Eroding the Boundaries of Cognition: Implications of Embodiment[1]

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Abstract

To accept that cognition is embodied is to question many of the beliefs traditionally held by cognitive scientists. One key question regards the localization of cognitive faculties. Here we argue that for cognition to be embodied and sometimes embedded, means that the cognitive faculty cannot be localized in a brain area alone. We review recent research on neural reuse, the 1/f structure of human activity, tool use, group cognition, and social coordination dynamics that we believe demonstrates how the boundary between the different areas of the brain, the brain and body, and the body and environment is not only blurred but indeterminate. In turn, we propose that cognition is supported by a nested structure of task-specific synergies, which are softly assembled from a variety of neural, bodily, and environmental components (including other individuals), and exhibit interaction dominant dynamics.

Keywords: Embodied cognition; Dynamic systems; Social coordination; Modularity; Faculty psychology

From long before psychology became a separate scientific discipline, it has seemed useful to think of the mind as a collection of separate faculties. For example, in the late 18th century, Thomas Reid separated out judgment, reason, memory, and conception, among other intellectual faculties, to go alongside a suite of other faculties, including moral faculties and the will. Later, most famously in the hands of Franz Gall in the 19th century, each of these faculties was associated with a specific brain area, as can be seen in the phrenological diagrams produced at the time. In the intervening 200 or so years, these ideas have gone in and out of fashion several times. Both are decidedly in fashion at the moment. In cognitive science, it has long been fashionable to take cognitive abilities to be separable from one another and to take experiments to be about, for example, attention, but not also about

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conception or memory. This is the case because most cognitive psychologists take the cognitive faculties to be separable modules (see, e.g., Fodor, 1983; Uttal, 2003). Evolutionary psychologists take this even farther and posit ''massive modularity'' (Cosmides & Tooby, 1992), according to which there are far, far more faculties than Reid ever dreamed of, each with its own evolutionary history. Advances in neuroimaging have led cognitive neuroscientists to identify the brain areas that are especially active in the exercise of these faculties.

This is the scientific state of the art in which recent research on embodiment in cognitive science is set. The cornerstone of that research is the notion that behavior, bodily structure, and environmental resources are far more deeply implicated in an adequate explanation of cognition than the outline above would suggest. The variety of research investigating this very general claim includes such things as work on the role that neural resources involved in motor-control might play in supporting higher order cognitive processes like language understanding (Glenberg & Kaschak, 2002; Pulvermüller, 2005); investigations into the influence that metaphorical mappings from elements of our embodied experience like moving around or standing upright might have on the way we think about abstract things like planning or morality (Lakoff & Johnson, 1999); experiments documenting the influence of bodily sensations like weight and warmth (Ackerman, Nocera, & Bargh, 2010; Williams & Bargh, 2008) or bodily actions like extending one's finger (Chandler & Schwarz, 2009) on cognitive processes like interpersonal judgment; considerations of the circumstances under which the manipulations of external resources must be considered to be part (and not just a causal side effect) of cognitive processing (Clark & Chalmers, 1998); and demonstrations of the influence of coordination dynamics on perception, action, and cognition (Chemero, 2009; Kelso, 1995).

We will discuss many of these research programs below, but our aim in this paper is not simply to catalog the array of interesting findings implicating body and environment as part and parcel of cognitive processing. Instead, we will argue that embodiment research questions some of the most deeply held beliefs in the cognitive sciences. First, it makes the localization of the cognitive faculties in specific brain areas problematic. It is not hard to see why this is the case: If the exercise of cognitive faculties happens in the body and, sometimes, the local environment, along with portions of the brain, one cannot localize the cognitive faculty in a brain area alone. Perhaps more surprisingly, recent research on embodiment also makes the identification of separate cognitive faculties problematic. Or, to put the matter differently, we will argue that one effect of research on embodiment is to undermine the architectonic principle of this special issue. One cannot isolate ''cognitive'' psychology from the study of perception, action, and social interaction. This essay, then, will not be about research on embodiment as pursued within cognitive psychology but about the nature of the cognitive system in light of research on embodiment.

