Beyond Distributed Cognition: Towards a Taxonomy of Nonreductive Social Cognition

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Abstract

Studies of social cognition often assume a reductionist, computational-representational conceptual framework. Distributed cognition is one of the few extant conceptual frameworks for a nonreductive understanding of social cognition. This concept's prototypical cases are exclusively of technical-scientific human institutions, including ships, cockpits, and the Hubble Space Telescope. In the first part of the paper, we outline the properties of distributed cognitive systems. We look at the case of wolf (*Canis lupus*) packs as an instance of distributed cognition in nonhuman systems. Nevertheless, a broad range of social cognitive phenomena across human and animal populations may not fit into this conceptual framework. We present a case study of bird flocks as a counterexample to distributed cognition. We propose "swarm intelligence" as an alternative concept of nonreductive social cognition. This is not to replace distributed cognition as a concept, but to add to and diversify the taxonomy of nonreductive social cognitive systems.

Keywords: social cognition; distributed cognition; swarm intelligence; bird flocks; wolf packs; nonreductive explanations

Introduction

As a field of research, social cognition grew out of a social psychology that was influenced by the cognitive revolution and its adherence to the computational-representational understanding of mind (CRUM; Gilbert, 1999; Thagard, 2005). CRUM holds that cognition consists of a series of computations performed upon representations. CRUM approaches to social cognition are reductionist in that social phenomena are explained by recourse to the mental or neural mechanisms of individuals. In other areas of the cognitive sciences, nonreductive and systems approaches have been developed as alternatives to CRUM, e.g., ecological psychology (e.g., Gibson, 1979/2015), extended cognition (e.g., Clark & Chalmers, 1998), embodied cognition (e.g., Rowlands, 2010), radical embodied cognitive science (e.g., Chemero, 2009), and radical embodied cognitive neuroscience (e.g., Favela, 2014).

The primary example of a nonreductive understanding of social cognition is Edwin Hutchins' distributed cognition. Hutchins (1995a) analyzed the cognitive structure of a navy ship's navigation across a network of agents (sailors) and navigational instruments. This study introduced an early social cognitive concept that did not reduce explanations to events in the brain. In his "cognitive ethnography," the entire system of sailors and nautical instruments constitute a cognitive system. Navigation of the ship is achieved only through the combined efforts of these actors and tools.

While distributed cognition has provided a nonreductive lens by which to understand social cognition, it is rooted in a highly specific prototypical case of social and instrumental organization. We outline the properties of distributed cognitive systems and give an example of a nonhuman social system (wolf packs) in which distributed cognition is operating. We then argue that not all social cognitive systems are cases of distributed cognition. We argue that other forms of social cognition exist, such as swarm intelligence, via a case study of bird flocks.

Distributed Cognition

Distributed cognition is a nonreductive account of social cognition that includes both agents and tools. Social cognition is not limited to mental events or brain activity in the individual agents who happen to constitute a social network. That is not to say that individual mental or neural events are irrelevant. However, the unit of analysis is the entire organization of agents and tools oriented around specific group tasks, such as a navy ship being navigated (Hutchins, 1995a) or an airplane cockpit being piloted (Hutchins, 1995b).

In Hutchins' studies of distributed cognition, the paradigm cases are of vehicles operated by two or more human agents. An airplane cockpit's cognitive organization consists of two agents (pilot and copilot) and an array of navigational instruments. An orthodox CRUM account of the social cognition of the cockpit would analyze the mental and neural events occurring in the brains of the two pilots. For Hutchins, however, the cognitive phenomena of perception and locomotion of the airplane as a whole occur as a coupled system of the pilots and their instruments.

Giere (2006) offers the Hubble Space Telescope (HST) as another prototypical case of distributed cognition. The HST is not merely a vehicle to be navigated or piloted, but a complicated instrument measuring ultraviolet, visible, and infrared spectra in deep space (Shayler & Harland, 2016). Its operators are human, but it is orientated and programmed with commands and algorithms rather than piloted or

navigated. The HST itself consists of a vast array of complex, specialized instruments. Significantly, not only does it produce images of deep space objects, but it also provides higher-level scientific outputs such as "authenticated claims about the age of the universe" (Giere, 2006, pp. 712-713). In this respect, the HST is more cognitively complex than a ship or cockpit. The HST collectively produces these scientific outputs as a system of instruments, engineers, and scientists. No one instrument or operator is sufficient to produce any one of these outputs. For example, claims about the age of the universe cannot be substantiated without the HST's spectral analyses of galactic redshifts. Likewise, galactic redshifts cannot be measured without human programmers or the scientists who requested such measurements to, for example, confirm the Hubble constant.

