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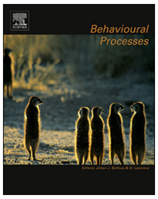

Distributed cognition criteria: Defined, operationalized, and applied to human-dog systems

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ABSTRACT

Distributed cognition generally refers to situations in which task requirements are shared among multiple agents or, potentially, off-loaded onto the environment. With few exceptions, socially distributed cognition has largely been discussed in terms of intraspecific interactions. This conception fails to capture some forms of group-level cognition among human and non-human animals that are not readily measured or explained in mentalistic or verbal terms. In response to these limitations, we argue for a more stringent set of empirically-verifiable criteria for assessing whether a system is an instance of distributed cognition: interaction-dominant dynamics, agency, and shared task orientation. We apply this framework to humans and working dogs, and contrast the human-dog socially distributed cognitive system with humans using non-biological tools and human interaction with draft animals. The human-dog system illustrates three operationalizable factors for classifying phenomena as socially distributed cognition and extends the framework to interspecies distributed cognition.

1. Introduction

“We are alone, absolutely alone on this chance planet; and amid all the forms of life that surround us, not one, excepting the dog has made an alliance with us.” Maeterlinck (1913)

Domesticated dogs (*Canis lupus familiaris*) provide humans with many of the social and physiological benefits of companionship, including the potential for increased levels of activity (Cutt et al., 2008) and oxytocin (Nagasawa et al., 2015), and lowered blood pressure (Vormbrock and Grossberg, 1988). However, the human-dog relationship extends beyond an emotional bond, such that some activities involve continuous interaction during shared tasks. Humans are assisted by working dogs, often engaging in tasks that their human counterpart is alone incapable of. Search and rescue, cadaver search, drug and bomb detection, and service for disabled people are common examples of humans and dogs coordinating their actions in order to complete a shared task (Koster, 2008; McConnell and Baylis, 1985; Miklósi et al., 2002; Naderi et al., 2001; Ostojić and Clayton, 2014; Ruusila and Pesonen, 2004). In many of these tasks, rather than the human delivering an order and the dog merely carrying out the command, the pair exhibits a highly interactionist relationship that facilitates task completion.

The human-dog system is unlike many other interspecies cooperative tasks in that the human and working dog exhibit properties of a socially distributed cognitive system (Keil, 2015), such that the collaboration between human and non-human animal results in a system-level behavior that is more than the sum of their individual contributions. This interaction is supported by a constellation of social and cognitive traits that dogs have in relation to humans due to their coevolution and convergent evolution, one that is not seen in humans’ interaction with other canid species (e.g., Gácsi et al., 2005; Neemeh et al., 2018).

In the next section we define concepts that serve as the foundation for understanding the human-dog system as a socially distributed cognitive system. We then define three necessary and jointly sufficient criteria that qualify an interaction as a socially distributed cognitive system: interaction-dominant dynamics, agency, and shared task orientation. Next, we demonstrate some of the key differences between human-dog systems and human-plus-non-biological-tools (e.g., blind person using a cane) and human interactions with draft animals (i.e., animals used to pull carts or plows). In doing so, we discuss how to operationalize criteria for distributed cognition and describe both qualitative and empirical evidence for defining humans and dogs as distributed cognitive systems. We conclude by exploring potential consequences of the proposed distributed cognition criteria, as well as implications of considering interspecies distributed cognitive systems.

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2. Distributed cognition

The definition of "cognition" has changed a great deal during the history of psychology (Favela and Martin, 2017). Nevertheless, there are phenomena and features commonly associated with the term in the contemporary cognitive, neural, and psychological sciences. Typical examples of cognitive phenomena range from decision-making, language, learning, and memory, to action and perception, as well as dreaming and emotion (Newell, 1992). It is also widely accepted that cognition is *computational* in that it follows regular procedures (e.g., input-output processes, syntactical structures, etc.), and it is *representational* in that computations manipulate symbols of varying sorts (e.g., concepts, images, rules, etc.) to produce action and thought (Pylyshyn, 1984; Thagard, 2005). These processes are typically assumed to be localized in the central nervous system (Baars and Gage, 2010). With all that said, the mind sciences are increasingly investigating non-brain-centric forms of cognition, such as distributed cognition.

Distributed cognition refers to situations in which task requirements are shared among multiple agents or, potentially, off-loaded onto the environment (Hutchins, 1995a). Although distributed cognition is still typically understood as being computational and representational in nature, the unit of analysis is not individual brains or nervous systems. Instead, the unit of analysis includes social and environmental distributed dynamics, which coordinate via material, organizational, and situational constraints (Theiner and O'Connor, 2010). Accordingly, a distributed cognitive system may include multiple agents, features of the environment, and their interactions.

Research into distributed cognition tends to focus on tasks carried out by two or more people with technological instruments working together to complete a task. Hutchins (1995b) forwarded the example of a plane landing where pilot and co-pilots work together to track the relationship between airspeed and wing configuration, which requires the coordination of multiple people and instruments to carry out a complicated cognitive task. During descent, pilot and co-pilot must consistently match wing configuration to the corresponding minimum maneuvering speed based on airplane gross weight. Extending flaps and slats at faster speeds can lead to excessive air loads on these parts, while waiting too long to extend could stall the plane and lead to a dangerous loss of altitude. This is an interactive process, as pilots may collaborate in preparing the landing data, including selecting the appropriate speed card and placing it where it can be referenced by both pilots. The pilot-not-flying may track and report the altitude, airspeed, and descent rate to the pilot-flying. The pilot-flying may call for a configuration change while the pilot-not-flying selects the flap setting and moves the flap handle, allowing the pilot-flying to maintain control of the yoke and throttles during flap extension (Hutchins, 1995b).

Understood as a distributed cognitive system, the cognitive abilities of the pilot-co-pilot-plane system are not confined to a single brain but occur among multiple agents and their environment. Through these interactions the distributed cognitive system is able to overcome the limitations of individual cognitive capacities, such as limits on computational/information-processing, which can affect the ability to safely attend to and control multiple aspects of the navigational task (Giere and Moffatt, 2003). The distribution of cognitive processes across individuals occurs among a variety of tasks and can happen intentionally or unintentionally. For example, human couples can unintentionally engage in "shared remembering" where they merge their memory systems, such that each individual remembers different information that is relevant to both parties and can oftentimes only be elicited in the presence of their partner (Harris et al., 2014; Margrett et al., 2011).