To argue that research on embodiment has these effects, we will rely on four related concepts that might be unfamiliar to some readers: soft assembly, interaction dominance, synergy, and 1/f scaling. For convenience, we define these concepts here.

Certain systems, such as an automobile or a laptop computer, are composed of a series of parts, each of which has a particular role that it fulfills. Other systems, such as flocks of birds, are more fluidly put together. In the latter case, it doesn't matter which particular birds

are part of the flock—any old bird will do—and each bird is capable of taking up each position in the flock. Indeed, during flight each bird will take up multiple positions in the flock. The flock is softly assembled, in that it is composed of a temporary coalition of entities, engaged in collaborative task. Some softly assembled systems exhibit interaction-dominant dynamics, as opposed to component-dominant dynamics. In component-dominant dynamics, behavior is the product of a rigidly delineated architecture of modules, each with predetermined functions; in interaction-dominant dynamics, on the other hand, coordinated processes alter one another's dynamics and it is difficult, and sometimes impossible, to assign particular roles to particular components. Sometimes softly assembled systems exhibiting interaction-dominant dynamics are called synergies. A synergy is a functional grouping of structural elements (molecules, genes, neurons, muscles, limbs, individuals, etc.) that are temporarily constrained to act as a single coherent unit (Kelso, 2009).

Work this decade has shown that 1/f scaling (a.k.a., 1/f noise or pink noise or long memory) is ubiquitous in smooth cognitive activity. 1/f scaling is temporal long-range dependencies in the fluctuations of a repeatedly measured behavior or activity. Analogous to spatial fractals, 1/f scaling denotes a fractal or self-similar structure in the fluctuations that occur over time (within a time-series of measurements). That is, higher frequency, lower amplitude fluctuations are nested within lower frequency, higher amplitude fluctuations as one moves from finer to courser grains of analysis (see, e.g., Holden, 2005; Kello & van Orden, 2009 for a more detailed description). 1/f scaling indicates that the connections among the cognitive system's components are highly nonlinear (Ding, Chen, & Kelso, 2002; Holden, Van Orden, & Turvey, 2009; Kello et al., 2010; Riley & Turvey, 2002; Van Orden, Holden, & Turvey, 2003; van Orden, Holden, & Turvey, 2005). This nonlinearity indicates that cognitive systems are not modular. When systems are nonlinear, operations are not easily localizable to a relatively small spatial or temporal region of the system but rather are distributed throughout the system. Therefore, the ''parts'' of the system cannot be treated as truly structurally or functionally separate for the purpose of localization. The systems are synergies.

In the remainder of this paper, we will present a series of cases in which embodied cognitive science (ECS) provides evidence that the systems responsible for cognition are synergies, softly assembled systems which exhibit interaction-dominant dynamics. This, we will argue, plays havoc with attempts to localize cognitive faculties in circumscribed locations and, even, to understand the cognitive faculties as separate from one another.

1. Breaking down boundaries in the brain

Interestingly, it is in part because ECS shares some fundamental assumptions with evolutionary psychology (EvoPsy) that it parts company with that sub-field on the topics of faculty psychology and modularity. A long-standing guiding principle of both ECS and EvoPsy is that cognition was built within a system primarily fitted to situated action. The central nervous system—the neocortex most definitely included—is first and foremost a control system for an organism whose main job is managing the myriad challenges posed by its environment. ''Higher'' cognitive faculties like language and abstract reasoning had to find their

neural niche within the constraints imposed (and the opportunities offered) by the way existing neural resources were deployed for this purpose, in a way mediated and guided by whatever continuing selection pressure there is to maintain fast, effective, and efficient solutions to pressing environmental challenges. Insofar as this is true, then—and this is the other guiding principle shared between EvoPsy and ECS—this phylogenetic history should have left detectable traces on both brain and behavior. Where EvoPsy and ECS part company is in their understanding of what those traces will look like and where to find them. In particular, ECS operates on the fundamental assumption that resource constraints and efficiency considerations dictate that whenever possible neural, behavioral and even environmental resources should have been reused and redeployed in support of any newly emerging cognitive capacities. Cognition, that is, is largely supported by ''old wheels, springs and pulleys only slightly altered'' and reconfigured to serve present purposes.