Giere treats the HST as more than a deep space telescope. It is a *scientific institution* producing empirical claims about the universe. Nevertheless, like Hutchins' navy ship and airplane cockpit, it remains constituted by a network of agents and nonagentic instruments and tools. Kirsh (2006) provides a similar framework for distributed cognition, altering the methodological focus from a systems analysis to one of both individuals and systems, i.e., a "bottom-up top-down model" (p. 250). We provide a formalized list of the components of distributed cognitive systems consistent with Hutchins (1995a, 1995b), Giere (2006), and Kirsh (2006).

Properties of Distributed Cognitive Systems

Distributed cognitive systems are not explained reductively. They are emergent in the sense that they are not merely the sum of the individual cognition of its components. Crucially, the actors are agentic (Giere, 2006). The sailors of the navy ship, pilots of the cockpit, and engineers and scientists of the HST exhibit significant degrees of agency.

These agents maintain their agency even as members of the system actively participate in its system-wide goals and joint tasks (cf. Amon & Favela, 2017). Significantly, the cognitive behavior of a distributed cognitive system is not limited to perception and locomotion. Giere's HST system is not merely orientated towards celestial objects to capture images. The HST (the physical HST and its operators) produces falsifiable scientific claims. The following is modified from Amon and Favela (2017).

S is a distributed cognitive system if:

D1. *S* is emergent.

D2. There is continuous coordination of agents and nonagentic tools as members of *S*.

D3. Each agent maintains a degree of individual agency within *S*.

D4. Each agent actively participates in the overall goal or joint task in which *S* is engaged.

D5. There is specialization of functions among members of *S*.

D6. The cognitive behavior of *S* is complex and not limited to perception and locomotion.

In the following, we discuss wolf packs as an example of distributed cognition in the nonhuman animal world. We then present the case of bird flocks as a counterexample of social cognitive systems that are not distributed cognitive systems. We propose a new concept for nonreductive social systems for cases not in lieu of, but along with, distributed cognition.

Wolf Packs as Distributed Cognitive Systems

Many paradigm cases of distributed cognition are anthropocentric and limited to human technical-scientific institutions (e.g., navy ship, airplane cockpit, and HST). However, social cognition is not limited to humans or such institutions. In some cases, collective animal systems may indeed be described by this anthropocentric concept. Wolf (*Canis lupus*) packs on the hunt[1] are one such case of distributed cognitive systems in the animal world.

Wolves hunting in pack formation consist of four to 30 individual members, with hunting efficiency negatively correlated to increasing pack size (Mech, Smith, & MacNulty, 2015). They are loosely organized around a breeder ("alpha" in older literature) but do not operate by a command structure. Individuals converge upon the prey and, assuming a successful hunt, a single wolf ultimately makes the kill (Tang, Fong, Yang, & Deb, 2012).

Pack hunting patterns, organization, and coordination are emergent (D1). Several apparent hunting strategies have been noted, including encircling, ambushing, and relay hunting (Mech et al., 2015). Mech (2007) notes that wolves express a degree of mutual comprehension. He concludes from this that wolves communicate hunting strategies. This hypothesis assumes the existence of communication mechanisms that have yet to be discovered. Current evidence provides a more parsimonious account: The observed hunting patterns are wholly explicable in terms of a set of basic perceptual and locomotive procedures operating on the individual level and giving rise to a global structure. This simple process constrains the position of individual wolves so as to be neither too far away from nor too close to other wolves of the pack. Furthermore, individual wolves coordinate their own positions relative to both their prey and relative to the breeder (Muro, Escobedo, Spector, & Coppinger, 2011). Global hunting patterns, such as encirclement, are not premeditated, directed, or otherwise centrally controlled. They emerge from these basic processes of local interaction (see Figure 1).

Within the pack, there is a continuous coordination of wolves (D2). Simulations by Muro and colleagues (2011) found that emergent hunting patterns can arise from the coordination of spatial positions in real time. Individual wolves coordinate their positions relative to those of both the breeder and the prey (see Figure 1). No advanced

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[1] Wolf packs are only distributed cognitive systems in the context of the hunt. Outside of this context, they retain only a loose association and they do not otherwise share in joint tasks.

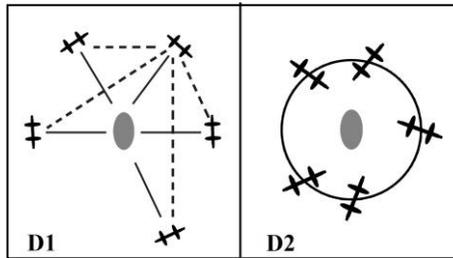communication of ideas or intentions is necessary to produce these patterns.

