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The Application and Extension of the Human-Animal Team Model to Better Understand Human-Robot Interaction: Recommendations for Further Research

Katelynn A. Kapalo, Elizabeth Phillips, and Stephen M. Fiore
University of Central Florida, Orlando, FL

In order to create effective human-robot teams, robots must possess social capabilities that match the expectations of their human teammates. However the ability of robots to approximate human capacities is limited due to technological constraints. Human-animal teams have thus been suggested as a suitable analog for modeling teaming between humans and non-humans. Due to the limited capacity for animals to express their intentions, it follows that human-animal relationships can provide a basic framework for understanding how humans interpret information from teammates with limited social faculties. The purpose of this paper is provide research recommendations to identify specific areas in which human-animal teams can be used to model human-robot teams and to provide suggestions for investigating this model empirically in the context of social interaction.

INTRODUCTION

Successful human-human teams utilize strategies such as proactive, efficient communication and coordinated behaviors to complete dangerous or difficult missions (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995; Fiore, Ross, & Jentsch, 2012; MacMillan, Entin, & Serfaty, 2004). Although much is known about how to support and train this in human teams, the introduction of semi-autonomous technology into the team context provides a real challenge for cognitive engineering. Specifically, because technology has not yet reached a point where robots are fully autonomous teammates or unfailingly reliable, human team members still need to control and guide the robot to varying degrees. This is problematic in that the use of robots in high-stakes environments has gained increasing interest in the last decade. Furthermore, in highly dynamic environments involving imminent risk, coordination and adaptability between the humans and robots is essential (Murphy, 2004). As such, in the near term, there is a need to look at options for facilitating teaming between humans and robots in a variety of socially situated contexts when robots do not have full autonomy or are not capable of human emulation.

In this paper we suggest that research on *human-animal teams* can provide a framework for understanding how to optimize teaming relationships between humans and other agents that do not possess human-equivalent capabilities (Phillips, Ososky, Grove, & Jentsch, 2011). Current research in this area identified key characteristics of human-animal relationships that can be modeled in human-robot teams (Billings et al., 2012; Phillips, Schaefer, Billings, Jentsch, & Hancock, 2016). Some of these characteristics include broad categories such as communication and training, while other areas have been identified as more specific, such as task interdependence (Phillips et al., 2016). We add to this and suggest that similar importance should be placed upon understanding mental states when investigating human-animal teaming relationships. In human-human interactions, it is essential for humans to have an understanding of the mental states of others to communicate mission needs and predict their teammates' future actions or behaviors. As such, it is foundational to effective communication and coordinating task interdependencies.

In human-animal teaming, mental state attributions are just as important. As an example, this is necessary in teams operating in dangerous environments, such as human-dolphin mine detection teams, where there exists a high degree of dependency upon the animal teammate. Here there is a continual need for the human handler to rely on the dolphin to receive updates on the surrounding environment regarding location, navigation, and threat detection (Phillips et al., 2012). Due to the limited and varying capacity for different types of animals to express their intentions, and the technological constraints currently driving robotics research, it follows that human-animal relationships can provide insight as to how humans interpret information from teammates with limited capacities, such as animals (Phillips, Ososky, Swigert, & Jentsch, 2012). In addition, the model of human-animal teams addresses a core issue related to human perception of robotic teammates. If we perceive animals as teammates instead of tools that merely extend our perceptual or physical capabilities, how might we model/engender similar perceptions towards robots? In short, because the human-team model represents the normative structure for collaboration, there is a need for research that extends this to develop strategies for human-robot teams working in complex environments where coordination is paramount.

Addressing this requires a richer understanding of how humans make mental state attributions about animals. The aim of this paper is to redress this gap and inform future research on human-animal and human-robot teams by creating a better understanding of mental state attribution. This requires that the human must have a sufficient understanding of how the animal is able to carry out tasks and how to infer information based on the cues available directly through interaction (cf. Gallagher, 2008). Specifically, we are interested in examining how the human-animal model can be leveraged to inform future research in HRI. First, we turn to a brief discussion of HRI research as it relates to social cognition. Second we discuss several constructs of interest for understanding mental state attribution: social presence, intentionality, agency, implicit communication, proxemics, and trust. Finally, we outline specific applications and recommendations for future research using this perspective to drive research in HRI.

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SOCIAL COGNITION IN HUMAN-ROBOT TEAMS

The overarching question is whether the human-human team model is appropriate for human-robot teaming. Ultimately, the success of this generalization depends on whether or not humans accept a robot as a teammate; that is, the degree to which a human accepts that a robot can help to meet team goals. In the near-term, research on human-animal teaming can help understand how humans coordinate with animals in service of task accomplishment. Further, research needs to examine, not just the behavioral coordination requirements traditionally studied in teams, but also the social dynamics emerging in human-non-human teams, and extrapolate this to human-robot teaming. In this section we briefly review some of the social cognitive factors we suggest are foundational to team interaction.