A logical place to look for evidence of such a history is in the distribution of and relationships between the neural circuits supporting various cognitive functions. ECS predicts that neural circuits originally evolved for one purpose will be reused in later developing functionality. And indeed there has been a long history of experimental work demonstrating exactly this. There is, for example, ample evidence that verb retrieval tasks activate brain areas involved in motor control functions, and naming colors and animals (i.e., processing nouns) activates brain regions associated with visual processing (Damasio & Tranel, 1993; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Martin, Ungerleider, & Haxby, 2000; Martin, Wiggs, Ungerleider, & Haxby, 1996; Pulvermüller, 2005). Similarly, it appears that perceiving manipulable artifacts, or even just seeing their names, activates brain regions that are also activated by grasping (Chao & Martin, 2000). And there are myriad demonstrations of interactions between language and motor control more generally, perhaps most striking the recent findings that manipulating objects can improve reading comprehension in school-age children (Glenberg, Brown, & Levin, 2007).

Demonstrations of the use of perceptual and motor circuits in higher order cognition are not limited to language. For instance, Casasanto and Dijkstra (2010) describe bidirectional influence between motor control and autobiographical memory. In one experiment, participants were asked to recall positive or negative autobiographical memories while moving marbles between two boxes, either up or down. They found that participants moved marbles more quickly when the valence of the memory was congruent with the direction of motion (up = positive, down = negative). In the reverse condition, participants were given a neutral prompt to recall an autobiographical memory while moving marbles either up or down. Casasanto and Dijkstra found that the valence of the memories tended to be congruent with the direction of motion. The results suggest that emotional experiences and motor schemas are mutually interrelated, each able to activate the other. There is also some interesting evidence from the neuroimaging literature. For example, Dagher, Owen, Boecker, and Brooks (1999) demonstrate that abstract planning can activate motor areas even when the task to be planned itself involves no motor activity; and several studies have found evidence for the involvement of hand motor circuits in number processing (Andres, Seron, & Oliver, 2007; Roux, Boetto, Sacko, Chollet, & Tremoulet, 2003; Rusconi, Walsh, & Butterworth, 2005; Zago et al., 2001).

All the studies cited above were conducted specifically to find such relationships expected to exist between specific kinds of tasks. But recent meta-analyses suggest that such neural overlaps between disparate cognitive functions are the general rule. Most recently, Anderson (2010) and Anderson and Pessoa (2011) conclude from a review of 1,469 fMRI experiments in 11 task domains (including vision, audition, attention, emotion, language, mathematics, memory, abstract reasoning, and action execution, inhibition, and observation) that a typical anatomical region (as delimited, for example, by Freesurfer) is involved in supporting multiple tasks across nine separate cognitive domains. Even relatively small pieces of neural real estate (equivalent to 1/1000th of the brain) typically support tasks across more than four of these domains.

Perhaps more important, earlier work by Anderson demonstrated that the differences between cognitive domains are marked less by differences in the neural circuitry devoted to each, and more by the different patterns of cooperation between mostly shared circuitry (Anderson, 2008). In addition, it appears that the functional complexes supporting tasks in newer—more recently evolved—cognitive domains utilize more and more widely scattered circuitry than do the complexes supporting older functionality like vision and motor control (Anderson, 2007, 2008).

