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What's New About Embodied Cognition?

O que há de novo sobre cognição corporificada?

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Abstract
In the past twenty years, growing numbers of researchers have sought to steer cognitive science in a new direction. These researchers have emphasized the body's role in cognition. Although the precise nature of this role often receives only vague description, perfectly clear is the idea that, whatever this role, the time has come for cognitive science to abandon old conceptions of the mind in favor of something new; and formerly trusted methods for its investigation must give way to novel techniques. This article will first present a brief description of the *computational* conception of mind against which embodied cognition typically positions itself. Following that will be a discussion of various research projects that embodied cognitivists take to challenge this computational conception. In conclusion, the chapter offers an assessment of the embodied challenge to computational cognitive science and considers its future prospects.

Key words: cognition, embodied, computational, cognitive science.

Resumo
Nos últimos vinte anos, um número crescente de pesquisadores tem procurado direcionar as ciências cognitivas em uma nova direção. Estes pesquisadores tem enfatizado o papel da corporificação na cognição. Embora a natureza precisa deste papel seguidamente receba apenas uma descrição vaga, é perfeitamente clara a ideia de que, qualquer que seja o papel, chegou a hora de a ciência cognitiva abandonar velhas concepções da mente em favor de algo novo; e métodos de investigação anteriormente confiados devem dar lugar a novas técnicas. Este artigo irá primeiramente apresentar uma breve descrição da concepção *computacional* da mente contra a qual a cognição corporificada se posiciona. Seguindo isso haverá uma discussão de vários projetos de pesquisa que os cognitivistas da corporificação tomam para desafiar a concepção computacional. Em conclusão, o capítulo oferece um acesso ao desafio corporificado para a ciência cognitiva computacional e considera perspectivas futuras.

Palavras-chave: cognição, corporificada, computacional, ciências cognitivas.

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Computational Cognitive Science

Since as early as the 1950s, cognitive scientists have been impressed with the possibility that mental processes are computational. Three examples illustrate the commitments of such a view.

(a) In the late 1950s, Newell, Simon, and Shaw developed a computer program called *General Problem Solver* (GPS). Among the abilities of GPS was the capacity to solve simple logic problems expressible in the sentential calculus. This by itself was impressive for the time, however the real novelty of GPS was, according to Newell and Simon (Newell and Simon 1961), that it solved these logic problems in the same way that a human being does. Making this true, they thought, was the fact that "the processes going on inside the subject's skin – involving sensory organs, neural tissue, and muscular movements controlled by neural signals – are also symbol manipulating processes; that is, patterns in various encodings can be detected, recorded, transmitted, stored, copied, and so on, by the mechanisms of this system" (Newel and Simon, 1961, p. 2014).

To be clear, Newell and Simon did not intend as mere metaphor the idea that processes within a human being are computational. Certainly, if one were to look into the brain of a human subject, one would not see symbols floating around. Nor would one see RAM chips, buffers, or a CPU. However, the computational cognitive scientist would insist that it is the brain's organization that is responsible for its cognitive abilities, not its physical construction, and the human brain gains its cognitive competencies from the fact that it is organized like a computer. Just as symbols in a desktop computer are realized in the flow of current through various switches, symbols in a brain appear as the flow of activity through various neurons. The thinking brain is thus a computing brain.

(b) At least since Helmholtz in the late nineteenth century, most vision theorists have assumed that the visual process starts with a pattern of stimulation on the 2-D retina and, from this initial input, somehow creates a 3-D visual description of the world. The assumption common to Helmholtz's theory of vision and its computational descendants is that the input for vision is impoverished to a significant degree. Without the introduction of various assumptions about the nature of surfaces and objects in the world – such as that objects further away create a smaller image on the retina than they do when closer – and inferential processes that find ways to exploit these assumptions, the task of vision would be impossible. This approach to vision has spawned a number of computational theories the goals of which are to detail the algorithms that transform the 2-D patterns of retinal stimulation into descriptions of a 3-D world. For instance, Marr and Poggio (1976) described an algorithm that computes the distance an object stands from a perceiver given information about the disparity of the images of the object on the subject's two retinas. Computational vision theorists have described other algorithms as well, e.g. algorithms that will recover information about an object's shape from information about its shading; or algorithms that will compute an object's size given information about its distance.

