

COMPARATIVE COGNITION & BEHAVIOR REVIEWS

Collaboration, Exploitation, and Distributed Animal Cognition

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In this commentary, I explore the space of “distributed cognition” across human and nonhuman animal cognition. First, I distinguish between three varieties in which cognition can be socially distributed and consider their respective implications for the conjectured relationship between group size (social complexity) and individual brain size (cognitive complexity). Second, I probe the relationship between distributed (collaborative) and extended (exploitative) cognition in contexts where our anthropomorphic understanding of this distinction begins to fade.

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As a card-carrying proponent of “4E cognition” approaches to cognitive science, which strive to understand mind and cognition as *embodied*, *embedded*, *extended*, and *enactive* phenomena, I am grateful to Ken Cheng’s erudite and insightful undertaking to bring animal cognition under the ambit of 4E cognition. In his own taxonomy, he ditches the “embedded” strand but adds the important facet of distributed cognition (DC), for which again I am thankful, because a concern with DC as a central feat of human cognition has been at the center of my own philosophical work. With my commentary, I seek to explore the space of DC across human and nonhuman animal cognition and probe the relationship between distributed and extended cognition in contexts where our anthropomorphic understanding of this distinction begins to fade.

My first observation concerns the conjectured relationship between group size (social complexity) and individual brain size (cognitive complexity). Assuming a rather straightforward correlation between the two, we

are told that the DC hypothesis (at least as applied to eusocial species; cf. O’Donnell et al., 2015) and the social brain (SB) hypothesis (Dunbar, 1998) yield conflicting predictions about the direction of this correlation (p. 3). As Cheng recounts the debate, DC generally predicts that brain size is expected to *decrease* with group size, because larger groups afford a greater differentiation of cognitive labor. Because this is assumed to reduce the cognitive load on any given member of the group, they can get by with smaller nervous systems (thereby cutting down metabolic costs). This prediction is said to stand in contrast to SB, which asserts a positive correlation between group size and brain size, exacted by the greater cognitive demands of sociality in primate modes of group living, for example, reciprocal altruism and coalition formation, but also resource competition and social deception.

I have my doubts that “Cheng’s conjecture” about DC (as I refer to it) holds at the suggested level of generality if we consider the full gamut of “socially distributed

cognition.” Without a careful analysis of cognitive task requirements, the assertion of any straightforward correlation between DC and brain size (or, more generously, individual cognitive complexity) must be viewed with suspicion. To begin with, whenever we analyze socially distributed cognition, we have to take into account two kinds of cognitive labor: first, the cognition required of individuals to perform the task at hand, and second, the cognition required to coordinate the task-specific cognitions that are distributed across individuals (Hutchins, 1995). Clearly, whatever organizational regimes are installed to regulate the division of labor greatly impact the kinds of cognitive tasks that individuals have to perform in particular group settings, which in turn affect the coordination requirements for putting them back together (cf. Davies & Michaelian, 2016; Goldstone & Gureckis, 2009; Theiner, 2017). I now describe three types of socially distributed cognition—each of which I illustrate with a concrete example—that differ qualitatively among each other with respect to the relationship between social and individual cognitive complexity, and thus bear directly on the plausibility of Cheng’s conjecture.

My example of DC1 is the ability of schooling fish—golden shiners, in this case—to track surrounding patterns of light by virtue of swarm intelligence (Berdahl, Torney, Ioannou, Faria, & Couzin, 2013). Being able to sense environmental gradients such as light, temperature, or salinity is a vital necessity for migrating animals, generally taken to require significant amounts of cognitive sampling and comparison, integrated over time. Single shiners, it turns out, are underachievers in this area. When exposed to shifting patterns of light, single fish perform only marginally better than random at staying in their preferred habitat, which is shaded (dark) waters. Incapable of tracking gradients, they follow a rudimentary, nondirectional rule to “swim slower when it’s dark here.” But in addition, shiners have a strong social instinct to stay close to their neighbors. As a result, if a few of them hit a darker patch and thus slow down, the rest of the shoal swivel into the shade; once inside, they all slow down, bunching up within the darkest region.

Important to note, a shiner’s decision to move is influenced far more by social than environmental cues.

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Although single shiners perform only local, scalar measurements, the collective gradient-tracking ability of the shoal emerges from the social dynamics of local interactions, the accuracy of which substantially increases as a function of group size. Applied to behaviorally equivalent instances of DC1, Cheng’s conjecture has a lot of purchase. Conceived as an emergent group-only feat, collective sensing has the advantage of being a fault-tolerant, cost-effective strategy that poses only minimal cognitive demands on the individual. From an evolutionary perspective, viewing the behavior of the collective as an adaptation to compensate for individual cognitive limitations, we should expect that the benefits reaped from higher level information processing relax the selection pressures on individuals’ cognitive abilities.

