Penultimate draft. Please cite published version, to appear:
Favela, L. H., & Chemero, A. (in press). The animal-environment system. In Y. Coelllo, & M. H. Fischer (Eds.), *Foundations of Embodied Cognition: Volume 1: Perceptual and Emotional Embodiment*. New York, NY: Psychology Press. www.tandf.net/books/details/9781138805811/

The Animal-Environment System

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Keywords: dynamical systems, ecological psychology, extended cognition, phenomenology, sensory substitution

Abstract

Embodied cognition is a well-established and increasingly influential branch of the cognitive, neural, and psychological sciences. Unlike embodied cognition, extended cognition is not as well-established or influential. Our goal is to defend the idea that if cognition is truly embodied, then it is embodied in systems, and if it is embodied in systems, then it extends beyond animal boundaries. In order to demonstrate this, we situate the idea of extended cognitive systems in a historical context. Then, we present a theoretical and methodological framework for investigating extended cognitive systems. Finally, we discuss some potential experimental work that could adjudicate the existence of extended cognitive systems.

1. Introduction

Embodied cognition is a non-brain-centric position concerning what causes and is constitutive of cognition. Embodied cognition, in one form or another has become an influential branch of cognitive science (e.g., Calvo & Gomila, 2008; Chemero & Silberstein, 2008a; Dale, 2008; Glenberg, 2010; Riley, Shockley, & Van Orden, 2012) and, by now, many in the neural and psychological sciences have acknowledged the constitutive role of the body in cognition (e.g., Edelman, 2006; Sporns, 2010; Tognoli & Kelso, 2014). If the grip has been loosened on the idea that cognition is confined to the brain, then it is reasonable to continue the line of thought and ask why cognition should be limited to the skin, scale, fur, or feather boundaries of an organism?

What follows is a defense of the idea that if cognition is truly embodied, then cognition is also extended. We treat "cognition" as something that systems do, and the "animal-environment" as a system. If cognition is something that systems do, and if cognition is embodied in that system, then cognition is something that extends beyond animal boundaries. The case will be made as follows: First, we distinguish "extended cognition" from "embodied cognition" and, more importantly, from "extended mind," as well as situate extended cognition in a historical context. Second, we present a theoretical and methodological framework for investigating extended cognitive systems. With the terminology, historical context, and investigative framework in place, we then discuss some potential experimental work that could adjudicate the existence of extended cognitive systems.

2. Embodied cognition, extended cognition, and extended mind

When attempting to make a case for extended cognition in animal-environment systems, some necessary conceptual clarification involves distinguishing "extended cognition" from "embodied cognition" and, more importantly, from "extended mind." There is an increasing amount of literature that can be categorized under the heading of "extended cognition" (for a very small sample see Arnau, Estany, Gonzalez del Solar, & Sturm, 2014; Clark & Chalmers, 1998; Froese & Fuchs, 2012; Hutchins, 1995, 2010; Menary, 2010; Rowlands, 2010; Silberstein & Chemero, 2012). A succinct way to define 'extended cognition' is the idea that the cognitive system extends beyond the boundary of the organism. This seemingly innocuous definition has already been the target of much criticism, particularly in the philosophy literature (e.g., Adams & Aizawa, 2008). Our goal in this section is not to defend the analytic or conceptual aspects of 'extended cognition.' We merely intend to show how extended cognition differs from embodied cognition and extended mind.

Like extended cognition, embodied cognition and extended mind are fraught with controversy. Extended cognition refers to cognition that extends beyond the boundary of the organism. Extended mind can be said to incorporate this feature, but it also contains a stronger metaphysical feature as well, specifically, a functionalist theory about the nature of mental states. According to functionalism, a mental state is what it is by means of what it does, by its relations to stimulus inputs and behavioral outputs and its relations to other psychological and non-psychological internal states of a system (Polger, 2012, p. 337). The material constitution of a mental state is not what makes it what it is. A mental state is not mental because it is realized in neural activity. It is mental because of what it does and how it relates to other aspects of a system. Thus, if Otto reads his notebook every time he needs directions to the museum, and if that notebook plays the same role as neurons encoding directions do for Inga, then it can be argued (by Clark & Chalmers, 1998) that Otto's mind includes his notebook because it plays the same functional role as Inga's neurons. Extended cognition, as we utilize the term, does not make claims about the necessary and sufficient conditions for the realization of mental states. Instead, 'extended cognition' serves as an empirically tractable concept pertaining to the perceptions and actions of cognitive systems.