Decades of research on groups documents that humans must possess the ability to make correct judgments about intention and agency in order to function effectively with other social agents. Likewise, in human-animal teams, humans must be able to interpret the actions and infer the intentions of the animal through observable phenomena. From this we can discern that robots must display, at minimum, cues that humans can interpret in order to predict and explain a robot's behaviors, underlying intentions, and goals (Fiore et al., 2013). If a robot is unpredictable, then a human will be unable to project into the future what the robot will do given specific features of the environment, task, and/or situation. But appropriate display of social cues is only half of the equation. Similarly if the social cues are robot provides are not easily understood, then humans observing the robot will be unable to discern its intention(s) or underlying goal(s) (Dragan, Lee, & Srinivasa, 2013; Talone, Phillips, Ososky, & Jentsch, 2015). Thus, it is important to understand how humans interpret the actions and behaviors *of* robots, especially those intended to function as teammates.

In the existing HRI literature, the extent to which humans view robots as social agents is unclear. Some have shown that basic social cues such as gaze, motion, and proximity, were interpreted and described by participants as though the robot exhibited emotion and personality (Saulnier, Sharlin, & Greenberg, 2011). Similarly, research varying social cues, such as the form of the gaze, or the degree of proximity robots will allow, shows that this alters the attributions humans will make about a robot following interaction (Fiore et al., 2013; Wilshire et al., 2015). Such research illustrates the importance of understanding how social cues influence attributions of agency and intention in the context of social interaction. If a goal is to make robotic teammates that easily integrate into teams with humans, it will be important to better understand how social cues can be leveraged within the team to help humans better understand their robot counterparts. We suggest that human-animal teams serve as a useful starting point for studying how such cues are leveraged by humans to complete tasks with other non-human entities or agents.

Social Presence in Teams

In the course of social interactions, humans are able to easily attribute mental states to other agents. While the actual mechanism through which this occurs is widely debated, one theory relying heavily on what we refer to as social cues, is the theory of *direct perception* or *interaction theory* (Gallager, 2008; Gallagher & Varga, 2013). This theory has been integrated with other theories in social cognition, to provide an explanatory mechanism for how it is that humans use behavioral cues to infer mental states (Wiltshire et al., 2014). The foundational concept is social affordances and has to do with the inherent meaning arising from interacting bodies in a social context; that is, the cues observed, and the signals (mental states) they are meant to convey.

We focus on mental state attributions elicited by social cues. These are of particular interest because they represent a category of information available to humans in most social interactions (e.g., posture, facial expression, prosody). But we suggest that they are also foundational to human-animal interactions. Further, they are part of the burgeoning field of artificial social intelligence in HRI. Specifically, robots can exhibit observable behaviors that act as cues enabling team members to build awareness regarding team member intentions, referred to as social signals (Lobato, Wiltshire, Warta, & Fiore, 2015; Wiltshire, Snow, Lobato, & Fiore, 2014; Wiltshire et al., 2015). In short, we suggest that cues exhibited by both animals and robots can contribute to the experience of *social presence;* that is, humans recognize they are interacting with another entity that demonstrates dynamic mental states (Fiore et al., 2013; Harms & Biocca, 2004; Wilshire et al., 2015). With this as a foundation, we offer the first research recommendation:

Recommendation 1: *Research on human-animal teams must examine the extent to which humans attribute social presence to the animal.*

Intentionality and Agency

We turn now to a discussion of intentionality and agency as they related to human-animal teaming. Our goal is to provide a more holistic understanding of the parallels between human-animal interaction and human-robot interaction. Towards this end, we examine existing constructs within the context of the human-animal teaming model to illustrate how this human-animal team framework could be instantiated into empirical studies to optimize HRI through the lens of human-animal social interaction. The foundation for this is the "media equation hypothesis" (Nass & Reeves, 1991). This was devised to better inform the way we conceptualized human-computer interaction by outlining reasons why humans tend to anthropomorphize inanimate objects such as computers, cars, etc. This tendency creates fundamental problems because computers and robots challenge the existing norms present in human-human social interaction.

In studying intentionality in the context of human-human interaction, Wiese, Wykowska, Zwickel, and Müller (2012) demonstrated that humans create a schema to predict behavior based on emotional and social cues. In the context of human-animal interaction, Billings et al. (2012) suggested that, in certain scenarios, an animal's instinctive behavior may override trained behaviors. This illustrates the challenges for humans ascribing intentionality to animals. In particular, humans need to anticipate that animals possess natural survival instincts. Therefore, the animal's goal will ultimately be to fulfill its own needs at the expense of the task it is working to accomplish. Considering this in the context of human-robot teaming, for robots, the need to "survive" will likely be less important since anything like survival instincts will be pre-programmed, likely known to the human, and, more importantly, put the human first (Billings et al., 2012). Others have tried to address the importance of classifying intentionality within a broad enough realm as to not exclude robots as social agents. Here some suggest that robots just need to display "deliberate and calculated behaviors" at minimum, to exhibit intentionality (Sullins, 2006, p. 28).

