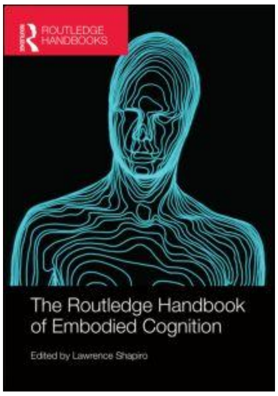

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6

EMBEDDED AND SITUATED COGNITION

Michael Dawson

Embodied cognitive science reacts against more established traditions within cognitive science (Clark, 1997; Dawson, 2013; Dawson, Dupuis, and Wilson, 2010; Shapiro, 2011). Shapiro has identified three main themes that separate the embodied approach from these traditions. *Conceptualization* is the notion that an agent's understanding of its world depends critically upon the nature of the agent's body. *Replacement* is the idea that an agent's interactions with its world replace the need for internal mental representations. *Constitution* is the position that an agent's world and body are constituents of (and not merely causally related to) an agent's mind.

The purpose of the current chapter is to explore what is implied when cognitive scientists describe cognition as *embodied*, *embedded*, or *situated* (Chemero, 2009; Clancey, 1997; Clark, 1997, 1999, 2003; Dawson *et al.*, 2010; Dourish, 2001; Shapiro, 2011; Varela, Thompson, and Rosch, 1991). This will be accomplished by contrasting these ideas with some traditional foundations of standard cognitive science (Dawson, 1998). In so doing, issues related to Shapiro's (2011) three themes of conceptualization, replacement, and constitution are developed.

Underdetermination in perception

Humans take visual perception for granted. Our experience is that we simply look at the world and automatically see it in high detail (Noë, 2002, 2004). This is the "video camera theory" of vision. However, failures to develop seeing computers made it apparent that the video camera theory was inadequate. Researchers discovered that the human visual system was effortlessly solving enormously complicated information-processing problems. Primary visual data (the proximal stimulus on the retina) does not contain enough information to determine a unique and correct visual interpretation. That is, a single proximal stimulus is consistent with an infinite number of different interpretations (Marr, 1969). This is called the *problem of underdetermination* or, borrowing a term from the study of language (Chomsky, 1965) the *poverty of the stimulus*. Problems of underdetermination are notoriously difficult to solve, but are apparently solved effortlessly by human visual processing.

How might problems of underdetermination be solved? Standard cognitive science claims that these problems are solved using *unconscious inference* (Bruner, 1957; Helmholtz, 1868/1968; Rock, 1983). According to this hypothesis, perception is identical to cognition; knowledge-driven inferential processing adds information that disambiguates the proximal stimulus and produces the correct interpretation.

This cognitive view dominates modern theories of perception (Pylyshyn, 2003). To them, sensation provides some of the information used to create a mental model. Next, thinking (e.g. unconscious inference) completes the model's construction by supplementing sensation. Once created, the mental model provides the basis for planning and acting. Thinking therefore stands as a necessary intermediary between sensing and acting, producing the *sense-think-act cycle* that defines the *classical sandwich* (Hurley, 2001).

However, what if the purpose of perception is not to build mental models, but is instead to control actions on the world? Embodied cognitive science replaces the sense-think-act cycle with *sense-act processing* (Brooks, 1999; Clark, 1997; Pfeifer and Scheier, 1999). According to this alternative view, there are *direct* links between sensing and acting. Embodied cognitive science views the brain as a controller, not as a model-builder or a planner. To investigate the implications of this position, consider an example from comparative psychology.

Case study: echolocation

In the traditional sense-think-act cycle, agents are passive receivers of information. In contrast, the sense-act theory of perception proposes that perception is active, because perceivers are constantly exploring their worlds. *Echolocation* is an example of an active sensing system because bats use self-generated energy to probe their environments (Nelson and MacIver, 2006). Many species of bats hunt by emitting ultrasonic sounds and by using ultrasonic echoes to detect target locations. This enables bats to discover and intercept targets as small as fruit flies or mosquitoes from distances of between 50 and 100 centimeters (Griffin, Webster, and Michael, 1960).

There are three definite stages in a bat's use of echolocation to hunt prey (Griffin *et al.*, 1960). In the *search phase*, bats fly relatively straight and emit sounds at a relatively slow rate of repetition. When the bat first detects an insect during the search phase, an *approach phase* begins: the bat turns towards the detected insect, and progressively increases the rate of repetition of its signals, presumably to locate its target more accurately. When the bat is close enough to the insect, it moves into a *terminal phase* and produces sounds at such a high rate that the result is an ultrasonic buzz that enables the bat to close in and capture the quarry.