Although it is difficult to provide a definition of 'embodied cognition' that adheres to all uses of the term, a few features are generally agreed upon (cf. Anderson, 2003). First, cognition is grounded in sensorimotor processes. Second, the body constrains and enables cognition. Third, there is no sharp division between cognition and non-cognition in the body. Extended cognition has much in common with this conception of embodied cognition. Both shift the emphasis in investigations of cognition from being strictly focused on the brain to increasing the importance of the body and sensorimotor processes. Also, both adhere to the claim that there is no sharp division between cognition and non-cognition. However, they differ in regard to what constrains and enables cognition. To be more specific, although the body and sensorimotor processes become more important when investigating cognition, embodied cognition typically involves commitments to the skin, scale, fur, or feathers of an organism as the boundaries of cognition. Extended cognition, while also incorporating the body and sensorimotor processes, also incorporates objects outside of the organism. Cognition does not happen just in brains or bodies, but happens in extended cognitive systems.

To recap, we treat a commitment to the existence of extended cognition as a commitment to the following three claims. First, cognition is not restricted to the brain. Second, cognition is necessarily tied to sensorimotor processes. Third, although the body is *a* constraint upon cognition, it is not *the* constraint upon cognition; that is, cognition is not restricted to the boundaries of the organism. Finally, and following from the first three features, cognition is a phenomenon that spans brain, body, and environment.

Our goal in the current work is to motivate the claim that extended cognition currently has the empirical backing to be a substantial part of the cognitive, neural, and psychological sciences. The purpose of this section has been to provide a very brief review of some of the conceptual issues pertaining to extended cognition. We did this in an attempt to clarify our usage of 'extended cognition' and not to add to the conceptual debate. We are not confident that this is an issue that can be settled in terms of conceptual analysis. In fact, some of the fiercest philosophical critiques of embodied and extended cognition do not think the issue is a conceptual one either. As Adams and Aizawa have stated:

> Our view has always been that, as a matter of contingent empirical fact, pencils, paper, eyeglasses, Rolodexes, and so forth happen not to be parts of any currently existing cognitive economy. It is, in principle, possible that, say, a pencil or notebook could be so employed as to be a contributor to a cognitive process. … This is just to say that portions of the body and tools in the extra-corporeal environment could be parts of cognitive processes, if only they were to bear the mark of the cognitive. (2008, pp. 128-129)

Although there is a conceptual aspect to their statement, specifically, defining "the mark of the cognitive," Adams and Aizawa purport to place more credence on the empirical facts. To those who reject embodied and extended cognition, we reply with a quote from an unlikely ally:

> [W]hen not much is known about a topic, don't take terribly seriously someone else's heartfelt conviction about what problems are scientifically tractable. Learn the science, do the science, and see what happens. (Churchland, 1996, p. 408)

We wholeheartedly agree with Patricia Churchland on this point. That is why in the next section we begin to shift the discussion of extended cognition from the conceptual to the empirical. We do this by placing extended cognition in the context of the phenomenological tradition and the sensory substitution literature.

3. Phenomenological tradition

The notion that cognition is spatially extended beyond the brain, and even the body, is not new (Chemero & Silberstein, 2008b). From William James' theory of perception (Banks, 2013) to work in robotics (Beer, 1995a), there has clearly been precedent for recent work in extended cognition. Some of the most vivid accounts of the pliable nature of bodily boundaries can be found in the work of the classical phenomenologists Martin Heidegger (1927/1962) and Maurice Merleau-Ponty (1945/2002). At least since Hubert Dreyfus' early critiques of artificial intelligence (Dreyfus, 1972), the phenomenological analysis of being-in-the-world by those such as Heidegger and Merleau-Ponty has been appropriated for scientific purposes (e.g., Kaufer & Chemero, 2015; Kiverstein & Wheeler, 2012).

