Interspecies Distributed Cognition

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Abstract

Studies in distributed cognition (d-cog) almost exclusively focus on human-centered technological systems, such as ships, aircraft, automobiles, scientific and medical institutions, human-computer interfaces, and transactive memory systems. First, we review the literature and claim that d-cog is species-neutral. We then propose three experimentally operationalizable, necessary, and jointly-sufficient criteria for identifying d-cog: task orientation, interaction dominance, and agency. Here we build on previous research on nonhuman intraspecies d-cog by presenting human-dog systems as cases of interspecies d-cog. Domestic dogs' (*Canis familiaris*) unique working relationships with humans allow for interspecies coordination and synchronization. Contrasting them with wolves (*Canis lupus*) and dingoes (*Canis dingo*), we suggest evolutionary history plays an important role in determining whether different species can form interspecies d-cog systems.

Keywords: animal cognition; distributed cognition; dogs; human-animal interaction; working animal

Introduction

A common view of social cognition takes groups to exist only insofar as its members believe it to exist (Schmid, 2014). The individual is the basic unit of the group and the group is reduced to the actions and mental states of its constituent members. Distributed cognition (d-cog), by contrast, offers a nonreductive account of group constitution and cognition. Just as cognition is distributed across the brain, d-cog posits that cognition can also be distributed across several agents and tools composing a multiagent system. Navigating a large ship, for example, does not involve localizable representations of geography, sea conditions, ship position, or spatial displacement within the ship's crew or instrumentation. Rather, many of these representations are distributed across multiple instruments and sailors (Hutchins, 1995a). Other systems analyzed as d-cog include airplanes (Hutchins, 1995b; Plant & Stanton, 2017), automobiles (Banks & Stanton, 2017), scientific and medical institutions (Cheon, 2014; Giere, 2006; Krieger et al., 2017), human-technology interfaces (Dror & Harnad, 2008), and transactive memory systems in couples (Harris et al., 2014).

Studies in d-cog typically privilege cognition taking place through the medium of language and discourse. However, cognition also includes perception, action, and affect (Chemero, 2009; Damasio, 2005). Correlatively, studies in d-cog typically focus on human systems, but other species such as nonhuman primates (Mosley & Haslam, 2016) and wolves (Neemeh & Favela, 2017) are also capable of d-cog. We propose a series of necessary and jointly-sufficient criteria to identify d-cog without privileging any single aspect of cognition or species. We argue that d-cog is species-neutral and can even occur interspecifically in certain circumstances. We examine human-dog systems as cases of interspecies d-cog and contrast them with cases of human interactions with wolves (*Canis lupus*) and dingoes (*Canis dingo*). We suggest a strong evolutionary component underlies the capacity to form interspecies d-cog systems. In the next section, we begin by outlining various conceptions of d-cog.

Distributed Cognition

D-cog refers to cognitive systems composed of agents and tools wherein elements of cognition, such as knowledge, are distributed across these agents and tools (Hutchins, 1995a, 1995b). Analyses occur at the system-level rather than individual. Furthermore, these agents and teams of agents "work together in pursuit of a common goal, which comprises multiple interacting subgoals" (Plant & Stanton, 2017, p. 2). D-cog systems are typically characterized by multiple agents and tools, at least some cognition being distributed across said agents and tools, a systems-level analysis, and collective or system-wide subgoals.

D-cog has been applied to a wide variety of navigational situations involving highly technical apparatuses, including ships (Hutchins, 1995a), aircraft (Hutchins, 1995b; Plant & Stanton, 2017), and automobiles (Banks & Stanton, 2017). An early application of "d-cog" was Hutchins' (1995a) "cognitive ethnography" of a navy ship. In his analysis, the sailors, captain, and other functionaries form a unified cognitive system along with the ship's navigational tools. Successful navigation involves distributed representations of position, spatial displacement, distance, rate, and time (Hutchins, 1995a, p. 58). Notably, d-cog is realized within a twofold structure: institutional organization and social structure. Organization is the formal set of input-output functions of the various agentic functionaries of the ship, defined by their bureaucratic and hierarchical rule-following, and those of the ship's multiple navigational instruments. These formal, representational functions are implemented within a broader context of a social structure that overflows codified rules and functions. This more amorphous structure includes elements of informal communication and interpersonal relationships beyond the formal relations across military hierarchies.