However, moths do not simply wait to become meals. Moth wing scales absorb sounds at the frequencies of bat ultrasonics, dampening a moth's echo (Zeng *et al.*, 2011). Furthermore, some moths have evolved transducers that permit them to hear bat echolocation signals (Fenton and Fullard, 1979; Roeder and Treat, 1961; Rydell, Jones, and Waters, 1995). As soon as such a signal is heard, a moth will execute a power dive towards the ground; this dive often includes a series of evasive maneuvers that involve tight turns, loops, and climbs (Roeder and Treat, 1961). In addition, some species of moth emit their own ultrasonic sounds. This causes bats to turn away from their prey (Dunning and Roeder, 1965) because the moth's signal indicates that the moth is of a type that is inedible or because the signal actually interferes with bat echolocation (Fenton and Fullard, 1979; Fullard, Simmons, and Saillant, 1994; Hristov and Conner, 2005; Rydell *et al.*, 1995).

The counter-measures developed by moths have themselves been countered by bats, some of whom use ultrasonic frequencies out of the range of moth hearing, or who hunt silently and listen for the sounds generated by their prey (Rydell *et al.*, 1995). Bats also learn from their echolocation encounters, changing their behavior to discriminate one type of target from another (Griffin, Friend, and Webster, 1965). There is a dynamic relationship between a single echolocating bat and an individual moth that hears and attempts to evade its predator.

Situating echolocation

Cyberneticists recognized that agents are intrinsically coupled to their environment, because an agent's actions can change the world, which in turn can influence the agent's future actions, a relation called *feedback* (Ashby, 1956; Wiener, 1948).

A bat that uses echolocation to hunt hearing moths is clearly in a feedback relationship with its environment. The bat's actions – both in terms of its flight and in terms of the sounds that it generates – depend upon the distance between the bat and its prey. Furthermore, when a moth detects this attack, it begins evasive maneuvers, which represents a change in the world caused by the bat's ultrasonic probing. In turn, this change in the world produces changes in the bat's behavior, as it alters its flight path to foil the evasion.

Critically, the coupling between the actions of the bat and the actions of its prey are occurring over drastically short periods of time (Griffin *et al.*, 1960). Bats are usually hunting targets that are less than a meter away, are flying at speeds of 1 to 6 meters/second, and have only a few milliseconds to process the echo from any given target (Horiuchi, 2005). As a result, bat flight is adjusted by neurons that only have enough time to generate one or two action potentials.

One of the motivations behind the hypothesis of sense-act processing is increasing processing speed by eliminating the "thinking bottleneck." The neuroscience of bat echolocation reveals a circuitry that is consistent with sense-act processing. For instance, auditory processing in the bat brain is tightly coupled with motor processing, particularly with motor circuits responsible for bat vocalizations (Moss and Sinha, 2003). This might reflect a sense-act system for modulating ultrasonic signals as a function of echolocation feedback; we saw earlier that the signals produced by bats vary throughout an attack sequence. Similarly, VLSI (very-large-scale integration) circuits that attempt to model the neural circuitry of echolocation, and use the output of this circuitry to control movements directly, have been successfully developed for autonomously steering robots through complex obstacle courses (Horiuchi, 2005).

Adequate theories of echolocation require considering the coupling between the bat and its world. Bats detect small, moving targets, do so while flying in three dimensions at high speeds, and detect (and react to) changes in target location in a matter of milliseconds. All of these constraints arise from the relationship between the bat and the dynamic world in which it hunts.

To say that an adequate theory of echolocation must take the coupling of a bat and its environment into account is to say that such a theory must be *embedded* or *situated*. When researchers describe cognition as being embedded or situated (Beer, 2003; Clancey, 1993, 1997; Pylyshyn, 2000; Roy, 2005), they emphasize the fact that agents are coupled with a dynamic world (Shapiro, 2011). Because of this, some of the explanatory force of an embedded or situated theory comes from appeals to properties of the world, or to properties of the world-agent interface (Ashby, 1956; Grey Walter, 1963; Simon, 1969).

Underdetermination and embodiment

Standard cognitive scientists have argued (Vera and Simon, 1993, 1994) that they have long cited environmental influences in their theories of cognition, citing Simon's parable of the ant (Simon, 1969) as a famous example of this commitment. However, standard cognitive scientists also admit that they have emphasized the "thinking" within the classical sandwich at the expense of the study of both sensing and acting (Anderson *et al.*, 2004; Newell, 1990). In embedded or situated cognition, the environment is more than just a source of inputs. When an agent is situated, its experience of the world depends crucially upon not only its sensory mechanisms, but also upon the nature of its body and the potential of its body to affect the world. "It is often neglected that the words *animal* and *environment* make an inseparable pair" (Gibson, 1979, p. 8).