One particular aspect of Heidegger and Merleau-Ponty's work appealed to in recent scientific research is their analyses of the phenomenology of equipment and tool use (e.g., Dotov, Nie, & Chemero, 2010; Nie, Dotov, & Chemero, 2011). Heidegger distinguishes three ways of experiencing tools: Ready-to-hand, unready-to-hand, and present-at-hand. "Ready-to-hand" refers to the experience of equipment successfully utilized, for example, hammering a nail, reading a book, or floating in a boat (Inwood, 1999). When tools are ready-to-hand, users do not experience them as tools, but see through them to the task they are engaged in. "Unready-to-hand" refers to the temporary breakdown of the successful utilization of equipment (Blattner, 2006). For example, when difficulty getting a key to turn in a locked door temporarily distracts you from the conversation you are having, the key and lock are experienced as unready-to-hand. In this case, the key and lock intrude on the conversation for a moment, and attention switches from the conversation to the suddenly obtrusive key. "Present-at-hand" refers to the experience of things outside the context of their functions, as mere objects. If a little jiggling fails to get the door to open, you might pull the key out of the lock and look at its shape, color, and so on. Experiencing the key as present-at-hand is experiencing it as an object with properties, and not as a useful piece of equipment.

In a discussion of the experience of the spatiality of one's own body, Merleau-Ponty discusses a blind man using a cane (1945/2002, pp. 165-166). In terms of the phenomenological experience of the blind man, the cane is not an object that is perceived for itself. The blind man does not experience the cane as an object that makes contact with the ground. The blind man experiences the ground at the end of the cane. Taking Heidegger's phenomenological analysis of equipment a step further, Merleau-Ponty says of the blind man and his cane:

> The points in space do not stand out as objective positions in relation to the objective position occupied by our body; they mark, in our vicinity, the varying range of our aims and gestures. ... Habit expresses our power of dilating our being-in-the-world, or changing our existence by appropriating fresh instruments. (Merleau-Ponty, 1945/2002, p. 166)

In this phenomenological analysis, Merleau-Ponty draws attention to the plastic nature of bodily boundaries as evidenced by the reshaping of our being-in-the-world that results from the incorporation of equipment. According to Merleau-Ponty, the "body" does not exist in an a priori set of dimensions in the world. This claim is consistent with Heidegger's phenomenological analysis of the modes of being of tools. Heidegger and Merleau-Ponty's phenomenological analyses of equipment and tool use share the implication that the bounds of the experienced self in the world are pliable.

For our purposes in this work, Heidegger and Merleau-Ponty's phenomenological analyses are not only significant for motivating a loosening of the boundaries of self. Their analyses are significant for two other reasons. One is that their analyses draw attention to the role of equipment and tools in extending the self. The other is that they point out the possibility that equipment and tools can substitute for or augment senses.

This section has provided some of the historical context from the philosophical literature and theoretical motivation for our defense of the claim that cognition is extended. This position is motivated by Heidegger and Merleau-Ponty's phenomenological analyses of equipment and tool use, which give reasons to think that not only is cognition functionally extended (e.g., when a blind man is able to use a cane to navigate), but the subjective experience is also extended (e.g., when the blind man "feels" the ground through the cane). In the next section, we present historical context from empirical literature on sensory substitution.

4. Sensory substitution

Heidegger and Merleau-Ponty appeal to the results of phenomenological analyses to motivate the claims that the boundaries of the body are plastic and that equipment and tools can be seamlessly integrated into one's experience of the world. Another consequence of these analyses is that equipment and tools can substitute for sensory deficiencies. In the case of the blind man, with the assistance of a cane, his sense of touch substitutes for his sense of vision. At least since the 1960s, empirical experiments have been conducted in the area of sensory substitution and augmentation. That work is another source of theoretical motivation for our claim that in being embodied, cognition is also extended. Whereas the previous section presented theoretical motivation based on phenomenological analyses, this section presents theoretical motivation based on empirical investigations.

Although there are many conceptual, theoretical, and methodological issues surrounding the notion of sensory substitution (Auvray & Myin, 2009; Lenay, Gapenne, Hanneton, Marque, & Genouelle, 2003), it is uncontroversial that there is evidence that what people normally do with one sense can be done with another. The use of Braille, for example, is evidence that an activity that is normally done with vision, that is, reading, can be done with touch. Not just for bats, echolocation is another example of sensory substitution in humans (e.g., Rosenblum, Gordon, & Jarquin, 2000; Thaler, Arnott, & Goodale, 2011). In the case of echolocation, vision is substituted with a combination of touch and hearing.