Distributed cognition occurs in a variety of everyday (e.g., shared decision-making, memory, and problem solving) and specialized tasks (e.g., automobile automation, dance, gaming, management, manufacturing, medical decision-making, navigation, software design, team sports, and search and rescue; Banks and Stanton, 2017; Heavey and Simsek, 2014; Kuhn, 2017; Lippa et al., 2016; Williamson and Cox, 2014). However, not all group-level activities are instances of "distributed cognition." Theiner and O'Connor (2010) discuss a variety of group activities that are not typically considered distributed cognition. One example is the kind of "group rationality" explored by economists. Here, the directed actions of individuals making self-interested, rational choices can lead to undirected collective effects, such as major changes in the market that do not seem to be the result of self-interested, rational choices. In other words, the group-level effects are largely an unintended artifact of the intended effects of the individuals and are to be distinguished from instances of distributed cognition.

The defining properties of distributed cognitive systems have been discussed in a number of works, starting with Hutchins' (1995a,b) conceptualization of distributed cognition as a set of shared representations that span agents and environment. From this definition, distributed cognition is described in terms of material media in which mental representations are "embodied" (e.g., text or maps) and the physical activities that propagate representations to multiple agents (Hutchins, 1995b). While Hutchins' work remains foundational, this framework led to largely qualitative accounts of distributed cognition that describe shared representations in the environment and relevant actions performed based on these representations. Others have expanded on Hutchins' work by attempting to bolster the notion of distributed cognition with concepts such as emergence and scaffolding, while some have treated Hutchins' work as a point of departure in order to develop similar theories such as distributed situational awareness.

Distributed cognition can be appealed to as a way to explain how other agents and tools accomplish tasks via interactions where the activity of the system is not reducible to the mere summation of its constitutive parts. In this way, distributed cognitive systems are understood as more than the sum of their parts, or, *emergent* (Theiner and O'Connor, 2010). One way to understand distributed cognitive systems as emergent is by highlighting the nature of the interactions of their constitutive components. Some forms of emergence arise via reciprocal causation between components, where the interactions give rise to new behaviors that contribute to the system's overall functioning (Favela, 2019; Poirier and Chicoisne, 2006; Sutton, 2006). Examples of this kind of emergence are found in research on human temporal estimation tasks (Amon et al., 2018). Increased entrainment to temporal signals was demonstrated over a range of temporal scales when distributed across dyads than by individuals alone. In other words, performance was improved when the task was distributed across an emergent system that arose via reciprocal coordination. Thus, emergence helps account for system-level properties in distributed cognitive systems that do not seem to be reducible to components alone.

Scaffolding is another concept that has been identified as a key feature of distributed cognition and is a process through which resources external to an individual are used to support cognition and overcome individual limitations (Clark, 1997; Sutton et al., 2010). Scaffolding has been fruitful in expanding human-centric formulations of distributed cognition to include interspecies distributed cognitive systems. For example, in the case of sheep herding, the human and dog co-contribute toward a task solution, where the limitations of the dog to herd sheep in a designated direction are supplemented by their human companion, who acts as an "external meta-cognitive and executive function for the dog" (Keil, 2015, p. 513). The human, or scaffolder, manages aspects of the task that are beyond the dog's capacity and may assist the dog perceptually, cognitively, or affectively (Keil, 2015; Stone, 1998).

Whereas concepts such as emergence and scaffolding help bolster early conceptions of distributed cognition, others have expanded more on Hutchins' approach by proposing an interrelated theory of distributed situation awareness (DSA; Stanton et al., 2009, 2006). Similar to distributed cognition, DSA focuses on shared representations or knowledge structures in memory (i.e., schemas) as a basis for distributed tasks (Plant and Stanton, 2017). DSA theory provides a number of additional tenets that qualify a group task as distributed, including agents that are loosely coupled via situation awareness and emergent behavior as a result of compensatory behavior between agents, criteria which have been the basis for a number of empirical studies examining distributed tasks (Stanton, 2015). Thus, DSA merges criteria forwarded by Hutchins with concepts such as emergence, while also expanding on this approach with an emphasis on situation awareness.

While others have provided conceptually and philosophically-based reasons for treating a particular system as an instance of distributed cognition, the literature varies in the criteria it uses to identify a task as "distributed" (e.g., emergence, scaffolding, schemas, shared representations, etc.). Without operationalizable criteria it is difficult to answer fundamental questions about distributed cognition, such as the conditions under which it arises and when it offers advantages in terms of task performance. As Vaesen, 2011 states, "The widespread adoption of the term distributed cognition (well beyond scientific circles) comes with the risk that it is used so loosely that it tends to mean little at all" (2011, p. 381). Furthermore, the emphasis on language, shared representations in the environment, and schemas restricts the distributed cognition paradigm to a limited range of human interactions. These criteria, along with emphases on "views" or "goals" (Stanton, 2015), fail to capture some forms of group-level cognition among human and non-human animals that are not easily measured or explained in mentalistic terms. In response to these limitations, we argue for a more stringent set of empirically-verifiable criteria for assessing whether a system is an instance of distributed cognition. Moreover, such a criteria can help to differentiate phenomena that can mistakenly be labeled as "distributed cognition," such as group minds, hive minds, and superorganisms (Neemeh and Favela, 2017). We build upon previous distributed cognition literature by proposing three criteria that are each necessary and jointly sufficient for the occurrence of a socially distributed cognitive system: interaction-dominant dynamics, agency, and shared task orientation.

3. Operationalizing criteria for distributed cognition

Here we explicate our three criteria for distributed cognition: interaction-dominant dynamics, agency, and shared task orientation. Central to our criteria is their ability to be operationalized so as to facilitate experimental work on distributed cognition. What sets such work apart from previous research is that, taken together, they also provide a means for quantitative assessment of the phenomena. This sets our criteria apart from most previous approaches that are primarily conceptual and qualitative in nature. We begin with interaction-dominant dynamics.

As noted by Kirsh (2006), coordination is the glue that holds a distributed cognitive system together, is observed at all levels of analysis, and gives rise to group-level patterns of behavior. Kirsh called for a better understanding of principles of coordination that give rise to distributed cognitive systems, and researchers answered this call by evoking the concept of emergence (Keil, 2015; Stanton et al., 2006; Salmon et al., 2009; Theiner and O'Connor, 2010). While useful in describing features of distributed tasks (i.e., interactions that are not aggregative; Poirier and Chicoisne, 2006), emergence is not an experimentally or quantifiably precise concept (Favela, 2019).

