Embodied Cognition

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Introduction

Psychology's mid-20th century cognitive revolution viewed thinking as information processing. This information processing hypothesis was inspired by the digital computer, and by demonstrations that this new device could perform many tasks that were assumed to require intelligence (Feigenbaum & Feldman, 1963). In other words, when cognitive psychologists hypothesize that cognition is information processing, they view 'information processing' as being analogous to the operations of a digital computer: the rule-governed manipulation of stored information. Traditional cognitivists therefore assume the existence of mental representations, and presume that thinking is manipulating these representations using a mental programming language (Fodor, 1975; Gardner, 1984).

In general, traditional theories elaborate this view of cognition into a three stage process. First, information from the environment is sensed. Second, this information is used to construct a model of the external world (i.e. a mental representation of the world) that can then be manipulated to plan actions to perform. Third, once an appropriate plan of action is developed (and once inappropriate plans are discarded), this action is executed. Thus, cognition is treated as a sense-think-act cycle called the classical sandwich (Hurley, 2001) because thinking is sandwiched between sensing and acting. According to the classical sandwich, thinking necessarily stands between sensing and acting: one cannot act without first thinking, and that the purpose of thinking is to plan action. Importantly, while the classical sandwich assumes three different processing stages, traditional cognitive theories almost invariably emphasize the 'thinking' stage, and underemphasize 'sensing' or 'acting' (Dawson, 2013).

Traditional cognitivism has led to many successful theories, and is the dominant school of thought within psychology and cognitive science. However, this approach has also faced many setbacks. Cognitive theories of human thinking, or computer simulations of human cognition, have often been successful for simple or small problems, but have performed poorly when scaled up to deal with more complicated situations (Dreyfus, 1972, 1992). In domains where real-time action on the world is critical, such as robotics, traditional theories are often flawed because they encounter a 'thinking' bottleneck: far too much time is spent updating and manipulating a representation of the world before actions are performed (Brooks, 2002). Some have argued that traditional cognitivism's emphasis on internal representations prevents it from developing adequate accounts of phenomena like understanding language, because such phenomena arise from rich interactions between the bodies of agents and the ways in which these bodies can sense and act upon the world (Winograd & Flores, 1987).

Such problems have led some researchers to develop new perspectives on cognition that adopt assumptions that are radically different from those adopted by traditional cognitivism. Embodied cognition is one such reaction (Clark, 1997; Dawson, 2013; Dawson, Dupuis, & Wilson, 2010; Shapiro, 2011). The purpose of this article is to introduce the major characteristics of embodied cognition, and to contrast these characteristics with the basic assumptions of traditional cognitivism.

Characteristics of Embodied Cognition

In very general terms, the theories of embodied cognition depart from those of traditional cognitivism by considering cognition to be a sense-act cycle instead of a sense-think-act cycle. This departure has two crucial consequences. First, there is a move away from emphasizing mental representations. This is because the external world is viewed as its own representation; it is accessed by being sensed instead of being modeled in the mind. Second, there is a move towards emphasizing sensing and acting. This in turn requires considering the rich relationship between both the world and the agent. How the world can be sensed, and how it can be manipulated, depends crucially on the structure of an agent's body.

While traditional cognitivism aims to explain complex behavior by appealing to the complexities of mental representations, embodied cognition is more likely to explain complex behavior as emerging from the complexities of the environment interacting with (simpler) properties of an agent. Let us briefly consider some of the key assumptions that provide the foundation for embodied cognition.

Environment. One key characteristic of embodied cognition is its recognition of the importance of the environment. While traditional cognition explains complex behaviors by appealing to complex mental representations, embodied cognition recognizes that environmental properties are critical contributors to this complexity. This is perhaps best reflected in Herbert Simon's parable of the ant (Simon, 1969). To explain the complex shape of an ant's path as it moves along a beach, Simon famously noted that "viewed as a geometric figure, the ant's path is irregular, complex, hard to describe. But its complexity is really a complexity in the surface of the beach, not a complexity in the ant" (Simon, 1969, p. 24).