Starting in the 1960s, Paul Bach-y-Rita and colleagues began experimenting with sensory substitution (1969, 2003). They first developed a tactile vision substitution system, which delivered visual information from a video camera via an array of stimulators that made contact with various parts of the body, such as the abdomen, back, thigh, and fingertips (Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969). Later experiments utilized a 49-point 1.8 x 1.8 cm electrotactile to apply small amounts of electric current to the surface of the tongue based on information from a head-mounted video camera (Bach-y-Rita, Kaczmarek, Tyler, & Garcia-Lara, 1998). The results of Bach-y-Rita and colleagues’ experiments, as well as the numerous similar experiments that followed, demonstrated both the feasibility of developing sensory substitution technologies and that at least some of the senses can be substituted for each other.

In regard to the place of extended cognition, empirical evidence of sensory substitution has two consequences. The first consequence is neutral concerning the idea of extended cognition. The neutral consequence is that a topic that was once solely the domain of philosophy is now empirically tractable. No matter how appealing their arguments, Heidegger's discussion of the modes of being and Merleau-Ponty's discussion of the pliability of bodily boundaries are based on purely first-person methods that are fraught with difficulties in terms of being objectively or scientifically verifiable (cf. Dennett, 2003; Lutz & Thompson, 2003). Merleau-Ponty's claim that the blind man does not sense the cane touching the ground, but senses the ground (1945/2002, pp. 165-166) rests on the ability of another to imagine what Merleau-Ponty himself imagines the experience of the blind man to be like. There is no objective arbitrator of the facts of Merleau-Ponty's claim as originally presented. However, if such issues as sensory substitution and extended cognition are empirically tractable, then perhaps the truth of Merleau-Ponty's claims about the blind man can be further justified via empirical investigation.

The second consequence for extended cognition is positive. The positive consequence is that some of the sensory substitution literature can serve as evidence in favor of extended cognition. Take Bach-y-Rita and colleagues' experiments with the electrotactile on the tongue that receives information from a head-mounted camera. Must the source and location of reception of visual information be near the natural morphological location of the eyes in order to count as visual perception? In other words, does the electrotactile-tongue-camera system only count as "true" sensory substitution because the camera and electrotactile are near the eyes, that is, where visual perception naturally occurs? As Bach-y-Rita and colleagues demonstrated in other experiments (1969, 2003), the camera can be in different locations and various parts of the body can receive the information, e.g., abdomen, back, thigh, and fingertips, without subjects losing perceptual capacities.

The previous two sections have presented some of the historical context and theoretical motivations for our claim that cognition can be extended. If results of sensory substitution are cases of extended cognition, then extended cognition is empirically tractable. Thus far, our case has rested on conceptual clarification and positioning in a historical context. As noted above, we agree with Churchland's (1996) point that the mere conviction of how things ought to be is no substitute for doing the science. Consequently, in the next section we present an empirical framework for studying extended cognition. This framework, which we call "radical embodied cognitive science" (Chemero, 2009), pulls much of its theoretical basis from ecological psychology and its methods from dynamical systems theory.

5. An empirical framework for studying extended cognitive systems

James J. Gibson's ecological psychology (1966/1979, 1973/1983) is the center of radical embodied cognitive science. According to ecological psychology, perception is direct in that it does not involve internal maps, images, or representations of the environment. Instead, perception is an unmediated relation between the animal and the environment. Gibson argues that this sort of unmediated relation to the environment is sufficient for guiding action because the environment contains affordances, or opportunities for behavior, and information sufficient to specify them. This is a very strong claim, and one that contradicts standard views in the cognitive sciences. For example, the traditional cognitive scientist correctly claims that the retinal image of a large, distant antelope would be identical to that of a small, nearby antelope. To determine whether an antelope affords catching, a cheetah has to use information from memory concerning the typical size of antelopes and from this, (unconsciously) compute how distant the antelope is. Then the cheetah would need to store the distance of the antelope, recalculate the distance some particular time later, use the difference between these two distances to calculate the antelope's velocity, and then use the distance and velocity to determine whether it could catch the antelope. Gibson claims that it only seems that the cheetah needs all this unconscious calculation because of our mistaken belief that vision begins with a retinal image. Seeing, according to Gibson, is an action, something that the cheetah does, not just with its eyes, but also with its moving eyes on a face on a head on a neck on a torso on legs. As the cheetah moves its eyes and head to look at the antelope, it produces parallax. Parallax is the displacement of the apparent position of an object from two different points of observation (cf. Jokisch & Troje, 2003). In moving its head, the cheetah creates motion parallax, a continuous transformation of the apparent position of the antelope and all the visible objects from the start point to the endpoint of the movement. (A simplified video of motion parallax is available at http://en.wikipedia.org/wiki/File:Parallax.gif.) The motion parallax caused by the cheetah moving its head changes the apparent position of the antelope relative to the other visible objects in front of and behind it in a way that is lawfully related to the distance of the antelope. In particular, the cheetah's head movement while looking at the antelope yields a regular visible change in the area of background that the antelope is occluding, and indeed this change is lawfully related to the distance of the antelope, with the change in occlusion of nearby objects being greater than the change in occlusion of distant objects. So, for an animal that moves, there is information available that is lawfully related to the distance of objects. Moreover, in the case we are imagining, the antelope is also moving. David Lee and his colleagues (e.g., Lee & Reddish, 1981) have shown that the optical variable tau, the ratio of the apparent size of an approaching object to the rate of change of the apparent size of the object, is available in light and is lawfully related to the time to contact with the approaching object. Thus, because animals and objects in the environment move during the course of perceiving, there is sufficient information in the light to specify both distance and time to contact, and an animal can simply see, without calculation, whether another animal affords being caught. The same goes for many, many other affordances (e.g., Amazeen & Turvey, 1996; Burton & Turvey, 1990; Carello & Turvey, 2004; Fajen, 2005; Michaels, 2000; Michaels & Beek, 1995; Turvey, 1990). There is information available in the environment for perceiving and acting upon these affordances, and this information can be picked up and acted upon without internal computations.