Modern embodied cognitive science's position that we must consider the interface between an agent and the world in relation to the agent's body relates to theories developed by other disciplines. Biologist Jakob von Uexküll coined the term *Umwelt* to denote the "island of the senses" produced by the unique way in which an organism is perceptually engaged with its world (Uexküll, 2001). One can only describe an Umwelt by describing the properties of both a world and an agent. Psychologist James Gibson proposed the ecological theory of perception (Gibson, 1966, 1979). Gibson's theory focused upon the coupling between an agent and the world, and emphasized that this coupling depends upon the nature of an agent's body. Gibson argued that the purpose of perception was to deliver *affordances*.

Affordances are the possibilities for action that a particular object permits a particular agent. Affordances require an integral relationship between an object's properties and an agent's abilities to act. Furthermore, an agent's abilities to act depend upon the structure of its body. In short, affordances are defined in relation to an agent's body.

The previous section on situating echolocation argued that if perception is embedded or situated, then a theory of perception must refer to the dynamic coupling between an agent and the world. The implication of the current section is that this theory must also refer to the nature of the agent's body. To provide an example of this, let us return for a moment to bat echolocation.

With echolocation, the difference in time between the echo's arrival to a bat's left and right ears uniquely determines the horizontal position of a prey insect. However, this information is not sufficient to determine the vertical position of the target. How does the bat's echolocation system solve this problem of underdetermination?

One of the notable features of bats is the extravagant shapes of the pinna and tragus of their external ears. Evidence suggests that these amazing ear shapes are important for a bat to determine a target's vertical position. For instance, gluing the tragus of its ear forward severely impairs a bat's vertical discrimination ability (Chiu and Moss, 2007; Lawrence and Simmons, 1982).

Why does the shape of the ear matter? The shape causes returning echoes to strike the ear at different angles of entry, producing specific distortions in the sound signal (Müller, Lu, and Buck, 2008; Obrist, Fenton, Eger, and Schlegel, 1993; Reijniers, Vanderelst, and Peremans, 2010). These distortions provide additional auditory cues that vary systematically with the vertical position of the target (Wotton, Haresign, and Simmons, 1995; Wotton and Simmons, 2000). In other words, the shape of a bat's ear alters sound in such a way that information about a target's vertical dimension is added to the incoming signal.

That the shape of part of a bat's body solves a problem of underdetermination is a radical departure from the claim that cognitive processes are used to deal with the poverty of the stimulus. Indeed, in the case of bat echolocation, it seems as though the bat's body has removed the problem of vertical underdetermination before auditory signals have reached the bat's brain!

Degrees of embodiment

In viewing cognition as embedded or situated, embodied cognitive science emphasizes feedback between an agent and the world. We have seen that this feedback is structured by the nature of an agent's body. This is because an agent's body places constraints on how the world is experienced (Umwelt) as well as on how the world is acted upon (affordance). This in turn suggests that agents with different kinds of bodies can be differentiated in terms of degrees of embodiment (Fong, Nourbakhsh, and Dautenhahn, 2003). Embodiment can be defined as the extent to which an agent can alter its environment. For instance, Fong *et al.* (2003, p. 149) argue "embodiment is grounded in the relationship between a system and its environment. The more a robot can perturb an environment, and be perturbed by it, the more it is embodied." In other words, as agents are more embodied, they are immersed in higher degrees of feedback.

Importantly, we must consider degrees of embodiment in the context of an agent's Umwelt. For instance, from the perspective of our Umwelt, bats do not seem to be very embodied at all, because they do not (for instance) move large objects around. However, from the perspective of the bat, we have noted that bat echolocation causes dramatic changes in its environment, changing the movements of flying insects that are attempting to avoid predators. Similarly, famous social robots like Kismet (Breazeal, 2002) may not appear to be strongly embodied, because they are only heads and have no arms to manipulate the world and no legs to move through it. However, in Kismet's social Umwelt, changes in its expression and head posture produce dramatic changes in expression, posture, and vocalizations of humans interacting with the social robot.

The more embodied an agent is, the more interesting are the potential architectures that can be used to account for its cognitive processing. For instance, entomologists have long been interested in explaining how social insects can produce large and complex structures such as termite mounds. These mounds range from 2 to 7 meters in height, (von Frisch, 1974), and a single mound may exist for decades. A colony's mound extends in space and time far beyond the life expectancy of the individual termites that create it.