Figure 1: D1. Individual wolves continuously coordinate their movements based on the spatial positions of the breeder (top right) and prey (center). D2. This can result in emergent hunting patterns, such as encirclement (after Tang et al., 2012). Credit: Ahmed Labban.

Each wolf maintains a degree of individual agency within the pack (D3). As noted, the association of the pack is very loose. During the hunt, individual wolves often take individual initiatives, such as cutting off the prey (Mech et al., 2015). Each wolf actively participates in the overall goal or joint task in which the pack is engaged (D4). In this case, the focus is on hunting. The collective task of hunting may be the only activity around which the pack becomes cohesive enough to be considered a distributed cognitive system. Otherwise, a reductive account as is standard in accounts of social cognition may be appropriate.

There is a specialization of functions among the members of the pack (D5). The pack is hierarchical with the breeders at the top of the hierarchy (Mech et al., 2015). During the chase, the breeder serves as one of the two reference points for other wolves. Therefore, there are at least two functional differentiations among the wolves of the pack.

The cognitive behavior of the pack is complex and not limited to perception and locomotion (D6). Hunting is a goal-oriented process of gathering food. The wolf pack does not merely perceive and move towards the prey. It actively seeks to slay it in order to consume it. The hunt itself is a complex and demanding task and each individual actively engages in the task. Certainly this is far less complex of behavior than making falsifiable scientific claims about the age of the universe. Nevertheless, it is beyond the mere perception and locomotion that may characterize the simplest of cognitive systems (cf. Maturana & Varela, 1980; Thompson, 2007).

Non-Distributed Social Cognition in Flocks

The prototypical cases of distributed cognition are of very specific types of human institutions. Social cognition is not necessarily circumscribed to such specialized technical-scientific institutions or setups. The social cognition exhibited by wolf packs is appropriately treated as distributed cognition.[2] However, not all social systems, human or nonhuman animal, may be compatible with this concept. We present bird flocks as an example of nonreductive, but non-distributed, social cognition.

Flocks of birds vary in size across species and environments. They can range from less than a hundred to many hundreds of thousands of individuals. *Quelea quelea* flocks, for example, typically range from several to 500 birds but occasionally coalesce to form swarms of biblical proportions with comparable plague-like effects on agriculture (Crook, 1960). They migrate, evade predators, locate food and water, and navigate to roosts.

Flocks do exhibit some of the features of distributed cognition, but not all. Flocks are emergent (D1). Self-propelled particle (SPP) models, as well as empirical vector analyses captured by computerized cameras, have for the first time made possible the study of cognition as a property of collective systems (Baglietto, Albano, & Candia, 2013). SPP models show that global flock patterns and behavior can arise from a simple set of procedures governing the local interactions of individual birds (Bialek et al., 2012). In this respect, they are similar to wolf packs.

Bialek and colleagues (2012) model starling (*Sturnus vulgaris*) flocks by a set of procedures of alignment synchronization. Individual birds each align themselves with several proximal birds, henceforth coordinators (see Figure 2). The number of birds used for alignment synchronization is small, especially relative to the potentially enormous size of the flock itself. An increase in this parameter to a larger set of coordinators increases the entropy of the system, destabilizing the flock and breaking it apart into several smaller flocks (Castellana, Bialek, Cavagna, & Giardina, 2016).

There is a continuous coordination of birds within the flock (D2). The procedures of alignment synchronization are simple and consist of successive zones of attraction, repulsion, and orientation (Couzin, 2008). If the coordinator is too far away, the bird moves towards it (or is "attracted" to it). If the coordinator is too close, the bird moves away from it (or is "repulsed" by it). If it is neither too close nor too far, it maintains its orientation (cf. Couzin, Krause, James, Ruxton, & Franks, 2002). Kattas and colleagues (2012) find similar results in homing pigeons (*Columba livia domestica*) using a different method than Bialek and colleagues (2012), creating a model directly from recorded flight data. These local processes produce an emergent global order of flock movement (Cavagna, Giardina, & Ginelli, 2013). The apparently wispy and erratic movements characteristic of flocks are effects of the inherent noise arising from imperfect alignments (Cavagna, Duarte Queirós, Giardina, Stefanini, & Viale, 2013). This global

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[2] O'Donnell and colleagues (2015) describe wasp swarms as distributed cognitive systems, a usage inconsistent with the established definitions. This is an example of how the lack of an array of different concepts of nonreductive social cognition can leave some researchers forcing square pegs into round holes.

order in turn affects individual flight trajectories in local regions of birds.