Like Newell and Simon's work with GPS, computational vision theorists take themselves to be investigating a computational process. The visual process proceeds through stages, the first taking as input a representation on the retina. Each subsequent stage begins with a representation that has been produced by the preceding stage, which it then modifies according to various "rules." The result is sent further "upstream" until, finally, an ultimate representation that constitutes a "solution" to the computational problem of vision appears.

(c) In the late 1960s Saul Sternberg relied on measures of a subject's reaction time in a recall task in an effort to discover which of two possible algorithms are involved in the process of memory retrieval (Sternberg, 1969). Subjects first memorized a set of numerals, ranging in size from one to six members. The subject was then shown a test stimulus. If the test stimulus was among those the subject had memorized, he would pull a lever indicating a positive response. If not a member of the memorized set, the subject would pull a different lever to indicate a negative response.

Consider two distinct "programs" that subjects might (unconsciously) employ in this task. According to the *exhaustive* search strategy, the subject's recall system would compare a representation of the test stimulus to a representation of each and every numeral stored in memory. Following this case-by-case comparison, the subject would pull the positive response lever if a match had been made and would pull the negative lever otherwise. Alternatively, the subject might use a *self-terminating* search strategy, according to which the subject compares a representation of the test stimulus to a representation of each numeral stored in memory *until* a match is made. Once a match is detected, the comparisons end and the subject makes a positive response. If the test stimulus were not among the numerals the subject had memorized, the self-terminating search must in effect become an exhaustive search, checking the representation of the test stimulus against representations of each of the numerals in the memorized set.

The subject's reaction time, i.e. the time elapsed between the subject's exposure to the test stimulus and pulling the lever, increases with each increase in the size of the set of numerals he has memorized. Sternberg expected this, because on either search strategy, if the representation of the test stimulus is to be compared to representations of memorized numerals, then naturally the more numerals the subject has memorized, the longer a series of comparisons will take. However, if the subject uses the self-terminating search, his reaction time for positive responses should (on average) be less than it is on negative responses, because (again, on average) a positive match does not require that the subject compare the representation of the test stimulus to every represented numeral, whereas a complete set of comparisons is necessary prior to making a negative response.

Sternberg's analysis of memory retrieval shares the computational perspective illustrated in the first two examples. Memory is conceived as an algorithmic process in which representations of numerals are stored and compared. The cognitive scientist's job is to collect evidence that favors one hypothetical algorithm over another. Descriptions of these algorithms resemble computer programs that start with an input, proceed through processing stages, and conclude with an output.

One additional point about the computational theory of mind deserves special mention. As Fodor (1980) observed, when conceiving of cognition as computation, one can (and, according to Fodor, should) adopt a *solipsistic* perspective toward its investigation. Interactions between an organism and its environment – between body and world – are in effect screened off from psychological significance given that the organism internalizes the world by use of representational states. Features of the world and the organism's actions upon the world matter only insofar as they constitute a source of the organism's initial representations of the world. Once formed, however, the cognitive scientist can "let go" the world and focus purely upon the path the representations follow from sensory surfaces, through algorithmic processes, to final output. As far as a computational cognitive scientist is concerned, his subject might as well be a brain in a vat.

The Embodied Alternative

Practitioners of embodied cognition have rejected the computational theory of mind in a number of distinct ways. Some, like Art Glenberg (Glenberg and Kaschak,

2002) and his colleagues, have argued that the computational theory of mind is incapable of accounting for language comprehension. A capacity to understand language, according to Glenberg, emerges not from computational manipulations on symbolic representational states, but from the embodiment of the organism. Others, like Randall Beer, deny that representation plays an important role in cognition. On Beer's view (2003), dynamic interactions between an organism's nervous system, body, and environment suffice to explain the organism's cognitive capacities. Representation is an unnecessary posit. A third reaction seeks to explicate a special kind of relationship between an organism and the environment that, so it is claimed, entails that the constituents of cognitive systems extend beyond the organism's brain and into the very world in which it is situated. In this section we shall examine each of these three responses to computationalism.