We expand on this literature by forwarding a type of emergence, called interaction dominance (Favela, 2019), as a core feature of socially distributed cognitive systems. This type of emergence is a quantifiable feature of systems, such that systems can be classed as relatively component dominant or interaction dominant (Holden et al., 2009). In component-dominant systems, the overall behavior of the system results from individual components that relate in additive and linear ways—i.e., the whole is the sum of its parts (Holden et al., 2009). In contrast, systems are *interaction dominant* when the dynamics of the interactions among the parts supersede the dynamics that the parts exhibit separately. Such interactions are exponential and nonlinear. Local interactions between components can give rise to ordered behavior that is not exhibited by the components individually. Accordingly, the system exhibits both global-to-local and local-to-global effects. In other words, interaction-dominant systems display components being affected by the whole system and the whole system is affected by the components. In that way, the whole system is different or more than the sum of its parts. In terms of task completion, a component-dominant system performs an action via a set of capacities and dynamics that are localizable to the individual components. For example, assembling a car is achieved via a component-dominant system because each part of the assembly line (be it a human or robot) is locally constrained, namely, the other parts of the assembly line do not alter its abilities and dynamics. Conversely, an interaction-dominant system performs an action via a set of capacities and dynamics that are not localizable to the components (Amon, 2016; Amon et al., 2018). For example, locust swarms are interaction-dominant systems in that the system-level structure and behavior (i.e., the swarm) is not localized to individual locusts, but instead requires understanding the reciprocal relationship of swarm-to-locust and locust-to-swarm (Favela, 2019). Accordingly, a central feature of distributed cognitive systems as interaction-dominant systems is the continued coordination of agents that influences each other's actions during a shared task orientation (Amon, 2016; cf. Favela and Chemero, 2016).

Experimental work by Szary et al. (2015) provides a simple demonstration of interaction dominance during a shared task. Individuals and dyads engaged in a semantic fluency task where they were asked to name aloud as many words in a category as they could. Dyads reliably outperformed individual participants in number of words provided, though they performed worse than a nominal grouping of individuals, likely due to collaborative inhibition effects. In addition, the time course of the dyadic interaction demonstrated statistical patterns that are characteristic of interaction-dominant dynamics, namely, lognormal and Pareto distributions. Generally speaking, the distributions of temporal dynamics demonstrated that feedback within dyads constrained the pattern of word naming. Dyads performed significantly better than individuals while also perturbing one another's performance throughout the interaction. Fractal analysis is another common method for quantifying the distributional properties of task performance and identifying interaction dominance (e.g., Amon, 2016; Holden, 2005; Ihlen and Vereijken, 2010; Van Orden et al., 2005). In this way, assessing for interaction-dominant dynamics via methods such as fractal analyses allows for the operationalization and quantification of the extent to which agents constrain and influence one another's actions as they participate in a task. In regard to our current purposes, for the human-dog system to count as a distributed cognition system, it would have to demonstrate tightly integrated coordination during task completion as evidenced by interaction-dominant dynamics. Displaying interaction-dominant dynamics alone is not sufficient for socially distributed cognition. Each member of the system must exhibit agency as well.

The second criteria that we claim is necessary for a human-dog system to be a socially distributed cognitive system is the extent of agency had by each member. Of the three criteria, agency is the most challenging to define and operationalize. On one end of the spectrum, the term has been defined so broadly as to allow for bacteria and plants to have agency. Such conceptions allow for agency so long as an organism makes some sort of modification to its environment for functional purposes, such as feeding or fleeing (e.g., Arnellos and Moreno, 2015). On the other end of the spectrum, the term has been defined so narrowly as to equate agency with a morality that only human persons have (e.g., Cohen, 1997). We do not intend to offer a complete and universal definition of "agency." Our aim is to explain what characteristics of agency are required to be displayed for parts of a system to exhibit in order for socially distributed cognition to manifest. As such, we present a description of agency along the lines of those set by Barandiaran et al. (2009) and Kelso (2016).

In the sense most central to our current purposes, "agency" refers to two characteristics: individuality and goal-directed action. First, an agent must be distinguishable from other agents and its environment (Barandiaran et al., 2009). This is a definitional claim with an ontological consequence. It is definitional in that, by definition, socially distributed cognitive systems are composed of multiple distinct agents. The ontological consequence is that the agent qua individual system is in significant ways spatio-temporally distinct. Here we rely on intuitions concerning what is significantly spatio-temporally distinct. An uncontroversial example is that Andy's nose is not separate from Andy, but his shoes are. A more controversial example is that oxygen is part of the environment, which is distinct from Andy, but Andy would die without breathing oxygen. It is a controversial example because it motivates the question, "Is oxygen part of the environment, part of Andy, or both?" The point of the second example is that, in many ways, agents are always "agent-environment systems" (Favela and Chemero, 2016). Nevertheless, at the spatio-temporal scale of whole animal-environment interactions, animals are readily able to distinguish themselves from other animals and their surroundings. It is in that sense, namely, that agent individuality has meaningful impact on their behavior, that distributed cognitive systems are comprised of multiple individual agents. Second, distributed cognitive systems are comprised of individuals with the capacity to carry out action towards an end (Kelso, 2016). The ability to perform goal-directed actions incorporates attentional and cognitive features. The attentional features are those involving the "ability to control one's focus of attention," and the cognitive features are those involving the "ability to control goal/task-related, deliberate thought" (Metzinger, 2013, p. 2).

In the context of distributed cognition, agency does not equate to independence (Despret, 2013; Nance, 2015) and is not limited to attentional and cognitive engagement. It refers to an individual animal's role in relation to other animals in the environment. An animal is considered *agentic* when it is an integral component of a complex relationship and, via its attentional and cognitive engagement, intentionally exerts influence over itself, other agents, and environment (Nance, 2015; Nash, 2005). In this context, *non-agentic* animals have their behavior controlled and directed, such that they are used for their physical presence, display a distinct behavior on command, and are not rewarded for variability in their behavior.