Together these findings strongly suggest an evolutionary pathway favoring the re-use and reconfiguration of existing circuitry to support new functionality, over the generation of new dedicated circuitry for each emerging purpose. At the very least, this indicates the implausibility of anatomical modularity. It also suggests that functional brain dynamics are interaction-dominant, that cognition is supported by coalitions of neural circuitry temporarily assembled to support the specific tasks at hand. Indeed, there is growing evidence that neural circuits are soft-assembled and interaction dominant. Several studies have found evidence of 1/f scaling in human neural activity (e.g., Bressler & Kelso, 2001; Bullmore et al., 2001; Buzsaki, 2006; Linkenkaer-Hansen, Nikouline, Palva, & Ilmoniemi, 2001). More recently, He, Zempel, Snyder, and Raichle (2010) have extended these latter findings by demonstrating that human arrhythmic brain activity contains mutually nested and coupled frequency scales—lower frequencies of brain activity modulate the amplitude of higher frequencies—a dynamic property not only characteristic of interaction-dominant systems but only exhibited by interaction-dominant systems. But it also recommends reflection on the reliability of our current cognitive ontology and the sharp boundaries between psychological faculties. If language and motor control and memory and vision and abstract reasoning—perception, action, cognition—are all supported by a shared pool of domain-unrestricted functional components, then this suggests that segregating the study of mind into those particular neighborhoods is more likely gerrymandering than carving nature at its joints. This is perhaps the most important, and most potentially transformative (not to say disruptive) of the many implications of ECS.

2. Breaking down boundaries between the animal and environment

Just as ECS has made modularity within the brain less plausible, it has also made it more difficult to separate the brain from the body and environment. This has been a major theme

of each of the disparate research programs that make up ECS. Although our focus in this section will be on a particular program in nonlinear dynamical modeling, similar points could be made via other sets of findings. Van Orden et al. (2003) argue that 1/f scaling found in an inventory of cognitive tasks is a signature of a ''softly assembled'' system exhibiting and sustained by interaction-dominant dynamics, and not component-dominant dynamics. As noted above, in component-dominant dynamics, behavior is the product of an architecture of components, each with pre-determined functions; while in interaction-dominant dynamics, parts of the system alter the dynamics of the other parts, with complex interactions extending to the body's periphery. When a participant is engaged in an experiment, a portion of her bodily and neural resources, along with environmental support structures, assemble themselves into a temporary, task-specific device (see, e.g., Kello, Beltz, Holden, & van Orden, 2007; Kello & van Orden, 2009; Van Orden et al., 2003 for an more extensive discussion). Soft device assembly as the product of strongly nonlinear interactions within and across the temporal and spatial scales of elemental activity can account for the 1/f character of behavioral data, while assembly by virtue of components with predetermined roles and communication channels cannot. Put in terms that make the contrast with modularity and faculty psychology most clear, only when dynamics are component dominant is it possible to determine the contributions of the individual working parts to the overall operation of the system. In other words, only systems with component-dominant dynamics can be modular; when dynamics are interaction dominant, it is difficult to localize the aspects of particular operations in particular parts of the system.

1/f scaling has been observed in the brain, and in a wide variety of cognitive and behavioral tasks, from tapping, to key pressing, to word naming, and many others (see van Orden, Kloos, & Wallot, 2009; for a review). This indicates that the task-specific, softly assembled systems encompassing portions of the participants' brain and body were responsible for the performance of the experimental task. That the portion of the cognitive system that engages in tasks such as these is not fully encapsulated in the brain is perhaps not that surprising, since each has a strong motor component. But we also see 1/f scaling in ''purely cognitive'' phenomena. In one example, Stephen, Dixon, and Isenhower (2009) and Stephen and Dixon (2009) have modeled insight in problem solving as a phase transition in a non-equilibrium dynamic system. They found that learning a new strategy for solving a problem coincides with the appearance of 1/f scaling, as measured in eye movements. This indicates that even leaps of insight do not occur in the brain alone—the eye movements are part of the cognition. As with the evidence from brain imaging discussed above, findings such as this impact not only the extent of the biological resources required for cognitive faculties but also the separation of cognitive faculties from one another. Finding that moving eyes are components of the interaction-dominant system that has the problem-solving insight makes it more difficult to separate cognition from motor control.