D-cog has also been widely applied to contexts of scientific and medical institutions and collaborations (Cheon, 2014; Giere, 2006; Knorr-Cetina, 1999; Krieger et al., 2017). By integrating cognition with social structure, d-cog allows for a description of scientific reason and praxis without reducing science to an untenable "objectivity" or to a purely social or political endeavor (Cheon, 2014). Knorr-Cetina (1999) analyzes CERN and molecular biology laboratories as d-cog systems (cf. Giere, 2006). CERN, qua d-cog system, is composed of theorists, experimenters, experiments, and experimental apparatuses, such as the Large Hadron Collider. This system is task-oriented, e.g., searching for the Higgs boson. These principle tasks, towards which the system is directed, are practically executed through a multitude of subgoals. Theorists and experimenters have markedly different goals, such as interpreting experimental results or designing an experiment. Individually, each theorist and experimenter also have their own shifting subgoals, such as performing a specific calculation. Despite the existence of vertical control mechanisms, such as regular meetings and committees, the system does not achieve task-orientation through vertical, top-down control. The d-cog across scientists and their discourse, experiments, and experimental apparatuses instead achieve task orientation largely horizontally: "No individual knows it all, but within the experiment's conversation with itself, knowledge is produced" (Knorr-Cetina, 1999, p. 178). In this way, d-cog is similarly applied to human-computer interactions (Dror & Harnad, 2008) and transactive memory systems (Harris et al., 2014).

In the literature, different elements of cognition are invoked: perception, action (navigation), and knowing (science, medicine, human-computer interaction, transactive memory systems). Nearly all studies focus on language and discourse as the medium of communication and representation. Correlatively, they also focus on human or human-centered systems. However, language is a relatively recent evolutionary development scaffolded upon evolutionarily older elements (Lakoff & Johnson, 1980/2003; Varga, 2016). Human cognition is not solely realized through linguistic means, and non-human-animal cognition is almost exclusively realized through nonlinguistic means. While non-human animals are capable of communication, they rarely utilize syntactic language. Some recent studies have recognized a role for d-cog in animal systems, such as nonhuman primates (Mosley & Haslam, 2016) and wolves (Neemeh & Favela, 2017). In the following, we propose criteria for d-cog that is species-neutral and does not privilege language.

Criteria for Distributed Cognition

There is currently no consensus on a precise definition of "d-cog" (Cheon, 2014). We propose three necessary and jointly-sufficient criteria for d-cog. One of the problems plaguing definitions of d-cog is they are unamenable to experimental operationalization. Acknowledging this difficulty, we have geared these criteria towards experimental operationalizability (cf. Kirsh, 2006). D-cog is characterized by:

i. Task orientation
ii. Interaction dominance
iii. Agency

First, d-cog is task-oriented. It is important to distinguish the overall task or tasks of the system from goals and subgoals held by individual members of that system. The task of the system can be defined without reference to intentional states, beliefs, or other "inner" mental states that may be difficult to determine in nonhuman animals and that do not exist in the equipment and environmental elements of the system. The task is itself distributed across the system, such that the system as a whole contributes toward achieving a certain objective.

The task of the system is empirically verifiable in the same way that the function of a cell is in biology: What does it do or what does it produce? The distributed task of the ship is to navigate from point A to B. That of CERN or the Hubble Space Telescope is to produce empirical knowledge.

Goals doubtless play an important role in d-cog, and goals may align with tasks. Goals, however, are "inner" intentional states, whereas tasks are more straightforwardly verifiable as functions of the system. Although in many of the cases surveyed tasks are pursued intentionally (i.e., with a goal), they can equally be performed unintentionally. For example, in transactive memory systems, two individuals in a romantic couple jointly remember events and details that neither fully remembers as an individual (Harris et al., 2014). However, this shared memory is not necessarily intentional and the couple may not realize their memory is an emergent phenomenon (Amon & Favela, 2017).

Second, d-cog is interaction dominant: it requires continuous coordination between its agentic and nonagentic equipment or environmental components. At CERN, for example, scientists coordinate with one another through both official (meetings, committees, status reports) and unofficial (meals, everyday conversation) means over time.[1] Agents coordinate with each other, as well as with equipment and environmental components. Theorists and experimenters both work on, for example, developing the data produced by the Large Hadron Collider, which is fed back into their work. This coordination is oriented towards a task (e.g., generating knowledge about high energy physics), and it mutually influences the actions of each component (Favela & Chemero, 2016).