The parable of the ant is nicely illustrated by the 1940s autonomous robot, called the Tortoise*,* invented by William Grey Walter (Grey Walter, 1950, 1963; Holland, 2003a, 2003b). The Tortoise displayed a variety of complex, life-like behaviors. The Daily Mail reported that "the toys possess the senses of sight, hunger, touch, and memory. They can walk about the room avoiding obstacles, stroll round the garden, climb stairs, and feed themselves by automatically recharging six-volt accumulators from the light in the room. And they can dance a jig, go to sleep when tired, and give an electric shock if disturbed when they are not playful" (Holland, 2003a, p. 2090).

However, such varied behavior was not produced by complicated internal mechanisms. The internal structure of the Tortoise was surprisingly simple: two sensing mechanisms, one for light and the other for physical contact, controlled two motors, one for moving and the other for steering. As the values detected by the sensing mechanisms changed, so too did the speeds of the two motors. The complexity of Tortoise behavior emerged from interactions between these simple mechanisms and the Tortoise's environment (e.g. light sources, obstacles). To generate more complex behavior, Grey Walter left the Tortoise's internal mechanisms unaltered, and instead increased the complexity of the robot's environment by adding multiple light sources, new obstacles, obstacles that reflected light, moving sources of light, and so on.

Importantly, one reason that complex behavior can emerge from the interactions between a complex environment and a simple agent is the fact that these interactions are generally nonlinear. For example, there is a nonlinear relationship between light level and steering motor speed in Grey Walter's Tortoise. In low light, the steering motor runs slowly; in medium light, the steering motor stops; in bright light, the steering motor runs at a higher speed.

Situatedness and Embodiment. If complex behavior emerges from the nonlinear interactions between the world and the environment, then additional assumptions must follow. First, agents must be able to sense properties of the environment. In embodied cognition, this ability is called situatedness. As the sensors of an agent become more sophisticated, or greater in number and variety, the agent will become capable of producing more and more complicated behavior provided that it is placed in an interesting environment (Braitenberg, 1984). In this context, an interesting environment is an environment in which various qualities that can be sensed are distributed unevenly.

In embodied cognition, agents are considered to be situated – and not merely as 'sensing' – because their ability to respond to properties of the environment is fundamentally related to the structures of their bodies. Situatedness is closely related to the early 20th century theoretical biology of Jakob von Uexküll. He 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). Von Uexküll realized that because different organisms experience the world in different ways, they can live in the same world but at the same time exist in different *umwelten*. One can only describe an *umwelt* by describing the properties of both a world and an agent. For instance, it can be easily demonstrated that the behavior of a simple robot can be changed by repositioning its light sensors by moving them further away from the center of the agent, or by changing their physical orientation (Dawson et al., 2010). Furthermore, in embodied cognition it is frequently assumed that agents actively explore their world to seek out new information as it is needed (Noë, 2004); the nature of such exploration depends upon the structure of agents’ bodies.

A second assumption that follows from the view that complex behavior emerges from the interactions between agents and environments is that agents must be embodied. To say that an agent is embodied is, in the most general sense, simply to say that the agent is physically present in the world. More sophisticated notions of embodiment drive embodied cognition. It can be argued that there is a continuum of embodiment, and that even if an agent physically exists this does not mean that it is completely embodied. Instead, embodiment is reflected in the degree to which the agent can affect or manipulate its environment (Fong, Nourbakhsh, & Dautenhahn, 2003). The more embodied an agent is, the more it can alter the world in which it is situated.

This notion of embodiment is therefore strongly related to Gibson’s ecological theory of perception (Gibson, 1979). Gibson’s theory relied upon the coupling between an agent and the world, and emphasized that this coupling depended upon the nature of an agent’s body. "It is often neglected that the words *animal* and *environment* make an inseparable pair" (Gibson, 1979, p. 8). One reason for this was because Gibson’s theory was an argument 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 ability to act on these properties. Furthermore, an agent’s ability to act depends upon the structure of its body. In short, an affordance must be defined in relation to an agent’s body.

In short, in embodied cognition’s emphasis on situatedness and embodiment, we see modern researchers endorsing two older notions, *umwelt* and affordance, as they emphasize the dynamic, nonlinear relationship between agents and their environments.

<u>Feedback</u>. In embodied cognition, agent behavior is driven by sense-act connections based upon situatedness and embodiment. An agent is viewed as being embedded in a dynamic relationship with its environment; its environment triggers particular actions from the agent. Importantly, if an agent’s actions can change the world, then these changes in turn can influence the agent’s future actions. Cyberneticists called this dynamic relation between agents and environments feedback (Ashby, 1956; Wiener, 1948). Ashby (1956, p. 53) noted “’feedback’ exists between two parts when each affects the other”, when “circularity of action exists between the parts of a dynamic system”. Feedback is an important source of behavioral complexity in embodied cognition, particularly in cases where an agent’s environment includes other agents.