One way to understand distributed cognitive systems is via a two-level schematization: One level is at the scale of the animal-environment system (Fig. 1). An animal-environment system (ϕ) is comprised of an animal system (θ), an environment (E), the sensory input from environment to animal (S), and the motor output from animal to environment (M). Another level is at the scale of the distributed cognitive system (Fig. 2). A distributed cognitive system (θ) is comprised of two or more agents with task instruments (α, β, …), the sensory input from one agent to the other (S), and the motor output from one agent to the other (M). The distributed cognitive system (θ) is always situated in an environment (E), and thus always contributed to an animal-environment system (ϕ; Fig. 1). Such a schematization provides a qualitative representation of distributed cognitive systems that can serve as the basis for a quantitative model, with differential equations being one way to demonstrate an organism's relationship to other features of the environment. By capturing distributed cognitive systems via a set of couple differential equations, we are able to both represent agents and quantify their influence upon each other. Consider the following model, (1) and (2), of a distributed cognitive system, θ (Fig. 2):

$$\frac{dX_a}{dt} = a(X_a;\, S_1(X_B)M_1(X_B)) \tag{1}$$

$$\frac{dX_B}{dt} = B(X_B;\, S_2(X_a)M_2(X_a)) \tag{2}$$

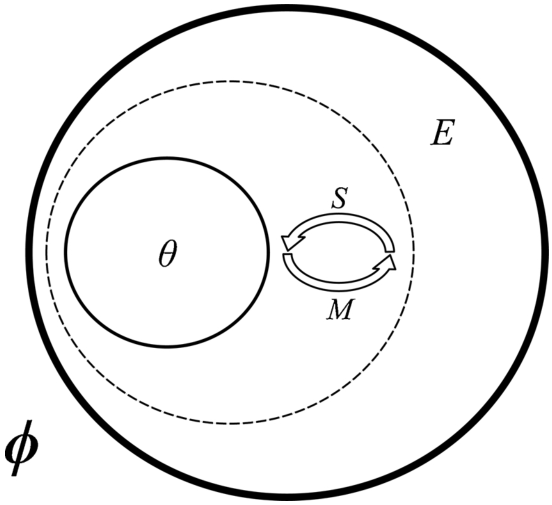

Fig. 1. Animal-environment system. An animal-environment system (ϕ) is comprised of an animal system (θ; which can be constituted by a single or multiple animals), an environment (E), the sensory input from environment to animal (S), and the motor output from animal to environment (M).

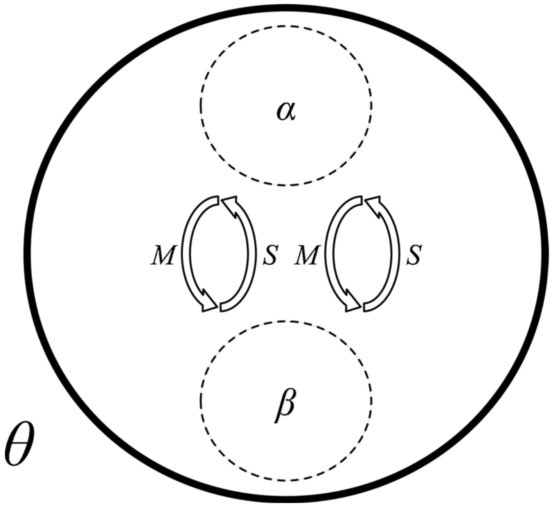

Fig. 2. Distributed cognitive system. A distributed cognitive system (θ) is comprised of two or more agents and instruments (α, β, …), the sensory input from one agent to the other (S), and the motor output from one agent to the other (M). The system (θ) is situated in an environment (E; Fig. 1).

Here we have a set of coupled differential equations that captures the dynamics of two animals contributing to a distributed cognitive system. Eq. (1) captures animal a, with sensory information S_1 and motor output M_1. Eq. (2) captures animal B, with sensory information S_2 and motor output M_2. Note the model is a distributed cognitive system for two reasons: First, the system θ is embedded in the larger system ϕ, which captures the single system θ acting in the world as a single system. Second, the model is nondecomposable in that neither equation, (1) or (2), can be solved separately from the other. Any changes to one part of the model has effects on the other part. Note that (1) captures animal a, but it also has an embedded variable for the other animal, B, and vice versa. Although Eqs. (1) and (2) are not a real model, the example illustrates how the dynamics and nondecomposable interactions of distributed cognitive system can be captured mathematically. Moreover, though each animal is contributing to a single system, such an approach makes clear that they remain individual agents with capacities to affect and direct the system they contribute to, as well as and be affected and directed by the other agent as well.

The third and interrelated criteria required for an activity to be considered socially distributed cognition is *shared task orientation*. This criterion is similar to agency in emphasizing the utilization of cognitive capacities. However, shared task orientation has to do with directed attention for an extended period of time on activities or features that are integral to performance of the task-at-hand. Agents can have different goals motivating their engagement in a particular task and may experience the task in different ways (Stanton et al., 2009). However, for the system to be distributed cognition, it is essential that the agents utilize directed attention and cognitive capacities to facilitate task performance. This may be evaluated in a variety of ways, including with observational methods, hormone and neuropeptide levels, eye trackers, motion tracking, linguistic analysis, and self-report (e.g., Gerencsér et al., 2013; Nagasawa et al., 2015; Rossi et al., 2014; Teglas et al., 2012), with the goal being to demonstrate directed and sustained attention on elements of the task. Experimental work by Rossi et al. (2014) provides an example of how shared task orientation can be empirically evaluated. In a preliminary study, Rossi et al. utilized a portable eye-tracking system to capture dogs' attentional capacities for social cues from humans during an object choice task, for example, giving a dog the choice between two or more cups with one containing an intended target such as food. In short, the dog's owner—or, depending on the trial, another unfamiliar person—were instructed to utilize hand gestures towards the target, namely, the cup with food. The dogs did not have any task-specific training prior to the experiment, other than pre-training to wear eye-tracking goggles and warm-up trials before the tasks began. Notably, the dogs exhibited prolonged eye gaze directed toward human hand gestures that referenced the target cup, as well as the cup that was gestured toward (Rossi et al., 2014, p. 146). This research provides an example of the kind of empirical work that can assess shared task orientation. The shared task is identifying the correct cup with food; the human shares in this task by having a goal of gesturing towards to the correct cup; and the dog shares in this task by looking at the correct cup for longer than incorrect cups. Hence, shared task orientation can be assessed by verbally asking a human and behaviorally measuring a dog's eye movements.