[1] The distinction between official and unofficial social communication is likewise pivotal in Hutchins' (1995a) analysis.

Systems are *interaction dominant* when the dynamics of the interactions among the parts surpass the dynamics that the parts exhibit separately (Favela & Martin, 2017; Holden, Van Orden, & Turvey, 2009). There is a bidirectional flow of constraints within such a system, such that global system states constrain local components, and local states constrain global (ibid.). In this way, interactions among components (i.e., agents and tools) in a d-cog system give rise to ordered behavior that is not exhibited at the individual level. While the coordination of system components can be difficult to measure, mathematical tools are available, e.g., fractal analyses (Amon, 2016; Van Orden, Holden, & Turvey, 2005).

Third, d-cog requires two or more of its components to be agentic. This criterion distinguishes d-cog from extended cognition (Amon & Favela, 2017). Extended cognition obtains when one component of the system is agentic and others are nonagentic. Otto, for example, who suffers from an attenuated memory, records directions in his notebook. When he remembers how to get to MoMA in Manhattan, he retrieves this memory from his notebook instead of from his neurons. His memory system for locations and directions is artefactual instead of biological (Clark & Chalmers, 1998). Coordination in this extended cognitive system only includes a single agent, whereas d-cog requires at least two.

Of these three criteria, agency is the most difficult to operationalize, particularly in the case of non-human-animals. The focus on task orientation rather than goals avoids the problem of ascribing mental states to animals. To retain our focus on formulating criteria that can be experimentally operationalized, agency in our use refers to the attentional, cognitive, relational, and inhibitory control capacities of an animal. These include abilities to contextually control the focus of attention, solve novel problems under conditions of uncertainty, socialize with other agents, and inhibit behavior for the sake of future goals[2] (Amon & Favela, 2017; Nash, 2015).

It is not necessary that the animals in question really do have the attentional, cognitive, and relational capacities in question. Rather, the hypothetical presence of these capacities must be able to explain their behavior more parsimoniously than comparable mechanistic accounts.[3] Not only must they make a good fit with the behavioral data, but they also must be plausibly attributed. That is, the degrees of freedom within the problem space must be plausibly high enough. A human who follows the trail of a deer has several degrees of freedom within the problem space to make a choice to pursue. An ant is largely constrained to following a pheromone trail and does not have comparable degrees of freedom within which to choose a path within the given problem space (Hölldobler & Wilson, 1990). Its behavior is not consistent with goal-oriented behavior inhibition or a contextual control of attention. This is how we propose to distinguish agentic from agent-like animals (Amon & Favela, 2017).

These three necessary and jointly-sufficient criteria are each designed with operationalizability in mind. In principle, any given system of agents and equipment or environmental components should be empirically determinable as distributed or not. These criteria are species-neutral and correlatively do not privilege language as the medium of cognition. If d-cog is species-neutral, however, it ought to cover not only interspecies animal cognition (Mosley & Haslam, 2016; Neemeh & Favela, 2017), but possibly even human-non-human interspecies systems. Next, we argue that it follows from these criteria that human-dog systems are instances of interspecies d-cog.

The Human-Dog System

Humans have a wide array of relationships with non-human animals, e.g., pets, working animals, zoo animals, livestock, and prey. Of the many species with which humans relate, domestic dogs (*Canis familiaris*) are among the few non-human animals with the capacity to develop strong, mutual emotional bonds[4] *and* serve as working animals.[5] This capacity results from a process of domestication dating back to early hunter-gatherer societies (Smith & Litchfield, 2010). The emotional bonds allow them to perform complex working tasks with humans such as guiding the blind, assisting the deaf, hunting, search and rescue, drug-sniffing, and shepherding. These tasks require a high level of coordination and social interaction, and are best understood as dynamically coupled processes (Merritt, 2015, p. 823).

Dogs contextually respond to a variety of human cues, including body language, gaze, gestures, and vocalizations (D'Aniello et al., 2016; Fukuzawa, Mills, & Cooper, 2005; Piotti & Kaminski, 2016; Virányi et al., 2004). They likewise communicate intentions through cues such as gaze, growling, and other vocalizations (Miklósi et al., 2000). Dogs can display deictic behaviors, such as pointing to an object of interest with their gaze.