Deriving Meaning from the Body

Imagine that you have arrived in a foreign country where the local language is completely unfamiliar to you. You have a dictionary for the language, but not one that translates the foreign vocabulary into your own language. You see a word on a sign, look it up in the dictionary, and read the definition. Of course, the definition is every bit as obscure to you as the original word. Moreover, using your dictionary to help you understand the definition is pointless. Each word you look up is followed by others that you also do not understand. Because none of the words is *grounded* in something that you do understand, you are unable to "break into" an understanding of the circle of symbols. But how do we initially come to understand our own language given that we have no previous language into which it can be translated?

John Searle's famous discussion of the Chinese Room illustrates a similar point (Searle 1980). A person without any knowledge of Chinese, but with a collection of manuals that describe which Chinese symbols to produce in response to Chinese inputs, would never come to understand Chinese, argues Searle. The thought experiment is intended to question the possibility that computational processes could ever suffice for understanding. The problem arises because computational processes are sensitive only to a symbol's syntax, and knowing how to manipulate symbols on the basis of their syntax tells one nothing about the meaning of the symbols. If thought truly were a matter of symbol manipulation, as computational cognitive scientists believe, it would be without meaning.

Impressed with Searle's reasoning and the problem that the dictionary example raises, Glenberg sought to locate the relation that endows language with meaning (i.e., that *grounds* linguistic symbols) in facts about an organism's body. According to Glenberg's *indexical hypothesis*, the human capacity to understand language rests on three steps. The first involves the nature of mental representations. The connection between symbolic thought and the objects in the world that they represent is not arbitrary as is, for instance, the connection between *words* and objects. That is, there is no reason that, e.g., vacuum cleaners should be represented with the words 'vacuum cleaner' – some other words would do just as well. Rather, the mental representation of an object is modal, in the sense that it retains the sensory features original to the perception of the object in the first place. If it was through vision that one previously experienced a vacuum cleaner, then the mental symbol that represents it does so by reconstituting the visual features of a vacuum cleaner (see Barsalou, 1999).

Second, having "in mind" now a perceptually grounded representation of a vacuum cleaner, one can extract from it what Gibson (1979) called affordances. The significance of embodiment enters Glenberg's theory at this point. The affordances of an object are those properties of the object that prove to be useful to an organism. Of course, depending on the type of body an organism possesses, objects will afford a variety of distinct uses. Thus, Gibson noted that a branch might afford a place to perch for a bird. Certainly, however, it could not afford a resting place for a cow. Similarly, stairs afford climbing for a human being, but not a horse. Because, according to Glenberg, one's representations of the world are in a perceptual format, rather than in some arbitrary format (as words arbitrarily represent their referents), one can extract from one's representations a knowledge of the affordances that the contents of the representations provide.

Finally, we come to the stage in the indexical hypothesis that describes how language becomes meaningful. Consider a sentence like "Hang your coat on the vacuum cleaner." How does a subject come to understand the meaning of this sentence? Notice that the sentence requires the subject to consider a non-standard use of vacuum cleaners. Glenberg argues that the subject must first form a representation of a vacuum cleaner and of a coat. Because the representations are perceptually encoded, the subject can infer the affordances of a vacuum cleaner as well as the affordances of a coat. The subject then "meshes" the affordances of each, discovering that coats can indeed be hung on (upright) vacuum cleaners, and thus can understand the sentence even though it describes a situation that is not typical for vacuum cleaners. Thus, "meaning is embodied – that is, … it derives from the biomechanical nature of bodies and perceptual systems" (Glenberg and Kaschak, 2002, p. 558).

Glenberg and colleagues have offered various empirical support for the theory of language comprehension the indexical hypothesis proposes. In one series of experiments, Glenberg and Kaschak investigated the *action-sentence compatibility effect*. Subjects were asked to judge whether a given sentence was sensible. The group of sentences to which subjects were exposed was divided into three types: (i) *toward sentences* that described an action involving motion toward the subject (e.g. "Open the drawer."); (ii) away sentences that described an action involving motion away from the subject (e.g. "Close the drawer."); and (iii) nonsense sentences, such as "Boil the air." In one condition, subjects had to move their hands away from their bodies to indicate that the sentence was sensible; in another, they had to move their hands toward themselves. Glenberg and Kaschak reasoned that subjects who had to indicate that they understood a toward sentence using an away motion, or an away sentence using a toward motion, would take longer to respond than subjects whose responses were in the same direction as the actions indicated by the sentences because the afforded actions that the sentences entail conflict with the actions the subject is required to perform. The data supported their conjecture, providing evidence of the existence of an action-sentence compatibility effect and thus supporting "the notion that language understanding is grounded in bodily action" (Glenberg and Kaschak, 2002, p. 562).