For example, consider the dynamics of a bat pursuing a moth. Many species of bats hunt by emitting ultrasonic sounds and by using their echoes to detect the location of targets. This enables bats to detect and to intercept targets as small as fruit flies or mosquitos from distances of between 50 and 100 cm (Griffin, Webster, & Michael, 1960). However, moths do not passively wait to become meals. Some moths have evolved transducers that permit them to hear bat echolocation signals (Fenton & Fullard, 1979; Roeder & Treat, 1961; Rydell, Jones, & 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 & Treat, 1961). In addition, some moths emit their own ultrasonic sounds to cause bats to turn away from their prey (Dunning & Roeder, 1965). In short, bats and moths are clearly in a feedback relationship with their environment. The bat’s actions – both in terms of its flight and in terms of the kinds of sounds that it generates – depend upon the distance between the bat and its prey. Furthermore, when a moth detects this attack, it begins evasive manoeuvers, 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. The feedback relationship between these two agents – which are each dynamic components of the other's environment – is required to explain the complexity of the behavior of either agent as predator pursues prey.

It is important to note that the dynamic interactions between bats and moths occur over exceedingly short periods of time. Bats are usually hunting targets that are less than a meter away, are flying a speeds of 1 to 6 m/s, and have only a few milliseconds to process the echo from any given target (Horiuchi, 2005). Embodied cognition researchers would argue that bats simply do not have time to construct a mental model of their world to be used to plan the trajectory of their pursuit. Embodied cognition's emphasis on sense-act processing is to eliminate the 'thinking bottleneck'. "Models of the world simply get in the way. It turns out to be better to use the world as its own model" (Brooks, 1991, p.139).

Sense-Act Mechanisms. The notions of situatedness, embodiment, and feedback are all tied into embodied cognition's emphasis on sense-act processing as an alternative to traditional cognitivism's preference for the sense-think-act cycle. As a result, it is not surprising that embodied cognition seeks support for its position by discovering evidence for neural mechanisms that directly link sensing to acting.

For one example, neuroscientists studying bat echolocation have discovered a circuitry that is consistent with sense-act processing. Auditory processing in the bat brain is tightly coupled with motor processing, particularly with motor circuits responsible for bat vocalizations (Moss & Sinha, 2003). This might reflect a sense-act system for modulating ultrasonic signals as a function of echolocation feedback.

Cognitive neuroscientists are also providing evidence for existence of sense-act mechanisms in the human brain (Goodale & Humphrey, 1998). Goodale and Humphrey argue that the dorsal stream in the human brain, with connections from visual cortex to parietal cortex, mediates the visual control of action. They propose that the dorsal stream converts visual information directly into motor commands. This proposal is supported by double dissociation evidence obtained from clinical patients. Patients with damage to their ventral stream are unable to describe the orientation or shape of any visual contour (Goodale, Milner, Jakobson, & Carey, 1991). However, while this information could not be consciously reported, it was available, and could control actions. The patient could grasp objects, or insert objects through oriented slots, in a fashion indistinguishable from control subjects, even to the fine details that are observed when such actions are initiated and then carried out. In contrast, damage to the posterior parietal cortex – part of the dorsal stream -- can cause optic ataxia, in which visual information cannot be used control actions towards objects presented in the part of the visual field affected by the brain injury (Jakobson, Archibald, Carey, & Goodale, 1991). Optic ataxia, however, does not impair the ability to the orientation and shapes of visual contours.

Scaffolding and Control. Embodied cognition views agents as being dynamically embedded in environments, and as being capable of acting upon and altering their worlds. The ability to change the world permits agents to use their environment to support or extend cognition. Using the world in this way is called cognitive scaffolding. For instance, using external devices (pens and notebooks, computers, etc.) to take notes during a lecture demonstrates the scaffolding of memory. More elaborate examples of scaffolding come from studies that examine practical problem solving activities in real world environments.

