mubin, O., and Obaid, M. (2014). Human–robot interaction and fiction: A contradiction. In M. Beetz, B. Johnston, M.-A. Williams (Eds.), *Social Robotics: Proceedings of the 6th International Conference on Social Robotics, ICSR 2014* (pp. 54–63). Heidelberg: Springer.
Savaki, H. (2010). How do we understand the actions of others? By mental simulation, NOT mirroring. *Cognitive Critique, 2,* 99–140.
Scherer, K. (2005). What are emotions? And how can they be measured? *Social Science Information, 44,* 695–729.
Scherer, K. (2009). Emotions are emergent processes: They require a dynamic computational architecture. *Philosophical Transactions of the Royal Society, Series B*, *364,* 3459–3474.
Schermer, M. (2015). Reducing, restoring, or enhancing autonomy with neuromodulation techniques. In W. Glannon (Ed.), *Free will and the brain: Neuroscientific, philosophical, and legal perspectives on free will* (pp. 205–228). Cambridge: Cambridge University Press.
Schmitz, M., Endres, C., and Butz, A. (2008). A survey of human–computer interaction design in science fiction movies. In *Proceedings of the 2nd International Conference on Intelligent Technologies for Interactive Entertainment* (Article 7). Brussels: Institute for Computer Sciences, Social Informatics, and Telecommunications Engineering.
Schore, A. (1994). *Affect regulation and the origin of the self.* Hillsdale, New Jersey: Lawrence Erlbaum Associates.
Sciutti, A., Bisio, A., Nori, F., Metta, G., Fabiga, L., Pozzo, T., and Sandini, G. (2012). Measuring human–robot interaction through motor resonance. *International Journal of Social Robotics, 4,* 223–234.
Sciutti, A., Bisio, A., Nori, F., Metta, G., Fadiga, L., and Sandini, G. (2014). Robots can be perceived as goal-directed agents. *Interaction Studies, 14,* 329–350.
Sear, R., and Mace, R. (2008). Who keeps children alive? A review of the effects of kin on child survival. *Evolution and Human Behavior, 29,* 1–18.
Seemann, A. (Ed.). (2011). *Joint attention: New developments in psychology, philosophy of mind, and social neuroscience*. Cambridge, Massachusetts: MIT Press.
Seo, S., Geiskovitch, D., Nakane, M., King, C., and Young, J. (2015, March 2–5). *Poor thing! Would you feel sorry for a simulated robot? A comparison of empathy toward a physical and a simulated robot.* Paper given at the International Conference on Human–Robot Interaction'15. Portland, Oregon.

Seth, A. (2013). Interoceptive inference, emotion, and the embodied self. *Trends in Cognitive Sciences, 17,* 565–573.

Shademan, A., Decker, R., Opfermann, J., Leonard, S., Krieger, A., and Kim, P. (2016). Supervised autonomous robotic soft tissue surgery. *Science Translational Medicine, 8,* 337ra64–337ra64.

Shiomi, M., Nakagawa, K., Shinozawa, K., Matsumura, R., Ishiguro, H., and Hagita, N. (2016). Does a robot's touch encourage human effort? *International Journal of Social Robotics.* Published online January 14.

Silvera–Tawil, D., Rye, D., and Velonaki, M. (2015). Artificial skin and tactile sensing for socially interactive robots: A review. *Robotics and Autnomous Systems, 63,* 230–243.

Skantze, G., Hjalmarsson, A., and Oertel, C. (2014). Turn-taking, feedback, and joint attention in situated human–robot interaction. *Speech Communication, 65,* 50–66.

Snowdon, C., and Ziegler, T. (2007). Growing up cooperatively: Family processes and infant care in marmosets and tamarins. *Journal of Developmental Process, 2,* 40–66.

Snowdon, C., and Ziegler, T. (2015). Variation in prolactin is related to variation in sexual behavior and contact affiliation. *PLoS One, 10,* e0120650.

Sorrell, T., and Draper, H. (2014). Robot carers, ethics, and older people. *Ethics and Information Technology, 16,* 183–195.

Stanton, C., and Stevens, C. (2014). Robot pressure: The impact of robot eye gaze and lifelike bodily movements upon decision-making and trust. In M. Beetz, B. Johnston, and M.-A. Williams (Eds.), *Social Robotics: Proceedings of the 6th International Conference on Social Robotics (ICSR 2014),* pp. 330–339. Heidelberg: Springer.

Sterelny, K. (2012). *The evolved apprentice: How evolution makes humans unique.* Cambridge, Massachusetts: MIT Press.

Suzuki, K., Garfinkel, S., Critchley, H., and Seth, A. (2013). Multisensory integration across exteroceptive and interoceptive domains modulates self-experience in the rubber-hand delusion. *Neuropsychologia, 51*, 2909–2917.