Picking up this information involves moving and change over time, which makes dynamical systems theory an appropriate modeling tool for modeling perception and action. Indeed, ecological psychologists have used dynamical modeling for several decades (e.g., Kugler, Kelso, & Turvey, 1980). In dynamical systems modeling, one uses the tools of calculus to explain the change over time of some system of variables. Two features of dynamical modeling will be important in what follows. First, the locations of the quantities tracked by the variables in dynamical models are not constrained to be on just one side of the skin-environment boundary (van Gelder, 1995). Second, as will be argued below, certain kinds of dynamical systems are non-decomposable, in that the equations that model them cannot be solved separately. This is best seen in a description by Randall Beer (1995b) (see Figure 1). The figure depicts a coupled agent-environment system, whose parts, the agent *A* and the environment *E* are modeled with the following equations:

1. $\frac{dX_a}{dt} = A(X_a; S(X_e))$

2. $\frac{dX_e}{dt} = E(X_e; M(X_a))$

Put in English, equation 1 says that the changes in the agent (*dA*/*dt*) are a function of the current state of the animal (*A*) and the agent's sensing of the environment (*S*(*E*)); equation 2 says that the changes in the environment (*dE*/*dt*) are a function of the current state of the environment (*E*) and movement of the animal (*M*(*A*)). These equations are coupled in that each has a variable that is a parameter in the other. Therefore, the equations cannot be solved separately. To solve either alone would require fixing the value of the parameter whose value is determined by the other equation. But since we know that parameter's value is partly determined by the equation we are solving, we know that our solution will be mistaken. We agree with Beer that this means that the proper object of study in a system like this is *U*, the extended agent-environment system, or, as we refer to it, the animal-environment system.

The equations above supplied by Beer are not real equations describing an actual system; they are placeholders for actual models of actual extended systems. However, similar claims about the non-decomposability of actual coupled agent-environment systems have been made by Van Orden, Holden, and Turvey (2003); Holden, Van Orden, and Turvey (2009); Dotov, Nie, and Chemero (2010); Silberstein and Chemero (2012); Anderson, Richardson, and Chemero (2012); among others. In each of these articles, it is claimed that cognitive systems exhibit *interaction-dominant dynamics* and are, therefore, *interaction-dominant systems*. This technical term can be read quite literally: A system exhibits interaction-dominant dynamics when the interactions among the components dominate or override the dynamics that the components would exhibit separately. Systems with interaction-dominant dynamics (i.e., interaction-dominant systems) are not modular.

Over the last few decades, it has been demonstrated that many well-functioning physiological systems are interaction dominant. Examples of this include human heartbeats (Peng et al., 1995), gait patterns (Hausdorff et al., 1995), and brain activity (Freeman, 2006), indicating that the chambers of the heart, the locomotory system, and parts of the human brain are interaction-dominant systems. It has also been shown, in some cases at least, that cognitive systems are interaction-dominant (Ding, Chen, & Kelso 2002; Riley & Turvey, 2002; Van Orden, Holden, & Turvey, 2003, 2005; Holden, Van Orden, & Turvey, 2009). For example, Van Orden, Holden, and Turvey (2003) gather direct evidence showing that cognitive systems are not modular; rather these systems are fully embodied, and include aspects that extend to the periphery of the organism.