We have presented our set of three necessary and jointly sufficient criteria for a phenomenon to be an instance of distributed cognition: interaction-dominant dynamics, agency, and shared task orientation. What is more, we explained how each feature can be operationalized so as to be quantifiable and thereby contribute to empirical research. Next, we explore cases that exhibit various combinations of these properties in order to distinguish distributed cognition from other phenomenon such as extended cognition. Accordingly, we present human-dog distributed cognitive systems, human-tool extended cognition, and non-distributed cognition human-plus-non-human-animal interactions.

4. Human-dog vs. human-tool vs. human-draft animal interaction

4.1. The human-dog dyad as a distributed cognitive system

Representing the most ancient domesticated species (Thalmann et al., 2013; Skoglund et al., 2015), certain dog breeds have traits that have been positively selected by humans (Wang et al., 2013). In domesticated dogs (*Canis lupus familiaris*), such positive selection pressures have resulted in their preference for human companionship over and above even the companionship of their fellow dog (Hare and Woods, 2013). This is unlike their wolf (*Canis lupus*) relatives who, even when raised by humans, often prefer the company of other wolves (Hare and Woods, 2013; Frank and Frank, 1982). Through their convergent evolution with humans, dogs have become more adept at responding to human communicative cues in cooperative contexts than other species (Piotti and Kaminski, 2016; Naderi et al., 2001). Gesture, gazing, postures, physical distance, and vocal sounds can be interpreted by dogs, with some dogs discriminating several hundred words (Andics et al., 2016; D'Aniello et al., 2016; Fukuzawa et al., 2005; Kaminski et al., 2004; Miklósi et al., 1998; Pilley and Reid, 2011; Virányi et al., 2004). Gácsi et al. (2013) demonstrated that dogs readily use these cues to inform their behavior, not only in instances of obedience, but during ongoing social interactions with humans. In their experiment, dogs or wolves were enticed into a game where they guarded a bag from a human. The experimenter ended the game by adopting a less aggressive posture and encouraging a cordial interaction. The wolves were unrelenting in guarding the bag, unwilling to let even their owners retrieve it after play ended. On the other hand, the dogs quickly adjusted their behavior based on the less aggressive cues provided by the experimenter and let the human retrieve the bag. The dogs were also more likely to look toward their owner when the experimenter went to take the bag, utilizing social referencing to inform their behavior (Gácsi et al., 2013; Merola et al., 2011, 2012). The authors conclude that, compared to wolves, dogs display more human-centered behaviors and adjust their behaviors more to that of humans' in interspecific interactions.

In addition to utilizing human social cues, dogs are also able to direct humans' attention towards a target, using so-called *showing behavior* (Kaminski et al., 2011; Miklósi et al., 2000; Piotti and Kaminski, 2016), which is behavior used by dogs to direct the attention of humans (Piotti and Kaminski, 2016). In a series of studies by Piotti and Kaminski (2016), dogs preferred to attend to an object they found interesting over one useful to their owner. However, once the task was simplified, the dogs were more persistent in showing their human companions the human-relevant object. This was particularly true when the human used verbal communication during the interaction. Dogs interacting with humans may display increases in behaviors such as mouth licking, sniffing, gaze, looking behavior, and vocalizations (e.g., Miklósi et al., 2000).

It has been suggested that the domestication of dogs has led to their ability to cooperate with humans, as the process of domestication has facilitated a positive selection bias for traits that made them less fearful toward humans and increased their attention and tolerance to human activities (Hare and Tomasello, 2005; Miklósi, 2008). However, dogs occupy a special place in many human societies that most domesticated animals do not. A growing body of literature compares the human-dog bond to the human adult and child in terms of proximity seeking, separation-related distress, and oxytocin release during bonding (e.g., Payne et al., 2015; Schoeberl et al., 2012; Serpell, 1996; Topál et al., 1998). The Cooperation Hypothesis suggests that it is not only the domestication process that increased dogs' responsiveness to humans, but that their wolf relatives similarly demonstrated a social orientation, such that dogs were predisposed to be cooperative companions (Range et al., 2015; Range and Virányi, 2015). In addition, the Two-Stage Hypothesis, states that cooperative traits were further selected for during domestication, as dogs were bred to help with a variety of tasks, such as herding and hunting (e.g., Udell and Wynne, 2008). Dogs are therefore distinct from other domesticated species: they are one of the oldest domesticated species, they display a natural social and cooperative orientation, and they were bred to occupy a variety of roles in human society.

These characteristics, among others, equip dogs to not only work cooperatively with humans to accomplish tasks, but to do so in virtue of their role as parts of a distributed cognitive system (Keil, 2015). In the example of the working dog that helps humans to find cadavers, the human enlists the dog in a search because of its extraordinary ability to detect scents (e.g., Amundsen et al., 2014). Cadaver dogs are trained to seek out a type of scent, indicate to their handler when they find its source (i.e., engage in showing behavior) and are rewarded for successful identification (Hearne, 1986/2007; Hearne, 1986). The cadaver dog becomes better at detecting subtle scents over the course of its training and eventually becomes proficient in helping—with or without leash—to lead a search party to its intended target in the search area. After extensive training, the dog no longer exhibits mere obedience but develops a more complex, interdependent relationship with its handler. A description of this relationship is given by Warren:

> A good cadaver dog needs to be deeply bonded to his handler and simultaneously be independent and to make decisions on his own. The dog needs to work as part of an inseparable unit with the handler, but also be independent enough that he's not constantly looking back for cues on what to do next. When [my dog] is working scent, he won't look back at me for minutes at a time. He will be out there, and I will be trying to stay out of his way so he can do his best work. (Lineberry, 2013)

We believe this is an apt description of an interspecies distributed cognitive system. The human structures the task by identifying a goal and a region of interest for scent detection. The dog contributes a skill that is not possessed by humans in order to complete the task. The task itself is distributed, such that both parties share a task orientation (i.e., find the body) and are necessary for task completion (i.e., by adopting complementary roles). Similarly, for a blind human with a service dog, the human may select the overall path the pair takes to their destination, but the dog will often play an ongoing role in guiding the human, so they navigate safely and efficiently. The human offloads a portion of the cognitive task to the dog, who in turn signals the presence of obstacles and available paths (Naderi et al., 2001). Success lies in their coordination of complementary sub-tasks, where they contribute their unique resources toward the completion of a shared task (Keil, 2015; Sutton et al., 2010).