From the above, we suggest a gap exists related to intentionality and understanding human-animal interactions. As a starting point for redressing this gap, some have pointed to task interdependencies in human-animal teaming as a means for inferring intentionality. Specifically, the degree of intentionality and agency may be interpreted indirectly from the influence of factors such as task interdependence (Phillips et al., 2012). For example, a human-canary team fulfills a different mission capability than a human-canine team and each have associated with them varying levels of interdependencies. To the degree there is any bi-directionality in these, it might be possible to glean intentionality. With this as stepping off point, we offer the following recommendation:

Recommendation 2: *Research on human-animal teams as an analog to human-robot teams must determine the degree to which handlers assign intentionality to the animal, as well as how intentionality is assigned to animals more broadly.*

With the above, we are better able to draw parallels between HRI and the human-animal team model. With this, future research can examine the degree to which humans attribute intentions to an animal, and whether this maps to existing literature on the perceived social presence of robots interacting with humans. Fundamentally, a human's perception of an animal and the degree to which the human perceives the animal as a social agent will influence the degree to which the human can make predictions about that animal's future behaviors. This line of research can then be used to provide a baseline comparison for identifying parallels in the HRI domain.

Implicit Communication

For human teams, communication is essential to coordinating joint activity (Breazeal, Kidd, Thomaz, Hoffman, & Berlin, 2005; Salas, Sims, & Burke, 2005). We limit our discussion to factors associated with implicit communication; more specifically, observable behaviors that may elicit both explicit and implicit responses from humans. In keeping with the human-animal model as an analog to HRI, we address the language limitations that are present in human-animal interaction. Because there are several types of human-animal teams, our goal is to provide a more general idea as to how these types of cues can be leveraged, regardless of the animal type.

Expression of action and social cues. Critical to the human-animal team model is a need to understand and infer the actions of the animal. In order to do so, humans rely on cues from the animal, which may include implicit communication (e.g., eye gaze, proximity) or explicit communication (e.g., commands). For the purposes of this paper, the expression of action will be confined to social cues. Social cues affect the way humans make mental state attributions based on intentions and emotions inferred from observable behavior (Olsson & Ochsner, 2008; Wiltshire et al., 2015). Because the presence of these social cues is a defining characteristic of a social interaction, these cues can provide researchers a method for understanding how humans make mental state attributions about other agents (Fiore et al., 2013; Wiltshire et al., 2015).

Human handlers need to gather information about what kinds of cues are important for understanding animal behaviors. Recent research shows that human-animal teams rely on gaze cues in ways similar to human-human teams. Specifically, dogs tend to follow similar visual scanning and gaze patterns as humans (Törnqvist et al., 2015). This finding constitutes a prime area for understanding intention through gaze patterns. Specifically, it suggests that research needs to examine the varying degrees to which humans and their animal partners draw from gaze patterns for making judgments of intentionality. Further, research should determine which cues are most salient to humans when making mental state attributions about their animal partners. With this as foundation, we offer the following research recommendations:

Recommendation 3: *Research on human-animal teams must examine the degree to which humans use social cues from the animal to understand the animal's intentions.*

Recommendation 4: *Research on human-animal teams must determine what cues are most salient to the human handler.*

These recommendations are focused on understanding aspects of non-verbal communication. Due to the limitations of language use in human-animal teams, parallels could be drawn between the human-animal model and HRI. Others have noted that alternative, non-verbal communications provide a potential avenue for investigating bi-directional communication between humans and robots (Bockelman-Morrow & Fiore, 2012). Signaling and non-verbal commands commonly used in human-animal teams demonstrate the utility of such communication without any reliance on explicit language driven approaches (Lackey, Barber, Reinerman, Badler, & Hudson, 2011; Phillips et al., 2016). For instance, in some contexts (such as military operations), simplistic forms of communication (e.g., gestures, verbal commands) like those employed in human-animal teams, can be beneficial in supporting teaming that can generalize to a variety of missions, especially those in which team members need to communication quickly, over long distances, or in instances of stealth operations.