Individual agency, to the degree to which it may exist to begin with, is not preserved in the flock. This violates D3. Individual birds within the flock, insofar as they constitute the flock, are not agentic in the same sense that a captain is free to abandon their ship. Nor do they express anything akin to the minimal agency of wolves in a pack. Individual wolves operate as a pack by a loose association and often act upon individual initiative (Mech et al., 2015). Birds in a flock, on the other hand, act predictably according to the basic processes of attraction, repulsion, and orientation. While flocks are noisy, the system's noise is constituted by the imperfect coordinating efforts of the birds.
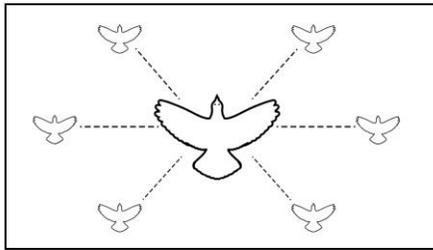

Figure 2: Individual birds within a flock coordinate their movements relative to the positions of a small number of proximal birds. Credit: Ahmed Labban.

In violation of D4, each bird does not actively participate in the overall goal or joint task in which the flock is engaged. When a flock evades a hawk, for example, the entire flock does not necessarily perceive the predator. This is especially true of larger flocks of tens of thousands of members or more. To evade the raptor, it is sufficient that a local group within the larger flock perceive and react to it. This local reaction, manifest as a sudden shift in flight paths, creates a ripple effect in the flock as the other birds attempt to realign themselves. In this case, the massive flock is not engaged in the joint task of predator evasion. Rather, a local group is engaged in predator evasion while the majority of the remaining birds are merely continuing to implement the processes of attraction-repulsion-orientation.[3] This situation contrasts markedly from that of wolves on the hunt, wherein each of the individual wolves perceives the prey and is actively engaged in hunting.

There is no significant specialization of functions among the members of the flock. Within the flock, each bird is more or less functionally isomorphic to the other birds. Hierarchies within flocks exist, but are fluid. "Leader" roles, such as directing migration routes (Mouritsen, 2003), are interchangeable and constantly shifting (Nagy, Ákos, Biro,

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[3] This may provide an alternate explanation for why individual vigilance against predators in *Quelea quelea* decreases with flock size (cf. Lazarus, 1979). Lazarus explains this effect in terms of an economy of energy, but it may simply arise from a situation in which only a local region of birds within the flock actively respond to predators.

& Vicsek, 2010). This contrasts with, for example, the captain of a ship or a pack breeder.

The behavior of the flock is limited to perception and locomotion, violating D6. Birds are individually complex and can perform a variety of functions besides moving and perceiving, such as fighting, mating, or raising offspring. Insofar as they constitute a flock, however, they are limited to basic procedures of attraction-repulsion-orientation.[4] These require only that 1) the bird perceives the coordinators, and 2) the bird adjusts its flight accordingly. The flock as a system likewise only perceives and moves. In the example of predator evasion, the flock (but not necessarily each member thereof) perceives the hawk and changes its flight patterns to evade it. Flocks do not fight, mate, or raise offspring. They are defined only as a perceptual-locomotive social system.

Crook (1960) notes curious synchronized, wave-like movements during feeding and drinking in *Quelea quelea*. While drinking, the birds collectively alternate their positions, moving forward birds who have not yet drank and moving back birds who have. These "wave-like progression[s]" (p. 5) are broadly consistent with a system of basic attraction-repulsion-orientation processes. Nevertheless, SPP studies of avian populations have yet to go beyond an analysis of flight patterns and this is a particular research desideratum.

Of the six criteria of distributed cognition, flocks satisfy only two. The concept of "distributed cognition" is too limited to capture the manifold manifestations of social cognitive systems. New concepts are needed to understand complex systems such as bird flocks. We introduce "swarm intelligence" as a concept capable of describing social cognitive systems with characteristics like flocks.

Swarm Intelligence as a Concept of Social Cognition

We appropriate the term 'swarm intelligence' from computing. In computing, swarm intelligence describes a set of optimization methods with emergent and self-organizing algorithms (Yang & Karamanoglu, 2013) inspired by bees, ants, wolves, and other collectivist organisms (Beekman, Sword, & Simpson, 2008). In our usage, "swarm intelligence" refers to a class of rudimentary and non-specialized social cognitive systems. The prototypical case we offer is the bird flock, although it may also cover cases such as schools of fish, mosquito swarms, and human crowds.