In these instances, the collective behavior of the dyad is more than the additive result of their behavior. Their relationship is interaction dominant in that their actions mutually constrain one another to give rise to a pattern of behavior that is not observed by the human and dog individually. The trained cadaver dog is better than its human companion in its ability to detect and follow scents and will lead the human toward the target (Hearne, 1986/2007; Hearne, 1986). The human also plays an active role throughout the task, taking into account changes in wind direction, restricting the cadaver dog to search a certain area, helping the dog avoid acute dangers, and offering encouragement, reinforcement, or break periods (Hearne, 1986/2007; Hearne, 1986). The ability of interest does not arise due to their individual behavior but because of their interaction with one another.

The guide dog and visually-impaired human also continuously interact and modulate one another's signals as they navigate to their destination. While it is possible for the dog and human to reach a particular location without one another's help, they will typically be more efficient and successful working together—not to mention safer. Their path and actions en route to the task completion are altered, such that their gross-level behavior is changed due to their interaction. Naderi et al. (2001) documented this interaction in naturalistic and experimental settings, including an obstacle course. In their study, guide dogs and their blind owners were asked to complete an obstacle course. Rather than the guide dogs exclusively leading the interaction, the human and guide dog initiated different behaviors during the search in order to facilitate task completion. For example, humans tended to initiate starting and stopping behaviors, while the guide dogs were more likely to initiate avoiding and stepping down behaviors. Furthermore, the role of initiator was only held for short periods of time, such that there was no clear leader or follower throughout the task. Instead, the pair demonstrated a highly interactive relationship that aided in them learning and mastering the obstacle course.

Note that the cadaver dog and guide dog are not merely demonstrating obedience. Through their perceptual and cognitive abilities, the dogs in each case shape the actions of their human companion, feeding back to the general process of the task via its own behavior as well as its influence over the human. These dogs do not carry out actions based on direct orders from a human. Rather, the dogs utilize decision-making under conditions of uncertainty. The cadaver dog, for instance, discovers the scent of interest and distinguishes it from numerous other scents, follows potential leads, eventually carving a path toward the scent's origin. In doing so, the dog utilizes its individual cognitive capacities and exerts influence over its environment.

Taken together, the human-dog dyad engaged in a working relationship can be considered a human-dog distributed cognitive system. First, their behaviors are interaction dominant in that the human and dog reciprocally constrain each other's behavior during task completion. Second, both parties exhibit agency by being integral components of a complex relationship and exerting influence over the environmental state. Third, the dog and human share a task-orientation, where their behavior is centered on the achievement of a shared task. In the case of the human-dog system, the unit of analysis is not the behavior of either individual but the dyadic interaction between the two.

4.2. *Objections to human-and-non-human-animal distributed cognition*

In line with mentalistic conceptions of cognition, one potential objection to classifying humans and working dogs as distributed cognitive systems concerns the *reasons* that are purported to be necessary for guiding intelligent action. Whether explicitly or implicitly, many of the standard conceptions of "cognition" in the cognitive sciences, philosophy of mind, and psychology endorse an understanding of cognition as being "normative" in nature (Sellars, 1956). Cognition is "normative" in the sense that it is fundamentally a kind of reasoning, and that reasoning guides action. For example, the question, "Why did Ana decide to walk through the left door instead of the right door?" is answered along the lines of, "Ana reasoned (cognition) that she was justified (normative) to walk through the left door (action) because X, Y, and Z." Along those lines, there is a sense in which cognition is a process for providing reasons for thought and action. Accordingly, the human-and-working-dog are not a distributed cognitive system in a way that meets our criteria because the working dog is not truly a cognitive part of the system. It can be argued that in the case of, for example, the cadaver-finding dog, its actions are a form of playing, or that it has been conditioned for reward in the form of food or praise. On the other hand, the human acts for *reasons* (cf. Dretske, 1999), such as a motivation to do their job for pay or to help a family find their missing loved one. Thus, so the argument goes, the dog cannot be a part of the distributed cognitive system because the dog does not do things *for reasons*; dogs do things because of instincts, training, etc. One could further argue that, since we stipulated that socially distributed cognitive systems involve parts that participate in task orientation, dogs cannot be part of such systems because they cannot give reasons for their task orientation.

First, if 'cognition' is defined as a capacity that only humans have, and/or it is a capacity necessarily tied to linguistic capacities—namely, the ability to conceptually formulate reasons for actions—then of course dogs are not cognitive animals. However, such a Cartesian view of cognition does not accord with empirical findings across a range of disciplines that demonstrate the (sometimes surprisingly high) intelligence of non-linguistic and non-human animals (Clark, 2005; Hochner, 2012; Massen et al., 2014). Accordingly, we view it as a non-starter to claim that cognition is a capacity only had by animals that are motivated by reasons couched in linguistic terms.

We argued above that the cadaver dog is not merely demonstrating obedience when it searches for a body, nor is it functioning merely as a tool like a cane. In the case of a cadaver dog, the dog is not merely agent-*like*, but has a high degree of agency due to its range of attentional and cognitive capabilities and flexibility. In accordance with such an approach, we can understand the cadaver dog as a cognitive agent that utilizes foresight and judgment while in conjunction with its sense of smell to complete a task—which is a task the dog is motivated to complete.

A second objection could be made on the grounds that dogs do not play an equal role in the human-dog system. As such, the dog's agency—another requirement for our definition of socially distributed cognition—is compromised. We do not find such an objection compelling in light of considerations we raised in connection with Hutchins' (1995b) discussion of the pilot and co-pilot relationship. As humans, both the pilot and co-pilot are agentic participants in their distributed cognitive system, with each member responsible for various aspects of the task completion. The co-pilot does not typically determine the overall route of the plane or where to land it—those are task constraints developed by others. Nevertheless, the co-pilot plays an integral role in coordinating with the pilot and others to land the plane safely, providing readings of the airspeed and wing configuration of the plane. In other words, just because someone is not involved in all aspects of decision-making or is "subordinate" to someone else, does not mean that they do not have agency. The co-pilot exerts significant influence over the plane's landing process, which is also the case for the working dog guiding a blind person or participating in a search party. It is debatable if the working dog has as much agency as the co-pilot, but we argue that the dog exhibits a greater degree of agency than animals in many other stimulus-response or obedience tasks.