Proxemics and Temporal Dynamics

Proxemics and temporal dynamics are considered a class of social cues that aid in understanding not only signals, but also cues that may arise organically from hierarchical relationships. Social cues like proxemics (i.e., space and distance requirements of humans and animals) and temporal dynamics (i.e., synchronization), often arise implicitly in human-human or human-animal interaction. These types of cues can be leveraged to understand the intention of the animal, or more specifically, how the human interprets these cues and makes predictions about the animal's future behavior. For example, a dog sniffing in a certain direction away from the human provides a clue that the dog is investigating scents, and potentially threats or targets, in that direction. The human can then assume that the dog has detected something of potential interest. This is particularly important in the context of high-risk situations where humans need to be continually updated regarding animal status and how its behavior will map to completion of a task.

Given this, research needs to inform our understanding if temporal patterns or interaction dynamics evolve while humans and animals are working together to complete a task or mission. The movement pattern of an animal falls within the classification of a temporal or proxemics cue. For this reason, if we are to continue using the human-animal team model as a method for examining HRI, we must investigate how humans interpret these cues and use them in the context of mental state attribution. With this in mind, we offer the following recommendation:

Recommendation 5: *Research on human-animal teams must examine the role of temporal dynamics and proxemics in teams to determine if we can map these factors to human-robot interaction.*

Once we have gained understanding of the proxemic and temporal dynamics of a human-animal team interaction, we can leverage this knowledge to determine whether or not the model provides support for extending these ideas to the HRI domain, particularly with regard to understanding how proxemic effects relate to the other constructs outlined in this paper, including trust.

Trust

While all of these factors contribute to a more holistic understanding of social presence in human-animal teams, it is important to recognize that these factors also contribute to our understanding of human-animal trust. Trust in future human-robot teams will be important, as trust helps to determine how users will rely on an automated system (Lee & See, 2004), as well as the degree to which a human will accept contributions from those systems. Without trust, humans may fail to take advantage of the benefits that a robotic system may provide in human-robot teams (e.g., processing of sensory data, decision-making alternatives, and suggestions for alternative courses of action). If we determine the extent to which trust prevails in human-animal relationships, we can then examine perceptions of trust in relation to human-robot teams.

For instance, models of human-animal interaction may provide a means to foster an accurate understanding of robotic capabilities and limitations. Several researchers have found that people often hold ill-formed or overly presumptuous understanding of robots, which is easily influenced by superficial features of the robot like communication style (Torrey, Fussell, & Keisler, 2013), origin (Lee, Kiesler, Lau, & Chiu, 2005), and form (e.g., the presence of anthropomorphic or biologically inspired limbs, the presence of extraneous hardware; Kiesler & Goetz, 2002; Sims et al., 2005). In addition, this understanding does not often align with real-world capabilities or limitations of current robotic technologies (Hancock, Billings, & Schaefer, 2011). This is a problem because prior research on human interaction with automated systems has shown that, when expectations are unmatched by reality, humans are likely to distrust or discontinue using the automated system (Parasuraman, & Riley, 1997). Models of human-animal interaction may help to build appropriately calibrated trust in robotic systems in which operators have clear expectations regarding what their robotic teammates can do, and are likely to do given environmental and task demands.

In addition, existing human-animal teams may be a means for us to study how trust is built among teams of humans and non-humans. While we acknowledge that extensive training in human-animal working teams may be the most logical explanation for how trust is engendered and maintained within the team, it is also possible that there are situations in which trust in the animal, and human-animal team are fostered quickly, and/or with little prior experience. Therapy animals working in hospitals, nursing homes, or other medical settings are good examples, and may provide useful information concerning how trust is fostered and maintained in interactions between animals and their handlers, as well as between animals and other humans in the environment. With this notion as a foundation, we offer the following research recommendation:

Recommendation 6: *Research on human-animal teams should examine how trust is developed and maintained within the human-animal team, and also between the team and other people operating near or around the team. Research could address whether there are other ways to develop and maintain trust aside from extensive training.*

If we can understand the degree to which humans use predictions of the animal's future behavior to determine their level of trust in their animal partner, then we can potentially extend this line of thinking to robots. Additionally, if there is another aspect of the human-animal relationship that builds trust without considering extensive training, this would be advantageous to consider in the context of HRI. Increasing trust without extensive training would not only reduce costs, but it would remove the need for dedicated robot handlers and allow multiple members of human-robot teams to interact quickly and efficiently with their robot teammates.

CONCLUSION

Human-animal teams operate in environments of varying complexity and uncertainty. For this reason, the human handler must make decisions based on the intentions of their animal partner. In order to understand the degree to which the human-animal team model is an effective analog for human-robot teams, it is essential to investigate the extent to which humans perceive animals as social agents. Our goal with this paper was to provide specific guidance on how to investigate the utility of the human-animal team model by studying how humans make mental state attributions about animals. The research recommendations included throughout should serve as a foundation to advance our understanding of human-animal teams as an analog to human-robot teams through experimentation. Our hope is that this effort contributes to a more holistic understanding of the complexity of social interactions between humans and non-human teammates.

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