Let me contrast the preceding case, then, with a distinct kind of DC2 that we find exemplified in the house-hunting abilities of honeybees (cf. Seeley, 1995, 2010, for reviews). In particular, I am interested here in the mechanisms by which the hive negotiates the speed–accuracy trade-off to maximize its chances of choosing the best available nest site. In this process, a search committee of several hundreds of “scout bees” is sent out, roaming the surrounding area in search of potential targets. Upon return to the hive, they draw others’ attention to good sites they have discovered by performing a “waggle dance”; the dance orientation indicates the site location, and the duration indicates the site quality. Initially, the search is random, but as a result of observing other bees’ dancing, scouts are more likely to investigate attractive sites advertised by others. If, after inspection of the site, they agree with the assessment, a scout will join the dance, which further increases support for popular sites. Once a certain threshold (“consensus”) is reached, the hive as a whole decides to move there. Does the observed distribution (DC2) of cognitive labor lend support to Cheng’s conjecture?

The answer is not as straightforward as in the first case if we break down the cognitive task requirements of nest choice as a collective decision-making problem. Following List and Vermeule (2014), we ought to distinguish between the “epistemic agenda-setting” stage, during which a collective settles on a range of options among which it will eventually decide, and the “stage of choice” in which this decision is made. For the hive to succeed, each individual agent (scout bee) must be able to (a) roam the space of possible options and identify noteworthy candidates, (b) make comparative assessments and rank these options, and (c) communicate to one another which options are worth considering. As

List and Vermeule showed, a speedy consensus for high-quality sites can be reliably reached only with the right admixture between *interdependence* at the agenda-setting stage and *independence* at the voting stage. The independence condition implies that each scouting bee must be able to assess the quality of a site it comes across and share that information in a way that positively (albeit imperfectly) correlates with that quality. The strength of this correlation can be taken to represent the individual bee's cognitive competence.

Unlike the collective sensing of golden shiners, where the shoal solves a problem that no fish is individually capable of cognizing, the cognitive competence displayed by individual scout bees lies in the same task domain as the decision at which the hive collectively arrives. The "wisdom of the hive" here stems mainly from pooling imperfect individual estimates of nest site quality in ways that effectively cancel out one another's errors (cf. Simons, 2004). This outcome is formally related to Condorcet's jury theorem, which states that majority rule will lead a group to choose the best option in such cases provided that individual judgments are positively correlated with the objectively best choice, and mutually independent (e.g., Grofman, Owen, & Feld, 1983). With the right blend of interdependence and independence (see earlier), moderate levels of individual cognitive competence (e.g., performing the waggle dance) are sufficient to secure the desired outcome (List & Vermeule, 2014). Still, the competence condition puts a lower bound on the cognitive complexity of individual bees that is necessary for the hive to succeed. This makes nest choice in honeybees, as a type of DC2, a scenario for which the validity of Cheng's conjecture is not evidently true.

My third and final example are collaborative interactions that go beyond basic cooperation insofar as they require distinctive forms of "we-thinking" or *joint intentionality* over and above *individual intentionality* (cf. Jankovic & Ludwig, 2017; Tomasello, 2014). Individual intentionality, as I use the term here, refers to the suite of cognitive competencies for engaging in flexible, goal-directed, individually self-regulated behavior. Consider tool use. Compared to other primates, great apes are especially skillful in making and using an open-ended variety of tools in insightful, often creative ways. For example, chimpanzees have been observed using both stone (or wooden) cleavers and stone anvils to fracture large fruit into smaller, bite-sized portions (Koops & McGrew, 2010). This implies an instrumental understanding of how cleavers have to be wielded to pound the fruit and how fruit has to be pounded on the rocky

outcrops that serve as anvils. More generally, individual intentionality involves the ability to represent causally and intentionally relevant features of a situation, choose actions that lead to fulfillment of one's goals, and self-monitor and evaluate specific behavioral outcomes vis-à-vis those goals.

Joint intentionality, as understood here, is an "upgraded" form of individual intentionality, repurposed for the collaborative pursuit of shared goals with a division of labor, often involving role specialization. A canonical model of collaboration in this sense is the "stag hunt" scenario known from game theory (Skyrms, 2004). Famously discussed by Rousseau, it describes a group of two (or more) individuals going out on a hunt. Each can get a hare by herself, but a hare is worth less than a stag, which the hunters can get only by joining forces, thereby incurring the risk that others might defect. Shared collaborative activities are cognitively more demanding than basic forms of cooperation or altruistic behavior. They require of each participant the ability to represent a goal that "we" aim to fulfill working *together* (rather than in parallel), with "you" and "me" simultaneously playing different but complementary parts, in mutually responsive ways, and an at least implicit understanding that "our" roles are (in principle) interchangeable. As Tomasello (2014) and others have argued, the coordinative and communicative requirements for joint intentionality depend on advanced psychological abilities and motivational propensities that are different in kind from those associated with individual intentionality. For example, to jointly engage in collaborative activities, participants need to attend to and conceptualize one and the same situation under different, perhaps even conflicting, perspectives ("This is how it must look from your point") and draw specific kinds of socially recursive inferences ("Given our shared goals, you'd expect me to think this is what you'll do"). Collaborators must also monitor and regulate their behavior with respect to the normative standards of the group, with a shared commitment to uphold their parts in the process, such as helping one's partner if necessary, sharing the spoils, and so forth.