There is reason to think that this expansion of the cognitive system does not stop at the boundaries of the biological body. For example, Dotov, Nie, and Chemero (2010, in press) and Nie, Dotov, and Chemero (in press) describe experiments designed to induce and then temporarily disrupt an extended cognitive system. Participants in these experiments play a simple video game, controlling an object on a monitor using a mouse. At some point during

the 1-minute trial, the connection between the mouse and the object it controls is disrupted temporarily before returning to normal. Dotov et al. found 1⁄f scaling at the hand-mouse interface while the mouse was operating normally, but not during the disruption. As discussed above, this indicates that, during normal operation, the computer mouse is part of the smoothly functioning interaction-dominant system engaged in the task; during the mouse perturbation, however, the 1⁄f scaling at the hand-mouse interface disappears temporarily, indicating that the mouse is no longer part of the extended interaction-dominant system. These experiments were designed to detect, and did in fact detect, the presence of an extended cognitive system, a synergy that included both biological and non-biological parts. The fact that such a mundane experimental setup (using a computer mouse to control an object on a monitor) generated an extended cognitive system suggests that extended cognitive systems are quite common.

This evidence from a specific variety of dynamical modeling in ECS converges with other evidence concerning the extension of cognitive systems beyond the biological body to incorporate tools. Cardinali et al. (2008) show that just as neurological changes must occur over developmental time to maintain effective control over a changing body, they also occur over very short time stretches. They found that using a reaching tool, which extends the effective reaching distance by participants by 40 cm, led to behavioral and perceptual changes after participants no longer had the tool. Behaviorally, they found that after using the tool, participants reached for objects as if their arms were longer than they in fact are; perceptually, they found that after using the tool, participants perceived consecutive touches on their arms and hands as being farther apart than they were perceived as being before using the tool. Both results indicate that using the reaching tool changed the participants' apparent arm length, even when they were no longer using it. Cardinali et al. interpret this as having happened because the tool was incorporated into the participants' understanding of the scale of their bodies, neurally implemented as a ''body schema.''

These results all indicate that the boundary between a cognitive agent and his or her environment is malleable. ECS strongly suggests that cognitive systems are not confined to brains, or even brains and bodies; instead, they sometimes encompass portions of the environment and, as we outline in the following section, this includes the most significant of environmental objects, namely, other human agents.

3. Breaking down boundaries between animals

The clear separation of ''you'' from ''me'' or one individual from another has historically been accepted as self-evident. That is, ''we,'' or, ''you'' and ''I,'' are faculties in our own right; largely independent, functionally autonomous, and bounded units or systems, separate from other humans and animals that are also largely independent, functionally autonomous, and bounded. The plausibility of this commonly held belief, however, has also been brought into question by research within the field of ECS (e.g., Goldstone & Gureckis, 2009; Marsh, Johnston, Richardson, & Schmidt, 2009b; Sebanz, Bekkering, & Knoblich,

2006), which has begun to provide evidence that the mechanisms of perception, action, and cognition can be defined across, as well as within individuals.

Preliminary evidence for this claim derives from research on interpersonal rhythmic movement coordination, which has demonstrated how the stable patterns of interpersonal rhythmic coordination are not the result of internal motor programs or hard-molded anatomical or neural structures (i.e., reflex-chains or central pattern generators), but rather reflect the natural, self-organizing dynamics of coupled oscillators (see Schmidt & Richardson, 2008, for a review). Specifically, this research has demonstrated that the rhythmic movements of two interacting individuals are intentionally and unintentionally (spontaneously) constrained to an inphase (i.e., 0° relative phase) or antiphase (i.e., 180° relative phase) relationship,[2] that inphase coordination is more stable than antiphase coordination, and that the relative stability of these two phase modes decreases as movement frequency and difference between the natural frequencies of the component movements is increased. What is most profound about this research is that the stability and patterning of the coordination that emerges does not depend on the specific movements or limbs involved, but rather on the strength of the informational (i.e., visual, auditory) coupling that connects the movements—the same dynamics are observed in intrapersonal interlimb coordination and between the finger, wrist, arm, leg, torso, or even the rocking chair movements of two individuals. Indeed, research on interpersonal rhythmic coordination has demonstrated that the order and regularity of such behavior has more to do with the nonlinear relations that couple the movements involved than it does with the particular anatomical and corporeal substrates or components of the human perceptual-motor system. It is for this reason that the organized system as a whole is said to be a softly assembled functional unit or synergy, as opposed to a hard-assembled system with fixed components and fixed connections among components (Kelso, 1995; Kugler & Turvey, 1987; Richardson, Fajen, Shockley, Riley, & Turvey, 2008; Riley, Richardson, Shockley, & Ramenzoni, 2011).