In each of the cases just mentioned, the primary evidence that the systems in question are interaction dominant is that they exhibit what is called *1/f scaling* in extended animal-environment systems. Many natural phenomena exhibit 1/*f* scaling. 1/*f* scaling (sometimes called '1/*f* noise' or 'pink noise') is a type of variability in a time series that is neither random nor predictable. 1/*f* scaling is fractal structure in a time series, so that the patterns of variability at short timescales is statistically similar in structure to variability at longer timescales. This sort of structured variability is a predictable consequence of interaction dominance. In an interaction-dominant system, inherent variability (i.e., fluctuations or noise) of any individual component *C* propagates through the system as a whole, altering the dynamics of the other components, say *D*, *E*, and *F*. Because of the dense connections among the components of the systems, the alterations of the dynamics of *D*, *E*, and *F* will lead to alterations to the dynamics of component *C*. That initial random fluctuation of component *C*, in other words, will reverberate through the system for some time. So too would nonrandom changes in the dynamics of component *C*. This tendency for reverberating fluctuations gives interaction-dominant systems what is referred to as "long memory" (Chen, Ding, & Kelso, 1997). 1/*f* scaling should be expected when the components of a system are so tightly integrated with one another that their activity cannot be explained independently (Bak, Tang, & Wiesenfeld, 1988; Van Orden, Holden, & Turvey 2003).

As discussed above, the fluctuations in an interaction-dominant system percolate through the system over time, leading to the kind of correlated structure to variability that is 1/*f* noise. Exhibiting 1/*f* noise is initial evidence that a system is interaction dominant. This suggests that the mounting evidence that 1/*f* noise is ubiquitous in human physiological systems, behavior, and neural activity is also evidence that human physiological, cognitive, and neural systems are interaction dominant.

To be clear, there are ways other than interaction-dominant dynamics to generate 1/*f* noise. Simulations show that carefully gerrymandered component-dominant systems can exhibit 1/*f* noise (Wagenmakers, Farrell, & Ratcliff, 2005). But such gerrymandered systems are not developed from any physiological, cognitive, or neurological principle, and are not taken to be plausible mechanisms for the widespread 1/*f* noise in human physiology, brains, and behavior (Van Orden, Holden, & Turvey, 2005). So the inference from 1/*f* noise to interaction dominance is not foolproof, but there currently is no plausible explanation of the prevalence of 1/*f* noise other than interaction dominance. Moreover, as the criteria for what features a system must exhibit in order to be an interaction dominant system change, so too may the analytic methods needed to capture those features (cf. Ihlen & Vereijken, 2010).

When investigating interaction-dominant systems, it is misguided to search for a specific biological mechanism responsible for 1/*f* temporal or spatial structures in physiological systems. Interaction dominance and 1/*f* noise are the result of *dynamics* exhibited by particular systems. These dynamics are substrate neutral, meaning the same dynamics can be exhibited by systems of varying composition. In addition to the examples above of physiological systems, the following is a small sample of other systems that exhibit 1/*f* noise: the Earth's magnetosphere (Consolini, 2002), earthquakes (Bak, Christensen, Danon, & Scanlon, 2002), and sand piles

(Bak, 1996). One of the main contenders for a theoretical explanation of the generation and maintenance of interaction dominance and 1/*f* noise is self-organized criticality (Bak, Tang, & Wiesenfeld, 1987, 1988; Chialvo, 2004). Self-organized criticality is put forward as a potential unifying account of various phenomena in nature and the laboratory that demonstrate 1/*f* noise temporal dynamics and spatial features such as scale invariance and self-similar structure. Systems are self-organized when the dynamics of that system result in structures of behavior over time without the direction of a central controller or external agent. Systems are in critical states when they are stable enough to maintain order but disordered enough so as to be adaptable to changes both outside and within the system. An adequate account of self-organized criticality goes beyond the scope of the current work. It is mentioned here merely to show that empirically supported theoretical research has been underway for a number of years that has the potential to explain how systems exhibit interaction-dominance and 1/*f* noise. For a review of self-organized criticality and references to other related work, see Favela 2014. For our current purposes, we do not take 1/*f* noise as final proof that a system is necessarily interaction dominant. We do, however, take the presence of 1/*f* noise to be an empirically and theoretically compelling indication that a system is interaction dominant and not component dominant.