One famous example is Sylvia Scribner's study of problem-solving strategies exhibited by different types of dairy workers (Scribner & Tobach, 1997). For example, workers assembled orders by converting information from computer printout into the required number of cases and partial cases of dairy products to be loaded onto each truck. However, the printout represented an order's information in a format that required the worker to convert it into more practical numbers of to-be-loaded products. Scribner found that novice workers solved this problem using mental arithmetic. In contrast, expert workers scaffolded the solution of this problem by working directly from the visual appearance of cases of dairy products. One of the expert participants in this study reported that "I walked over and I visualized. I knew the case I was looking at had ten out of it, and I only wanted eight, so I just added two to it … I don't never count when I'm making the order, I do it visual, a visual thing you know" (Scribner & Tobach, 1997, p. 303).

The external world can not only be used to store information, but can also be used to manipulate it. Examples of this are provided by a variety of navigational tools that 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).

There are also interesting examples in which computations are performed by the shapes of agent bodies. For instance, let us briefly return to bat echolocation. With echolocation, the horizontal position of a prey insect is uniquely determined by the difference in time between the echo's arrival to a bat's left and right ears. However, this information is not sufficient to uniquely specify the vertical position of the target. Evidence suggests that the extravagant shapes of the pinna and tragus of bats external ears are important for computing a target's vertical position. These shapes cause returning echoes to strike the ear at different angles of entry, causing specific distortions in the sound signal (Muller, Lu, & Buck, 2008; Obrist, Fenton, Eger, & Schlegel, 1993; Reijniers, Vanderelst, & Peremans, 2010). These distortions provide additional auditory cues that vary systematically with the vertical position of the target (Wotton, Haresign, & Simmons, 1995; Wotton & 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. The bat's body computes a solution to the vertical positioning problem before sound signals even reach the bat's brain.

Finally, scaffolding also provides an external means of systematically controlling action to achieve complex goals. For instance, entomologists have long been interested in explaining how social insects can build large and complex structures such as termite mounds. One important idea about the 'plan' for the construction of social insect nests is the notion of <u>stigmergy</u> (Grasse, 1959; Theraulaz & Bonabeau, 1999). With stigmergy, the actions of a group of agents are controlled via a shared environment. Environmental cues cause an agent to act upon and change the world. These changes in turn alter the later actions of this agent, or those of other members of an insect colony. Grassé's notion of stigmergy is the proposal that termite building behavior is not planned or regulated by the insects themselves, but is instead controlled externally by the changing appearance of the mound.

<u>The Extended Mind</u>. We have seen that one consequence of embodying cognition is that an agent's environment can be actively exploited or modified to scaffold cognition. This in turn leads to a radical and controversial hypothesis: that the mind extends into the world (Adams & Aizawa, 2008; Clark, 1997; Clark & Chalmers, 1998; Wilson, 2004). According to the extended mind hypothesis, the mind and its information processing is not separated from the world by the skull. Instead, the mind interacts with the world in such a way that information processing is both part of the brain and part of the world -- the boundary between the mind and the world is blurred, or has disappeared.

Where is the mind located? The customary view – typified by traditional cognitivism – is that thinking is inside the individual, and that sensing and acting involve the world outside. However, if cognition is scaffolded, then some thinking has moved from inside the head to outside in the world. "It is the human brain *plus* these chunks of external scaffolding that finally constitutes the smart, rational inference engine we call mind" (Clark, 1997, p. 180). As a result, Clark describes the mind as being extended, because it spreads from inside our skull to include whatever is used as external scaffolding. In other words, one key difference between traditional cognition and embodied cognition concerns where minds are located.

Conclusion

Traditional cognitive theories emphasize sense-think-act processing, presuming that the purpose of cognition is to construct models of the external world that can be used to plan future behavior. Embodied cognition is a reaction against this view, and assumes that mental models of the external world are not required, because the world can serve as its own model. Embodied cognition therefore attempts to replace the sense-think-act cycle with sense-act processing that permits the world to directly control action. This view places a greater emphasis on the nature of the environment, and on the structure of agents' bodies, than is found in traditional cognitivism. Agents are taken to be situated and embodied in an environment. What can be sensed in the environment, and how the environment can be altered by agents, depends critically on the interaction between worlds and bodies. The complex behaviors of agents may be explained by appealing to feedback between agents and environments that are mediated by sense-act mechanisms, and which permit critical components of the mind to extend into the world by means of cognitive scaffolding.

Cross-References

Cognition, embodied perception, perception-action theory,

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