Somewhat controversially, Tomasello has argued that joint intentionality is a species-specific human cognitive trait that is not found among nonhuman primates. I won't weigh in on this ongoing debate here, although it seems a safe bet that neither golden shiners nor honeybees have the cognitive prerequisites for joint intentionality. For present purposes, suffice it to note that the ability to engage in shared collaborative tasks requires, but

at the same time enables, varieties of socially distributed cognition (DC3) that go against Cheng's conjecture. In this respect, DC3 concurs with SB that we should expect a positive correlation between increases in social and cognitive complexity. However, the difference is that Tomasello and colleagues have placed a unique emphasis on collaboration and cooperative communication ("Vygotskian intelligence"; cf. Moll & Tomasello, 2007) as evolutionary drivers of joint intentionality, as displayed by humans, as opposed to the evolutionary focus on social competition and instrumentalist manipulation within the "Machiavellian intelligence" tradition (Byrne & Whiten, 1988; Humphrey, 1976).

Thus far, in my attempt to disambiguate the multifaceted notion of DC, I have taken for granted that all of the preceding varieties of DC are deployed in the service of group-level tasks. Indeed, it is hardly controversial to subsume the collective sensing of a shoal, the foraging and relocation patterns of honeybees, and the shared collaborative practices of humans under the banner of collectively intelligent behavior, in the fairly modest sense that intelligent groups are responsive to environmental contingencies; exhibit a division of labor; and can adapt to novel situations in flexible, goal-directed manners. As Cheng is well aware (p. 3), this somewhat conservative notion of collective intelligence does not exactly upset the Cartesian apple cart unless it is further argued that certain collectives form *cognitive systems* in their own right, with emergent cognitive states and processes that are distinct from those of their members.

Although there is a long tradition of comparisons between social insects and human beings, referring to not only their social but also cognitive organization (cf. Hofstadter, 1979), there has been a flurry of recent work on "colony-level cognition" (Marshall & Franks, 2009) that has brought to light deep structural correspondences between the ways in which brains and insect colonies gather, integrate, and process information (cf. Couzin, 2009; Seeley, 2010). For example, there are common mathematical models of the physically diverse mechanisms that underlie, for example, both migrating choices of ants and honeybees and motion discrimination of the primate visual cortex. Adopting this more liberal, functionally oriented perspective on DC holds great promises for unifying the study of individual and collective cognitive systems in revealing ways (Huebner, 2013; Theiner, 2017; Theiner, Allen, & Goldstone, 2010). From a network-theoretic perspective, Goldstone and Theiner (2017) reviewed a number of cognitive mechanisms involved in perception, attention, memory, and problem

solving that have been attested at both individual and group levels, to argue for a "nonzero sum" perspective relating multiple, interacting levels of cognition.

The second main point on which I wish to reflect further is the relationship between (individual) tool use and (social) cooperation as potential vehicles of extended cognition. In his discussion of extended animal cognition, Cheng describes the cooperative efforts of weaver ants in constructing their nests from leaves, such as pulling them into shape, bending the foliage, and drawing their edges toward one another. The collective nest-building activities of weaver ants are another instance of DC, of course, but my focus here lies on Cheng's treatment of the ants' recruitment of silk-dispensing larvae (of their conspecifics) as a putative example of "extended cognition" (pp. 6–8). These larvae, which workers retrieve from nearby nests, secrete sticky substances that they normally use to spin their cocoons but are reused by the workers in this context to glue together the edges of leaves. As Cheng points out, the selection and handling of the larvae requires great care: First, the larvae to be chosen must be neither too young nor too old, their heads must be tapped in a special way to secrete the silk, and the workers need to maneuver diligently from edges to edges to make sure the silk-glue is applied in just the right way.

Appealing to Kaplan's (2012) "mutual manipulability" criterion, Cheng proposes that we view the workers' glueing behavior as a manifestation of *extended* cognition, thereby likening the workers' use of other live organisms, the larvae, to an environmental resource or tool. To show that Kaplan's criterion is satisfied, Cheng argues that a two-way communication ("signaling") is taking place between the worker and the larva. In one direction, a worker's cognitive state affects her handling of the glue stick (e.g., placement and timing); in the other direction, the silk-secreting (or lack thereof) behavior of the larva is taken as a signal modulating the worker's tapping. This raises the question, On what grounds exactly do we consider this mutual arrangement as an instance of environmentally (or technologically) *extended* worker cognition, rather than as socially *distributed* worker-larva cognition?