Dogs display interspecific emotional and behavioral synchrony with humans through contact, e.g., vision and touch. For example, dogs are sensitive to their owners' happiness or distress and reflect positive or distressed behavior in response. Dogs even appear to be susceptible to yawning upon seeing humans yawn, especially those with whom they have a bond (Duranton & Gaunet, 2015). This ability to interspecifically synchronize facilitates the performance of joint tasks, the human-dog bond, and learning. It is important to note that caution is needed to not anthropomorphize dogs' intentions or mental states.

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[2] Behavior inhibition is classically the gold standard of identifying agency; e.g., humans in which this is significantly impaired may not face legal responsibility for their actions.

[3] Dennett (1983) refers to this as taking the "intentional stance."

[4] Levels of oxytocin, which mediates emotional bonds, increases in both humans and dogs in a relationship dyad (Nagasawa et al., 2015).

[5] For example, cats can form strong emotional bonds with humans but are ill-suited to be working animals. Carrier pigeons, on the contrary, can serve as working animals but likely do not form strong emotional bonds with their keepers.

Dogs' abilities to respond to human cues, communicate intentions to humans, synchronize their emotions and behaviors with those of affiliated humans, and follow leaders make them well-suited to performing joint tasks with humans. Furthermore, their acute sense of smell makes them useful in searching for cadavers, missing persons, avalanche victims, and narcotics. We argue that it follows from the criteria given above that human-dog systems, especially in situations where the dog is serving as a work animal with an affiliated human, are cases of interspecies d-cog.

First, human-dog systems are task-oriented. As we noted, tasks are distributed across the system, whereas intentional goals are individual mental states. We do not need to prove that a dog has a specific mental state to demonstrate that the system is task-oriented. Furthermore, task orientation does not necessarily require individuals to have the same goals. Drug-sniffing dogs are a prime example of this. They are trained to associate the scent of certain narcotics with a toy. During their regular training, they are given this toy to play with as a reward for successfully locating drugs. Taking the "intentional stance," we can say that the drug dog's behavior is best understood by recourse to explanations of play. During a search, the dog is looking for their toy to play with. As one customs officer reports, "She [the dog] enjoys the search and is excited while she's searching, but it's because she wants her ball and a fuss. It's a game" (Wilkinson, 2008).

Through this training, the affiliated police officer determines the task by arranging the dog's goals to spatially converge upon their own, even if they remain different in content. Regardless if the handler's attribution of intentions to the dog is mistaken, the system is oriented towards the task of searching for drugs. Though their individual goals may diverge, the dog and human both function together as a drug detection system. Although the goals in this case are individual and not shared, the task is distributed across the system itself.

Second, human-dog systems are interaction dominant: their actions mutually constrain one another to give rise to a pattern of behavior that is not observed by the human and dog individually (Amon & Favela, 2017; cf. Keil, 2015). In the drug-search task, the handler determines the task by training the dog to respond to drug scents and restricts the problem space, e.g., airport. The dog in turn influences the handler, guiding them towards narcotics that may be far away. The handler keeps the dog on track and within the proper field of action. Upon locating the drugs, the dog communicates this information to their handler by a "freeze-stare" (Wilkinson, 2008). The handler and dog both guide one another. Although the handler may determine the task, both the human's and the dog's behavior mutually influence one another and are continuously coordinated, reshaped, and rerouted. Because neither are wholly in control and their behaviors mutually influence one another, the system is interaction dominant.

Third, both the human and dog components of the system are agentic, albeit to differing degrees. Dogs have sufficient attentional, cognitive, relational, and inhibitory control capacities to be considered agentic by our criteria. In our example, drug dogs do not simply follow the handler's lead. They have sufficient attentional capacities to search for the drugs without being simply directed by their handler. This is even more evident with guide dogs for the blind, who take the dominant role in leading their companions through space (Naderi et al., 2001). They can solve novel problems under uncertainty (e.g., neither the human nor the dog knows where the drugs may be, and they must follow multiple leads). Inhibitory control is another common marker of agency, and people who lack this capacity at birth or due to disease or senescence are often not held legally or morally responsible for their actions. There is evidence that dogs have at least a rudimentary form of inhibitory control and are able to modulate their behavior according to context and expected reward (Bray, MacLean, & Hare, 2014).