A recent extension of the interpersonal coordination research by Harrison and Richardson (2009) provides a rather compelling example of how the behavioral order of a social movement system is not proscribed a priori but rather emerges as a functional grouping of structural components (neurons, muscles, limbs, etc.) temporarily constrained to act as a single coherent unit. In this study, pairs of naïve participants were instructed to walk and jog at a comfortable pace while they were joined together (one behind the other) via a 75 cm long foam appendage. Not surprisingly, the results revealed that the leg movements of the pairs became spontaneously phase locked (coordinated). What was surprising was that the pairs exhibited a distinct preference for certain quadrapedal gait patterns (i.e., pace, trot), with differences in gait preference being a function of the differences in gait stability. Thus, the findings not only revealed that the stable multi-legged coordination patterns that characterize quadrupedal animals can emerge without direct neural-muscular coupling between all of the participating limbs, but they also provide clear evidence that the organizational mechanism for stable interpersonal motor control does not have to be a centralized mental or neural-cognitive structure, nor does it have to be it an inherent property of the constituent motor system(s)—none of the participants had ever been a quadruped before, nor were any of the participants aware of the coordination they were producing. Instead, the stable

patterns of movement coordination simply emerged from the free interplay of the neural, muscular-articulator, mechanical, and informational degrees of freedom that existed both within and across the individuals involved.

Research on the perception and execution of social affordances—possibilities for action that are performed by more than one person or require more than one person to perform—provides additional support for the claim the two individuals can form a coherent perception-action unit or synergy (e.g., Chang, Wade, & Stoffregen, 2009; Isenhower, Richardson, Carello, Baron, & Marsh, 2010; Richardson, Marsh, & Baron, 2007). For instance, Chang et al. (2009) investigated the perception of aperture passability for an inter-personal perception-action system, which comprised an adult perceiver with a child as a companion. The results demonstrated that the adult-child dyads perceived the minimum aperture width that they could pass through on the basis of the body-scaled information defined by the adult-child dyad together (i.e., not by the adult or child alone). Knowing when to pass through the aperture or not was a functional relation of the agent-agent system as a whole. Isenhower et al. (2010) obtained complementary findings for pairs of participants performing a plank-lifting task. Participants were required to lift and move wooden planks of various sizes from one side of a room to another. The participants in a pair were free to choose whether to move the planks alone or together, although approximately 2/5 of the planks were sufficiently large that they required that pairs lift the planks together. By presenting the planks in ascending and descending size, the authors found that pairs transitioned between solo and joint action abruptly (bifurcated), at a ratio of the pairs' collective action capabilities relative to plank size. Accordingly, the implicit commitment to act as a ''plural subject'' of action (Gilbert, 1996), that is, the ''decision'' to choose to cooperate (or not) was something that occurred as a dynamic response to a meaningful relation defined across an agent-agent system. As with rhythmic interpersonal synchrony, the coordinated behavior resulted from the functional relations (couplings) inherent to the social system as a whole (not the individual participants); the coordination arose and dissolved spontaneously, dependent on the system parameters and functional task constraints (Marsh, Richardson, & Schmidt, 2009a; Richardson, Marsh, & Schmidt, 2010).