Hierarchical structure alone is not reason to discount a system as a case of distributed cognition. In this case, the degree of agency exhibited over the course of the task need not be equal at any time. Similarly, in the case of the human and cadaver dog, since each member brings a different set of skills to the task, there are times when one will exhibit more control over their system. This can be a beneficial feature of distributed cognitive systems, as shifting control may be able to overcome the limitations of individual cognitive capacities. In summary, we do not think our case for understanding the human-dog system as a case of interspecies distributed cognition is undermined by either appealing to a supposed necessity of actions motivated by reasons couched in linguistic terms, or a distributed cognitive system exhibiting hierarchical structure. Next, we elaborate on the three criteria by juxtaposing the human-dog distributed cognitive system with two non-distributed cognitive systems: human-tool and human interactions with draft animals.

4.3. Human-tool interaction

Extended cognition refers to cognitive systems that expand to incorporate features beyond a system's periphery (e.g., skin, scale, fur, and feathers; Favela and Chemero, 2016). For example, mathematical problems sometimes require the aid of extracranial tools such as pencil and paper to perform long division (Clark, 1989; Clark and Chalmers, 1998). In this case, the cognitive capacities of manipulating mathematical symbols and values that are typically treated as happening in the brain are bolstered by placing those symbols and values in an external form so as to facilitate larger calculable quantities, that is, quantities that are difficult or impossible to process intracranially without the aid of external tools. In this way, mathematical cognition is extended outside the cranial and skin boundary to and from the paper.

Similar to socially distributed cognitive systems, human-tool interactions may be framed as a way to extend cognition outside of the boundary of the brain and nervous systems. In addition, humans working in conjunction with tools can result in interaction-dominant dynamics (Favela and Chemero, 2016; Favela and Martin, 2017). However, there are crucial differences between extended cognition and distributed cognition. First, human-tool interactions do not incorporate other cognitive systems. Human-tool interactions involve the substitution or augmentation of an individual's cognitive capacities: a cane substitutes for a blind human's vision and augments her haptic capabilities (Favela et al., 2018); and a smartphone (Chalmers, 2008), notebook (Clark and Chalmers, 1998), or the Internet (Storm et al., 2017) substitute and augment a human's memory.

A second and key distinction between socially distributed cognitive systems and human-tool interaction is agency. A cane and smartphone are not agentic. They merely extend and agent's sphere of influence and cognitive capacities. A human couple experiencing shared remembering is a socially distributed cognitive system because each part maintains a high degree of agency within that system. In addition, certain human-dog interactions constitute socially distributed cognition in light of the high degree of agency maintained by both contributing cognitive systems. A guide dog could be mistakenly understood as merely being an extended tool for a human to substitute for or augment her impaired visual capabilities. However, the guide dog maintains agency in a manner quite unlike a mere tool (e.g., a cane; Naderi et al., 2001). As discussed above, the human enlists the dog for tasks such safe and successful walking because of its ability to see and navigate. Thus, the human structures the task by identifying a goal and a region of interest for navigation and the dog contributes a skill that is not possessed by the human it guides. The task itself is inherently distributed, such that both parties are highly interactive as they participate in a shared task (i.e., safely get from point A to point B), are necessary for task completion (i.e., by adopting complementary roles), and are agentic (i.e., not non-agents or merely agent-like). Human-tool systems, like a visually impaired human using a cane, are extended systems and not socially distributed system. Along these lines, in the following section we discuss the use of draft animals as more akin to an extended system whereby the non-human animal augments the strength of the farmer but does not typically exercise agency during shared-task completion.

4.4. Human and draft animal working relationship

Dogs are certainly not the only animals that humans have developed working relationships with. For present purposes, our goal has not been to point out the different kinds of animals that humans have learned to work with, but to highlight the ways in which the criteria of distributed cognitive systems applies to interspecies interactions, in particular, humans and dogs. As we argued above, the human-dog system is a case of socially distributed cognition because the relationship demonstrates interaction-dominant dynamics, agency, and shared task-orientation. While a review of the history of human-non-human animal relationships goes far beyond the scope of the current work, it is instructive for us to point out one common type of human-non-human animal relationship that does not meet these conditions, specifically, the utilization of non-human animals as draft animals.

Draft animals are harness animals that are used for their tractive force, or ability to pull carts and agricultural implements such as plows. Even relatively weak animals can perform work at 60–80 W or that of approximately five healthy adult humans (Smit, 2006). Donkeys (*Equus africanus asinus*) are one such draft animal, which have been utilized by humans for approximately 5000 years (Beja-Pereira et al., 2004) for transportation of humans and their possessions, as well as for demanding physical labor related to farming (Hagmann and Prasad, 1995). While donkeys may have the potential to engage in socially distributed cognitive systems with humans, they do not qualify as such when typically utilized for purposes such as ploughing fields.

First, when a human uses a draft animal to plough a field, there is not a shared task-orientation. Draft animals are conditioned to pull a cart by training via simple rewards that are paired with a harness, leads, various drags, and eventually pulling. The donkey is reinforced to take direction or be driven by its handler, with behaviors in line with the human's goal being rewarded while others are ignored, punished, or negatively reinforced, such that the most common "training tool" is often the whip (Hagmann and Prasad, 1995). In fact, training is often circumvented altogether: Of 59 smallholder farmers in Zimbabwe surveyed regarding their use of donkeys for agricultural work, none of them reported engaging in training (Hagmann and Prasad, 1995). The working donkey is therefore constrained to tread in a designated direction. It may veer off the path slightly with the human following closely behind, but the draft animal is not encouraged to contribute to the task beyond its ability to pull, carry, or traverse a difficult landscape in the direction designated by its handler. That the draft animal's attentional and cognitive capacities are secondary to its mechanical ability to pull is illustrated by the fact that it is easily replaced by nonliving tools, such as tractors (Smit, 2006). In essence, the draft animal is utilized as a biological tool.

Second, the typical relationship between human and draft animal is one properly characterized as component dominant and not interaction dominant. As discussed above, a system is interaction dominant when the capabilities of the parts are superseded by the global capabilities resulting from the interaction of the components. We argued above that the human-dog system is an interaction-dominant system in that the capabilities of the human-dog system supersede what the human or dog can do in isolation. Moreover, the capabilities of the human-dog system are not the result of merely adding together the capabilities of the human and dog—such would be the case if their relationship was one of component dominance. The human-donkey relationship is, on the other hand, largely component dominant. The working donkey may provide feedback to the human by obeying, disobeying, gesturing, or slowing its movements when tired, which has the potential to interfere with task completion. However, the fact remains that the human initiates a "go" signal and the donkey provides little input into the path used to complete the task. Given rocky terrain, the human may defer to the donkey to identify the easiest path for plowing, but in this case, the donkey perceives and responds largely to immediate environmental constraints. Just as the human's commands constrain the actions of the donkey, the environment limits the space of possible actions the donkey can take.