If 1/*f* noise is indeed indicative of interaction dominance, then we can propose a solution to what Weiskopf (2012) calls “the Goldilocks problem” of finding boundaries of cognition that are not too wide or too narrow, but are “just right.” In particular, the Goldilocks problem is the problem of conceptualizing extended cognition so that it is neither impossible in principle nor guaranteed in advance. The results on 1/*f* scaling and physiology provide a way to understand extended cognition: An organism and a nonbodily object comprise a single, extended cognitive system if they are coupled to one another in the same way that the components of a well-functioning physiological system are coupled to one another. That is, an organism and a nonbodily object comprise a single, extended cognitive system if they collectively have interaction-dominant dynamics. This standard makes it an open empirical question whether there are extended cognitive systems, and is much stricter than standard functionalist criteria for calling a cognitive system extended. In fact, this standard almost certainly would not apply to Otto and his notebook. In this current work, we are more interested in whether it applies to persons-plus-tools.

Notice that this way of understanding extended cognition is not a case of the so-called "coupling-constitution fallacy," according to which merely causal connections between brain-bound cognitive systems and the environment are confused for cases in which brain-body-environment are all constituents of the cognitive system (Adams & Aizawa, 2008). If an organism and nonbodily object exhibit interaction-dominant dynamics, this is evidence that they comprise a unified system in the same say that other physiological systems that exhibit interaction-dominant dynamics are unified systems. Claiming that an interaction-dominant person-plus-tool system is a case of mere causal connection, and not a true unified system, is tantamount to saying that the chambers of the human heart or the regions of the human cortex are merely causally connected to one another, but the heart and cortex do not form true unified entities. We take it that this is not an attractive option.

The question for current purposes is whether interaction-dominant systems extend beyond the body periphery, whether person-plus-tool systems can be shown to exhibit interaction-dominant dynamics. Demonstrating this is tantamount to demonstrating that human-plus-tool systems can be as tightly integrated as the components of a beating heart are. This has been demonstrated empirically. Dotov and colleagues (2010) have shown that cognitive systems can be made to extend beyond the periphery to include artifacts that are being utilized to perform a task. Participants in their experiments played a simple video game, controlling an object on a monitor using a mouse. Approximately halfway through the one-minute trials, the connection between mouse movements and the movements of the object the mouse had been controlling was disrupted. Dotov and colleagues predicted and found $1/f$ scaling in accelerations at the hand-mouse interface when the mouse was functioning properly, but that the variability "whitened" (i.e., approximated pure white, or random, noise) during the mouse disruption. After the perturbation, the $1/f$ scaling reappeared. As discussed above, this indicates that during normal operation, the computer mouse is part of the interaction-dominant system engaged in the task. That is, during smooth playing of the video game, the mouse was a constituent in the cognitive system. When the mouse connection is temporarily disrupted, the extended system is also temporarily disrupted. The fact that such a mundane experimental setup (i.e., using a computer mouse to control an object on a monitor) could generate, disrupt, and then re-establish an extended cognitive system suggests that extended cognitive systems are common. In the final section, we discuss additional empirical research that could potentially add to the case for the existence of extended cognitive systems.

6. Future prospects

The purpose of this paper has been to answer the following question: If it is believed that cognition is embodied, that is, that cognition is not confined to the brain, then should cognition also be treated as being limited to residing within the skin, scale, fur, or feather boundaries of an organism? We have attempted to demonstrate that if cognition is embodied, then it is also extended. To make this point, we have appealed to the phenomenological analyses of Merleau-

Ponty and Heidegger, and experimental research on sensory substitution. In addition, we have offered a theoretical and methodological vantage point from which to investigate the possibility of extended cognitive systems: Radical embodied cognitive science.