Tennie, C., Call, J., and Tomasello, M. (2009). Ratcheting up the ratchet: On the evolution of cumulative culture. *Philosophical Transactions of the Royal Society B, 364,* 2405–2415.

Thomas, F., and Johnson, O. (1981). *The illusion of life: Disney animation*. New York: Disney Editions.

Tielman, M., Neerincx, M., Meyer, J.-J., and Looije, R. (2014, March 3–6). *Adaptive emotional expression in robot–child interaction*. Paper given at the International Conference on Human–Robot Interaction '14. Bielefeld, Germany.

Trivers, R. (2011). *The folly of fools: The logic of deceit and self-deception in human life.* New York: Basic Books.

Tronick, E. (2007). *The neurobehavioral and social–emotional development of infants and children.* New York: W. W. Norton.

Trovato, G., Kishi, T., Endo, N., Hashimoto, K., and Takanishi, A. (2012, November 29–December 1). *Development of facial expressions generator for emotion expressive humanoic robot.* Paper given at the 12th IEEE-RAS International Conference on Humanoid Robotics. Osaka, Japan.

Ullman, D., Leite, I., Phillips, J., Kim–Cohen, J., and Scassellati, B. (2014, July 23–26). *Smart human, smarter robot: How cheating affects perceptions of social agency.* Paper given at the 36th Annual conference of the Cognitive Science Society (CogSci 2014). Quebec City, Canada.

Ungar, M. (2005). Pathways to resilience among children in child welfare, corrections, mental health and educational settings: Navigation and negotiation. *Child and Youth Care Forum, 34,* 423–444.

Ungar, M. (2011). The social ecology of resilience: Addressing contextual and cultural ambiguity of a nascent construct. *American Journal of Orthopsychiatry, 81,* 1–17.

Urquiza–Haas, E., and Kotrschal, K. (2015). The mind behind anthropomorphic thinking: Attribution of mental states to other species. *Animal Behaviour, 109,* 167–176.

Van Erp, J., and Toet, A. (2015). Social touch in human–computer interaction. *Frontiers in Digital Humanities, 2,* Article 2.

Vitale, J., Williams, M.-A., and Johnston, B. (2014, October 27–29). *Socially impaired robots: Human social disorders and robots' socio-emotional intelligence.* Paper given at the 6th International Conference on Social Robotics, ICSR 2014. Sydney, Australia.

Warren, Z., Zheng, Z., Das, S., Young, E., Swanson, A., Weitlauf, A., and Sarkar, N. (2015). Brief report: Development of a robotic intervention platform for young children with ASD. *Journal of Autism and Developmental Disorders, 45,* 3870–3876.

Warren, Z., Zheng, Z., Swanson, A., Bekele, E., Zhang, L., Crittendon, J., Weitlauf, A., and Sarkar, N. (2013). Can robotic interaction improve joint attention skills? *Journal of Autism and Developmental Disorders, 45*, 3726–3734.

Weisner, T. (1987). Socialization for parenthood in sibling caretaking societies. In J. Lancaster, J. Altmann, A. Rossi, and L. Sherrod (Eds.), *Parenting across the lifespan: Biosocial dimensions* (pp. 237–270). New York: de Gruyter.

Whiten, A., and Erdal, D. (2012). The human socio-cognitive niche and its evolutionary origins. *Philosophical Transactions of the Royal Society B, 367,* 2119–2129.

Wilson, D. (2015, March 2–5). *Chasing our science fiction future*. Paper given at the International Conference on Human–Robot Interaction '15. Portland, Oregon.

Yamamoto, K., Tanaka, S., Kobayashi, H.,Kozima, H., and Hashiya, K. (2009). A non-humanoid robot in the "uncanny valley": Experimental analysis of the reaction to behavioral contingency in 2–3 years old children. *PLoS One, 4,* e6974.

Young, K., Parsons, C. Elmholdt, E., Woolrich, M., Van Hartevelt, T., Stevner, A., et al. (2016). Evidence for a caregiving instinct: Rapid differentiation of infant from adult vocalizations using magneto-encephalography. *Cerebral Cortex, 26,* 1309–1321.

Zheng, Z., Das, S., Young, E., Swanson, A., Warren, Z., and Sarkar, N. (2014, May 31–June 7). *Autonomous robot-mediated imitation learning for children with autism.* Paper given at the IEEE Conference on Robotics and Automation (ICRA). Hong Kong.

Zheng, Z., Young, E., Swanson, A., Weitlauf, A., Warren, Z., and Sarkar, N. (2015, July 27–31). *Robot-mediated mixed gesture imitation skill training for young children with ASD.* Paper given at the International Conference on Advanced Robotics (ICAR). Istanbul, Turkey.