The recent work of Roberts and Goldstone (2009) examining the mechanisms by which a group of individuals coordinate their behavior to complete a ''Binary Search'' task provides a more traditionally cognitive example of how social systems are softly assembled and exhibit interaction-dominant dynamics (see also Theiner, Allen, & Goldtsone, 2010 for a detailed description of this work). In this research study, internet-connected individuals played a game in which they were told that a computer would randomly generate a target number between 51 and 100 and that their job was to guess (as a group) what the target number was over a series of ''guessing'' rounds. For each round, participants were instructed to enter a number between 0 and 50. The group's responses were then summed and compared to the target number. Participants were then given feedback about whether the collective response was too high or too low. This guess-then-feedback process was repeated until the group successfully arrived at the target number. Not surprisingly, groups were able to perform the task successfully and improved over time (groups took fewer rounds to reach the target number as the number of games played increased). Of particular

relevance to the current discussion was that for large groups the reactive strategies adopted by the members of a group spontaneously differentiated, with some members adopting the role of reactors (i.e., always increased or decreased their guess on a subsequent round), while other members adopted the role of non-reactors. That is, over time the variability of reactivity for the individual group members decreased (individual group members reacted more consistently), while the variability of reactivity across group members increased (the diversity of reactive strategies increased). Equally important was that the spontaneous differentiation of group members was found to be related to the overall performance of the group—the degree of reactive diversity was positively correlated with task performance. The cognitive success of the group was, therefore, not reducible to any one individual group member, nor was it the result of the steady-state dynamics of the constituent individuals, but rather it was an emergent capacity that arose from the interactions among the individual group members. Successful groups converged onto a globally stable pattern of behavior, whereby the stability of this behavioral pattern was dependent on a specific organization of the component individuals, not the individuals themselves. The same individuals, at a different time and given a different set of initial conditions or responses, could (and most likely would) have evolved a different pattern of reactive strategies and yet achieve the same level of group success (Roberts & Goldstone, 2009; Theiner et al., 2010). Hence, the cognitive system was a functional grouping of individuals that were temporarily constrained to act as a single coherent unit or synergy, one that was softly assembled and exhibited interaction-dominant dynamics. The group itself exhibited cognition.

4. Conclusion

Kelso (2009) has claimed that the components of synergies are themselves synergies. We have seen here that ECS supports this claim. The research on social coordination dynamics, interpersonal perception, and group cognition (Section 3) shows that multi-person systems can be synergies, softly assembled and exhibiting interaction-dynamics. The components of these systems are embodied and embedded human agents. Human agents, as well as human agents plus tools that they use, are also synergies (Section 2). Among the components of embodied human agents, of course, are the neural synergies that enable cognition, perception, and action (Section 1). Again, although we have not provided any direct evidence for this latter claim, it does not seem outlandish to propose that the cells that make up the soft assembled coalitions of brain areas active in particular cognitive tasks are also synergies. Such a claim would seem to be essential for cognition to be truly embodied (and embedded), as it implies an understanding of human cognition in terms of nested sets of highly interdependent coordinative structures, involving comparatively macro-scaled interpersonal systems down to comparatively micro-scaled neural systems. Because the systems at each of these scales are softly assembled synergies with interaction-dominant dynamics, the role played by the components that comprise those systems is largely indeterminate.

This indeterminacy has important consequences for the cognitive sciences. Most important among them is the erosion of boundaries. First, ECS is inconsistent with

anatomic modularity. Task-specific synergies are softly assembled from a variety of components, spanning commonsense boundaries. This means that there is no specific brain area responsible for, say, object identification. Indeed, instances of object identification might be accomplished by a softly assembled coalition of components spanning brain, body, tools, and, even, other agents. Second, the traditional cognitive faculties, those that were traditionally assumed to be accomplished by anatomical modules, can no longer be distinguished from one another. Perception, action, judgment, language, and motor control use the same neural real estate assembled into distinct coalitions. Moreover, multiple faculties are often involved in tasks that have been thought to be the province of just one of them. The upshot of this is that ''embodied cognition'' is a misnomer. Embodied cognition is not just cognition and it does not just happen in the body.

Notes

1. The preparation of this manuscript was supported in part by the National Science Foundation (awards BCS-0750190 and BCS-0926662).
2. In-phase synchrony occurs when the movements of each individual are at equivalent points of the movement cycle, while anti-phase synchrony occurs when such movements are at opposite points of the movement cycle.

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