According to radical embodied cognitive science, perception, action, and cognition are approached with broadly Gibsonian assumptions, and experimental data is analyzed using the tools of dynamical systems theory. We have recommended a method for determining when cognitive systems are extended. Using dynamical analyses, we can show that a system is a unified, interaction-dominant system. We have taken the presence of $1/f$ scaling to be indicative of a unified system. Given this, showing that $1/f$ scaling is present when a human is using a tool indicates that the human-tool system is interaction dominant. Using this approach, experimental results from Dotov and colleagues (2010) indicate that human participants-plus-external-device can comprise unified, interaction-dominant systems. These human-plus-device systems are extended cognitive systems. In addition, ongoing experiments in our lab aim to show that humans-plus-sensory-substitution-devices comprise unified, interaction-dominant systems. Preliminary experiments on perception-action judgments demonstrated that participants were able to make judgments via sensory substitution devices (i.e., a cane and the Enactive Torch [Froese et al., 2012]) that were functionally equivalent to those made with vision (Favela, Riley, Shockley, & Chemero, 2014a, 2014b). Indeed, following Merleau-Ponty, the sensory substitution devices in use have the same status as sensory organs. If one accepts that cognition is embodied and that, for example, eyes and skin are sensory appendages of cognitive systems (cf. Burton, 1993), then one should also accept that nonbiological sensory substitution devices are also parts of cognitive systems. Given this, it seems clear that extended cognitive systems exist. If extended cognitive systems exist, then, as we have argued, cognition is embodied in animal-environment systems.

7. References

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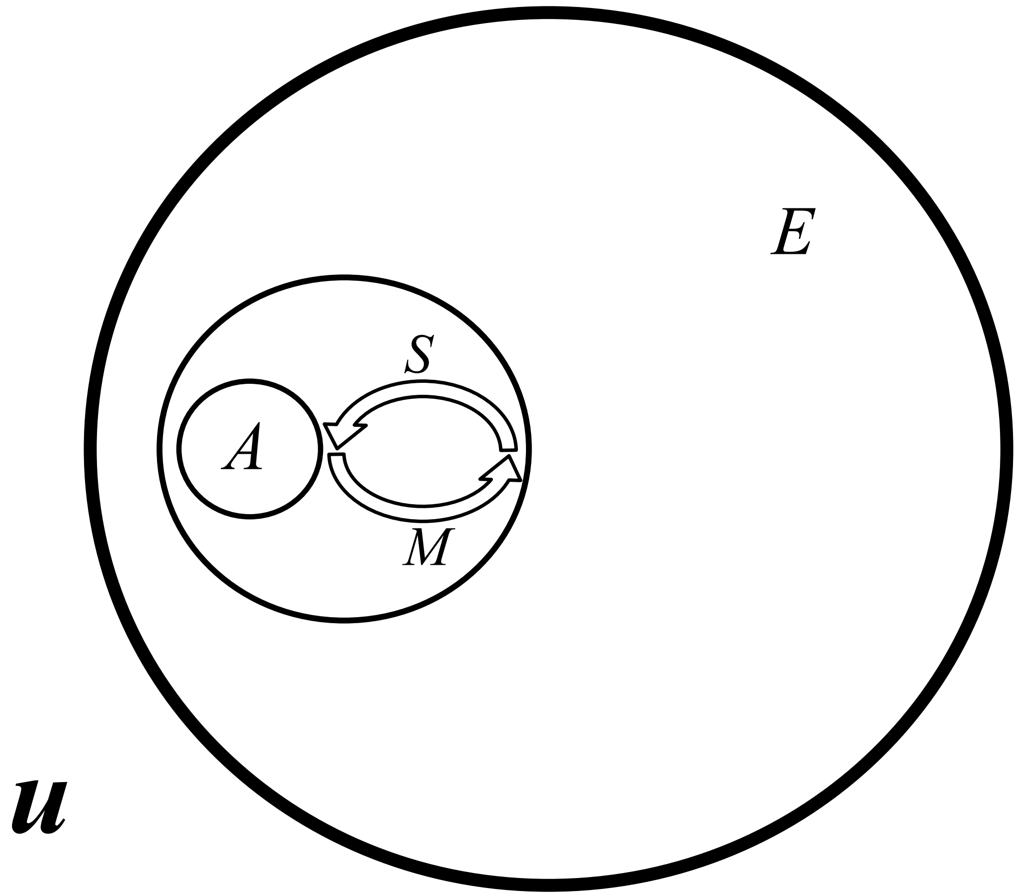

Figure 1. The system *u* comprised of agent (*A*) and environment (*E*) interactions, where *S* refers to sensory input and *M* refers to motor output. (Figure inspired by Beer, 1995b, p. 182.)