Other Canid Species: Wolves and Dingoes

Unlike dogs, wolves (*Canis lupus*) and dingoes (*Canis dingo*) have never been fully domesticated. These species provide a continuum of evolutionary adaptation to human communities, with wolves being feral, dingoes being tamed (i.e., adapted to humans but not domesticated), and dogs being fully domesticated. Contrasting them with dogs suggests interspecies d-cog may require an evolutionary component such as taming or domestication as a precondition (cf. Hare & Tomasello, 2005); i.e., not just any species can form interspecific d-cog systems with other species. While wolves remain wild, dingoes have existed alongside human populations for thousands of years, and are among the first developed human-canine relationships (Smith & Litchfield, 2009, 2010). In traditional Australian aboriginal communities, dingoes lived on the outskirts of the community without ever fully being domesticated. Wolves, on the other hand, have never been domesticated or tamed, although small numbers have been acclimated to human interaction for purposes of pet-rearing or scientific experiments.

When hunting, wolves in a pack form intraspecific d-cog systems. They display all the characteristics of d-cog: task-orientation, interaction dominance, and agency (see Neemeh & Favela, 2017). However, unlike dogs, they do not respond to human cues without an intense period of training (Gácsi et al., 2013). Even when socialized with humans, they show lower levels of interaction with humans than dogs, communicate through cues less, and are more aggressive (Bentosela et al., 2016; Smith et al., 2016). Humans themselves are more reticent to work with wolves for reasons of safety and law. Many behavioral studies of wolf socialization with humans involve pups, and pet wolves are often released or killed upon maturation (Smith & Litchfield, 2009). Due to both wolf indifference and human reticence, wolves are unable to engage with humans in joint tasks exhibiting interaction dominance. As such, they are largely incapable of forming d-cog systems with humans.

Dingoes maintain eye contact with humans more than wolves do, but less so than dogs (Johnston et al., 2017). Some dingoes have even been tamed and kept as pets. Owners typically report their pet dingoes as exhibiting greater reticence towards strangers than dogs (Smith et al., 2016). Dingoes have a greater capacity to form bonds with humans than wolves and exhibit a moderate comprehension of human cues. They were once used by aboriginal Australian women as hunting dogs (Balme & O'Connor, 2016), and at least one case has been reported of a dingo working as a service animal for a hearing-impaired man (Dickman & Lunney, 2001). They are less capable of dynamic relationality with humans than domestic dogs. Nonetheless, they may be able to form task-oriented, interaction-dominant systems with humans in a manner comparable to dogs under special circumstances.

The evidence from dogs' canid relatives suggests that effective interspecies d-cog requires an evolutionary adaption of species to one another. While dogs' emotional and behavioral synchronization with humans is predicated upon their capacity to synchronize with one another, wolves have the latter ability and yet do not synchronize with humans (Duranton & Gaunet, 2015). Dogs exhibit a greater period of sensitivity to socialization with humans than wolves, a trait best explained by selective breeding and domestication (Bentosela et al., 2016). Dingoes, which have been tamed for thousands of years but never fully domesticated, represent an intermediate stage between dogs and wolves with respect to their capacity for interspecies d-cog. This is likely due to their moderate level of coevolution with human populations (Smith & Litchfield, 2009). When studying other species' capacities for interspecies d-cog, it is important to take evolutionary history into consideration, especially with respect to the proposed partner species.

Conclusion

D-cog is most often used to study human social, scientific, navigational, and technical systems, but it need not be restricted to human agents. There is a lack of consensus on precisely what d-cog consists of, and many definitions remain abstract and not experimentally operationalizable. We propose three necessary and jointly-sufficient criteria with experimental operationalizability in mind: task orientation, interaction dominance, and agency. Although human systems such as aircraft or CERN rely heavily on language and discourse as a medium of cognition, other elements of cognition such as perception and action can also be distributed across the system. Because language and discourse are not essential, it follows that d-cog is species-neutral. D-cog has been applied to nonhuman intraspecies systems (Mosley & Haslam, 2016; Neemeh & Favela, 2017). Human-dog systems such as search and rescue dogs, hunting dogs, drug dogs, guide dogs, and shepherding dogs are prime examples of interspecies d-cog. We provide this case as a proof-of-concept, and in the future hope to test this in a laboratory setting.

Related canid species have differing capacities for forming similar systems. In some cases, with proper rearing and training, dingoes may be able to perform similar tasks. Wolves, however, cannot due to both their developmental and behavioral traits and humans' reticence to work with them. Correlatively, dogs have been wholly domesticated, dingoes have been tamed, and wolves remain feral. This suggests that evolutionary history plays an important role in the ability for different species to form interspecific d-cog systems together.

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