Finally, and perhaps most significant when characterizing an interspecies distributed cognitive system, the donkey working as a draft animal does not maintain agency when working with a human in the way a dog does when part of a human-dog system. As we argued above, although a cadaver dog, for example, may have gone through a training phase, when it is set on the task of finding a body, the dog tracks a particular scent and utilizes its cognitive capacities to lead the human. To some extent, dogs are merely obeying orders, but it is also the case that many acts that require human agency are similarly conditioned (e.g., pilots and co-pilots taking orders from an air traffic controller during plane landing). Unlike the working dog, the working donkey does not exhibit agency in a joint task like ploughing. Furthermore, the donkey is not encouraged to utilize its independent cognitive capacities to facilitate task completion beyond merely pulling a plough in a designated direction. The donkey's behavior is no better explained via appeal to cognitive states than by behavioral conditioning. Accordingly, the human-donkey relationship is not a distributed cognitive system. If the relationship is to be characterized in a cognitive manner, then the donkey is like a tool serving as an extension of the human's capacities.

Many animals, domesticated and otherwise, learn to respond to a stimulus with a particular behavior. There are other human and non-human animal joint tasks that are more complicated than those exhibited by humans and draft animals. Homing pigeons (*Columba livia domestica*), for example, are able to complete the seemingly complicated task of carrying a message for a human to a secondary location, potentially many kilometers away. Training is reward based, with the pigeon obtaining food for successful completion of the task of returning to home base after longer and longer distances. As with a draft animal, this task is akin to obedience: once the human delivers the command or trigger (e.g., removal of food from one location and promise of reward at another), the pigeon begins its task in order to obtain a reward. Following the training phase, there is less-and-less interaction between the human and pigeon, until they cease to influence one another's performance once the signal, in this case removal of food, is transmitted to initiate the animal's behavior.

An animal's inability or lack of engagement in distributed tasks with humans does not necessarily define its social and cognitive capacities. Dogs have a privileged position in the animal cognition research literature because of their remarkably attuned socio-cognitive faculties, their convergent evolution with humans, and their cultural significance. However, this does not exclude other animals as having similar potential to coordinate and engage in shared tasks. Donkeys and pigeons may have the cognitive capacity to become integrated into a socially distributed cognitive system. However, in the case of donkeys as draft animal and pigeons as messengers, they do not exhibit features of a distributed cognitive system in practice. While it may be possible for these animals (i.e., donkeys or pigeons) to engage in socially distributed tasks, the example of draft animals demonstrates that not all human and non-human animal interactions exhibit properties of a socially distributed cognitive system.

5. Conclusion

To date, socially distributed cognition has largely been discussed anthropologically in order to qualitatively describe joint tasks carried out by human pairs or groups (e.g., Hutchins, 1995a; Keil, 2015; Kirsh, 2006; Neemeh and Favela, 2017). The literature has only begun to outline properties that a system must exhibit in order to be a socially distributed cognitive system (e.g., Theiner and O'Connor, 2010; Stanton et al., 2006). Nonetheless, for a phenomenon to be treated scientifically, a working set of conditions must be defined. We propose three operationalizable criteria for an interaction to qualify as a socially distributed cognitive system: interaction-dominant dynamics, agency of participants, and shared task orientation. In particular, interaction dominance is a measurable phenomenon that can be studied in a variety of interactions using data from movement, vocalizations, and response times, among other behaviors (Amon, 2016; Szary et al., 2015; Holden, 2005; Ihlen and Vereijken, 2010; Van Orden et al., 2005). Accordingly, methods for assessing interaction-dominant dynamics can be used to infer the extent to which individuals are acting as part of a single, organized system (e.g., Amon, 2016). Future research is needed to bolster our criteria by formally quantifying the interaction dominance of human-dog systems.

This framework extends distributed cognition theory to a broader range of task-related interactions while also formalizing a set of operationalizable criteria to distinguish distributed cognition from other sorts of group work. This theoretical framework is suitable for distinguishing interspecific interactions that are cognitively distributed across social agents (e.g., humans and guide dogs) from tasks that are not cognitively distributed (e.g., humans and draft animals). Notably, these criteria do not rely on the presence of language, expanding the scope and utility of distributed cognition theory to situations in which non-verbal "attunement" is used as a means of interaction (Keil, 2015).

Distributed cognition can help researchers understand collaborations and socio-cognitive behavior across species. In addition, an operationalizable framework may aid in identifying principles of coordination that underlie successful performance during group tasks. Broadly speaking, treating cognition as distributed is a novel way to understand various kinds of interactions, and can shed light on the *why* and *how* of certain complex, group-level behaviors.

Many other animals have been used in the service of human goals, for example: camels to carry heavy provisions, dolphins to search for mines, elephants for battle, and pigeons to send messages. Some animals like the domesticated horse (*Equus ferus caballus*) may even exhibit dynamics of socially distributed cognitive systems when acting along with their human rider to complete tasks such as steeplechasing (cf. Hearne, 1986/2007; Hearne, 1986). While it is likely there are other instances of human and non-human animal interactions that qualify as socially distributed cognition, we argue that domesticated dogs (*Canis lupus familiaris*) are one species that engages in a variety of complex tasks in relation to humans, some of which are instances of interspecies distributed cognition. Contemporary domesticated dogs are the result of positive selection pressures for characteristics that have allowed them to flourish in human society (Udell and Wynne, 2008). Such selective pressures likely encourage them to engage in tasks that other non-human animals may not be predisposed towards. Accordingly, the genetic, historical, and social background of dogs facilitates their ability to become parts of distributed cognitive systems along with their human companions (Naderi et al., 2001). Humans and dogs have learned to offload and share portions of their cognitive capacities with one another as they work to complete mutual tasks. Such considerations may begin to explain the intuition of many that dogs are a species with a relatively unique relationship to humans, and that such relationships reveal the adaptable and malleable nature of cognition.

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