In the case at hand, this may be a moot issue because the contribution of the larva is behaviorally (let alone cognitively) minimal to an extent that it essentially functions as nothing but a glue stick—a mere tool. But if we take human intuitions as our guide, shared *collaborative* interactions among people are categorically distinct from a single person's *exploitative* incorporation of an

external artifact (cf. Huebner, 2016; for an interesting discussion of borderline cases, see Blomberg, 2011). Must we leave such anthropomorphic sentiments behind in the analysis of situated animal cognition? If not, then what might distinguish genuine *social cooperation* (or collaboration) from what should be more aptly described (as Cheng does) as *socially extended tool use*? Kaplan's mutual manipulability criterion, I surmise, is not fine-grained enough to differentiate between the causal couplings that underlie exploitative tool use from social collaboration. To show this, let us contemplate another evocative scenario in some detail.

My example draws on Turner's (2002) groundbreaking analysis of the collective intelligence of mound-building termites (of the *Macrotermes* genus). Scattered across the savannas of Southern Africa, termite mounds function as impressively engineered respiratory devices ("external lungs") for the colony, built to capture wind energy that ventilates the subterranean nest and to facilitate gas exchange. The structure and function of the mound is exquisitely adapted to serve the ventilation needs of a termite colony, which contains not only millions of workers but a considerably larger biomass of fungi, which they cultivate. Collectively, it is estimated that these organisms consume oxygen at the rate of a goat or cow. Thus, the maintenance of a viable nest atmosphere in which ventilation rate matches the respiratory demands of the colony (which can vary considerably) presents a formidable challenge. As Turner described in great detail, the termites succeed in this task by turning the mound into a "smart" organ of homeostasis.

Using Kaplan's criterion, we can show that the dynamic architecture of the mound—an abiotic structure—is part of the extended physiology of the colony (see Turner, 2002, Chapter 11). As an ongoing source of disturbance, soil is continually eroded from the mound, which termites replace by transporting soil from inside to the corresponding surface location. For the mound to serve as an organ of homeostasis, the respective rates and patterns of external erosion from, and internal deposition to, the mound must be finely tuned, and dynamically coupled to the desired composition of the nest atmosphere. That is, if the mound is hyperventilating, this will trigger patterns of soil movement that reduce the mound's capture of wind energy; conversely, a detected lack of oxygen will trigger patterns of soil transport that enhance the air flow into the mound. Hence, the termites and the mound stand in a relationship of "mutual manipulability."

As a potential contrast, consider the relationship between the termites and fungi (*Termitomyces*), which termites cultivate in large structures ("fungus combs") that take up most of their nest interior. This interspecies relationship is commonly described as a "mutualistic cooperation" or "symbiosis." But by the preceding token, one could argue that the fungi are really extracorporeal parts of the termites' digestive systems. They are digestive aids, "mere (biotic) tools" recruited by insects to convert otherwise indigestible cellulose into more nutritious compost that the termites can consume. Invoking Kaplan's criterion, once again, reveals that the behavioral patterns of the two species are dynamically coupled, mediated by the structure of the combs. The combs as such are composed of macerated woody materials, collected and chewed up by foragers. When they return to the nest, after a quick pass through their guts, the foragers excrete the material, which immediately gets picked up by nest workers who add it on the top of the combs. Somewhere along the way, the woody materials are inoculated with fungal spores, which—once deposited in the comb—grow and begin to spread. The fungi, in turn, play an indispensable metabolic role: They break down cellulose into simpler sugars and nitrogen on which the termites feed, from the bottom of the comb. Again, the two parties stand in a relationship of mutual manipulability, but we should take heed that their causal entanglement is symmetrical. That is, might we not equally conclude—as Turner is fond of quipping—that the *Macrotermes* mound should perhaps be viewed as a *fungus*-built structure, where fungi cultivate termite populations to act as homeostatic regulators?

My bigger question, expressed in Cheng's terminology, is thus whether there is a principled distinction between socially *distributed* and socially (or technologically?) *extended* animal cognition that does not simply turn—in a potentially question-begging manner—on intuitive considerations as to what constitutes a living organism and what doesn't. As I have argued, Kaplan's purely causal criterion seems ill-equipped to discriminate between these two types of situated cognition. Are there any distinctively cognitive or social task requirements that might underpin such a distinction, similar to how shared intentionality differs from cognitively less demanding modes of cooperation? Or must we conclude that our intuition to delineate sharply between DC and extended cognition is an anthropomorphic (or perhaps animal-centric!) reflex, charged with moral overtones that, for the most part, have no purchase in comparisons with other phyla?

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