One important theory contends that *stigmergy* controls termite mound construction (Grassé, 1959; Theraulaz and Bonabeau, 1999). The term comes from the Greek *stigma*, meaning sting, and *ergon,* meaning work, capturing the notion that the environment is a stimulus that causes particular work (behavior) to occur. Grassé demonstrated that termites' building behavior is not regulated by the insects themselves, but is instead controlled externally by the mound. That is, the appearance of a local part of the mound serves as a stimulus that causes termites to alter that part of the mound in a particular way. However, if stigmergy is to work, then agents must be embodied to the extent that they can change the world in appropriate ways.

Stigmergy is an example of a novel contribution to cognitive science provided by embodied cognitive science. Control mechanisms that choose which primitive operation or operations to execute at any given time are fundamental to theories of cognition. Typically standard cognitive science internalizes control (e.g. the central executive in models of working memory [Baddeley, 1986]). With concepts like stigmergy, embodied cognitive science counters this standard approach, and explores the possibility that the external world is a fundamental source of control (Downing and Jeanne, 1988; Holland and Melhuish, 1999; Karsai, 1999; Susi and Ziemke, 2001; Theraulaz and Bonabeau, 1999).

It is important to remember, though, that notions like stigmergy are not merely appeals to external sources of information. The degree to which stigmergy controls an agent depends upon the agent's coupling with the world, and therefore depends upon an agent's body, as well as the potential changes to the world that agent's body makes possible. The more embodied an agent is, the more capable it is of altering the world around it, and of modifying the affordances available to it.

Active externalization

In spite of repeated warnings during its formative years (Hayes, Ford, and Agnew, 1994; Miller, Galanter, and Pribram, 1960; Norman, 1980), standard cognitive science has steadfastly underemphasized the role of the environment. It has been argued (Dawson, 2013) that the root of this stubborn stance is in cognitivism's reaction against behaviorism; cognitivists were concerned that behaviorists viewed humans as passive responders to the environment (Gardner, 1984). By rejecting the role of environment, standard cognitivism excluded a central plank of behaviorism. The notion of degrees of embodiment prevents embedded or situated cognition from devolving back into behaviorism. Humans are perhaps the most embodied agents on the planet, in the sense that they actively strive to manipulate their environment (Bronowski, 1973). As a result, humans can exploit their coupling with the world to deliberately extend or externalize their cognitive processes. The use of external structures to support cognition is *cognitive scaffolding* (Clark, 1997).

Research on practical cognition, or mind in action (Scribner, 1985; Scribner and Beach, 1993; Scribner and Tobach, 1997), has revealed that humans are masters at using the world to scaffold everyday problem solving. For example, Scribner discovered that a reliable difference between expert and novice dairy workers was that the former were more likely to use environmental resources to scaffold their activities. Expert workers used the visual appearance of dairy crates to determine how to fill orders of different amounts of dairy products.

The external world not only provides information storage, but may also manipulate stored information. A variety of navigational tools permit the results of computations to simply be inspected after data is recorded on them (Hutchins, 1995). "It seems that much of the computation was done by the tool, or by its designer. The person somehow could succeed by doing less because the tool did more" (Hutchins, 1995, p. 151).

Critically, our ability to alter the environment does not mean that we are decoupled from it. Humans actively manipulate and create their world, but dynamically respond to it too. This means that cognitive scaffolding is not without constraints. Artifacts, equipment, or technologies that provide scaffolding exist at the interface between a person and the world. Successful scaffolding will reflect this embedding, and be successful because it is appropriate to the possible actions available to the person that takes advantage of it. It would seem, then, that an examination of the nature of artifacts that are pervasive in human societies should reveal a great deal about human cognition.

This suggests that embodied cognitive science could flourish as a science of design. Viewing cognitive science in this fashion is not a novel idea. Simon's (1969) famous monograph *The Sciences of the Artificial* argued that design was central to the study of cognition, and also provided one of the seminal arguments in favor of a science of design. However, Simon viewed the science of design from the perspective of standard cognitive science, describing it as a problem-solving process that searched for optimal designs using representational techniques.

More modern approaches to design (Dourish, 2001; Norman, 1998, 2002; Schön, 1992; Visser, 2006; Winograd and Flores, 1987) are much more sympathetic to the embodied perspective. The relationship between artifacts and agents is central: the more aware an agent is of an artifact's affordances (and the less aware of the artifact as an object) the better is its design. "A device is easy to use when there is visibility to the set of possible actions, where the controls and displays exploit natural mappings" (Norman, 2002, p. 25). Embodied cognitive science may depart from the standard approach by examining the character of good design to explore the nature of the coupling between agents and environments. "Man – or at least the intellective component of man – may be relatively simple; most of the complexity of his behavior may be drawn from his environment, from his search for good designs" (Simon, 1969, p. 83).

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