S is a swarm-intelligent system if:
S1. *S* is emergent.
S2. There is a continuous coordination of individuals as members of *S*.
S3. Individual agency is minimal insofar as the individual constitutes *S*.

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[4] The properties of the collective need not resemble the properties of its members (Hutchins, 1995a).

S4. The cognitive behavior of *S* is limited to perception and locomotion.

S5. Communication or interaction between members of *S* as they constitute *S* is minimal.

S6. The organization of *S* is relatively isomorphic, with no significant specialization of functions.

Flocks are emergent (S1). Overall flock movement in flight arises from the local processes of attraction-repulsion-orientation. This global order in turn affects the local movements of individual birds. Comprehending why one bird happens to be caught up in a swirling arm of a murmuration requires a dynamical systems analysis of the entire flock. There is a continuous coordination of individuals as members of the flock (S2). Individual birds orientate themselves continuously in reference to several neighboring birds (see Figure 2).

Individual agency is minimal insofar as the individual constitutes the flock (S3). We noted this earlier as a violation of D3. Regardless of how agentic individual birds may be, they do not exhibit any significant agency within the collective. The cognitive behavior of the flock is limited to perception and locomotion (S4). Flocks are restricted to evasion, migration, and food-locating behaviors. For example, while ants construct elaborate nests as a form of collective shelter, most birds are only capable of creating roosts individually.

Communication or interaction between members of the flock insofar as they constitute the flock is minimal and there is no communication of intentions (S5). While birds have complex modes of communication (e.g. birdsong), they do not directly communicate qua members of a flock. The only information indirectly communicated is relative distance and position. The organization of the flock is relatively isomorphic. There are no significant specializations of functions among members of the flock (S6). Some transient local leaders might guide flight away from predators or towards food sources, but these positions are not enduring.

Overall, swarm intelligence is far simpler than distributed cognition. It does not necessitate any shared goals or joint tasks and its cognitive functions are limited to perception and locomotion. Nevertheless, it may describe systems as varied as bird flocks, mosquito swarms, schools of fish, and human crowds. Indeed, schools of fish and human crowds appear to operate by the same basic processes of attraction, alignment, and repulsion as do flocks of birds (Couzin, 2008; Moussaid et al., 2009).

Conclusion: Towards a Taxonomy of Nonreductive Social Cognition

The field of social cognition remains dominated by reductionist and CRUM approaches. Since the mid-1990s, studies in distributed cognition have challenged this orthodoxy and demonstrated that social cognition can be understood from a nonreductive and systems perspective. Nevertheless, distributed cognition remains circumscribed in its applicability to different social cognitive systems. Its

paradigm cases are of human technical-scientific institutions. We provide formal criteria for the identification of distributed cognition consistent with Hutchins (1995a, 1995b), Giere (2006), and Kirsh (2006).

Distributed cognition remains useful for describing some systems that are nonhuman or non-technical-scientific, such as wolf packs. We demonstrate point-by-point how wolf packs are cases of distributed cognition. However, this concept is inappropriately applicable to many other social cognitive systems. We offer bird flocks as a counterexample to distributed cognition and propose "swarm intelligence" as an alternative concept of nonreductive social cognition. These two forms of social cognition are not proposed as absolute categories, but rather as relative points of difference between which gradations may exist.

The implications of this are significant. Beyond flocks, swarm intelligence is potentially found among schools of fish, mosquito and other flying insect swarms, and human crowds (cf. Moussaid et al., 2009). Swarm intelligence does not operate in lieu of distributed cognition. Nor is it the only alternative type of nonreductive social cognition. New concepts are needed to establish a more accurate taxonomy of nonreductive social cognition as diverse as the phenomena under investigation. Such a taxonomy allows the many and varied phenomena of social cognition to be recognized as such and studied through an appropriate theoretical lens (cf. O'Donnell et al. 2015 for a misattribution of distributed cognition in part due to such a lack of diversity).

As we have demonstrated, wolf packs or the HST do not operate by the same organizational principles as do bird flocks. This is not surprising given their radically different structures, functions, and components. What is far more surprising is that wolf packs operate, on an abstract level, analogously to certain technical-scientific institutions. Still other types of social cognitive systems await discovery. Ant colonies may not be well described by either distributed cognition or swarm intelligence. For example, unlike birds in a flock, ants have up to 12 modalities of communication (Hölldobler & Wilson, 1990). Furthermore, they are able to engage in intricate collective projects such as nest building without a central planner. Ultimately, the project of creating a taxonomy of different social cognitive systems will serve to delineate and extend the outer bounds of the concept of "cognition."

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