Glenberg's work on language comprehension nicely illustrates various commitments of embodied cognition. The indexical hypothesis arises from a perceived inadequacy in computational accounts of meaning – the symbol grounding problem – and proceeds to develop an alternative that emphasizes the body's importance. Glenberg's indexical hypothesis is not without its critics (see Shapiro, 2011, for discussion). One might fault it for accepting too readily that computational theories of meaning really do face a symbol grounding problem. Additionally, one might suspect that Glenberg has conflated issues surrounding meaning with those concerned with judgments of sensibility. Adams (2010; Adams and Aizawa, 2001, 2008) points out that the sentences Glenberg assigns to the nonsense category may not be *sensible*, but subjects can still understand their *meaning*. Indeed, precisely because subjects understand the meaning of "Boil the air" are they able to judge that it is not sensible.

Cognition Without Representation

Some embodied cognition researchers, especially those who adopt a dynamical systems approach to understanding cognition, have argued that the concept of representation at the center of computational theories of cognition is unnecessary. An example often cited to motivate this remarkable claim concerns an engineering problem known as the *governing problem*. As steam engines became more widely used in the late eighteenth century the need to finely regulate their output became more important. The speed at which the engine turned needed to be carefully *governed*. Facing such a problem, a computationally-minded engineer might propose a program that would solve the problem. The program would begin with a representation of the engine's current speed, would then compare this representation to a representation of the desired speed, would then calculate whether the current speed had to be increased or decreased, would then compute the correct adjustment to the engine, and then would start the process all over again with a representation of the newly adjusted engine speed.

But now consider the solution that engineers actually adopted. The engine was geared to a vertical spindle to which were attached two arms with balls on their ends. As the rotation of the spindle increased, centrifugal force would carry the balls up, causing a throttle valve to shut, which would then reduce the amount of steam entering the engine. As the amount of steam decreased, the engine slowed, reducing the speed of the spindle, causing the balls to drop and the valve to re-open, allowing more steam into the engine which in turn increased its speed. The device could be calibrated to maintain the desired engine speed.

Whereas the first solution to the governing problem proceeds computationally and is best understood by appeal to concepts like rules and representations, the second offers a mechanical answer, and is usefully modeled by mathematical equations designed to describe how changes in one part of the mechanism, e.g. the speed at which the balls rise, affects how other parts of the mechanism, e.g. the valve opening, in turn change. The differential equations that provide a complete description of all the possible states that the mechanism might enter constitute a dynamical systems model of the mechanism.

Of particular interest in this dynamical description of the governing mechanism is its indifference to representation. The explanatory framework in which representations figure is simply inapplicable to the mechanical governor. Nothing compels one to attribute representational states to various pieces of the mechanism: certainly nothing in the mechanism appears to make use of representational states. Nothing qualifies as a CPU that reads and writes symbols; nowhere is there a memory buffer in which are stored representations of engine speeds and compares them to other representations.

But, cognitive scientists like van Gelder have wondered, what if the mechanical governor" is preferable to the Turing machine as a landmark of models for cognition" (van Gelder, 1995, p. 381). That is, what if a better way to approach cognition is to adopt a non-computational perspective, modeling cognitive capacities as dynamical systems that are best explained in the terms of differential equations that make no mention of representational states? A number of cognitive scientists have chosen to do just this.

One example of this kind of work involves a simulated agent that moves horizontally left and right (Beer, 2003). As it moves back and forth, one of two kinds of object fall from above. The agent's task is to position itself beneath the falling object if it is a circle, but to avoid the object if it is a diamond. Success in this task indicates that the agent has mastered a simple categorization task. It has learned how to distinguish circles from diamonds.

One might naturally suppose that an ability to distinguish circles from diamonds requires some sort of representational capacity. Surely the agent must be able to represent the circle and the diamond if it is to be able to distinguish one from the other. Nevertheless, Beer denies this. Rather than constructing representations of its environment, the agent simply has seven upwards-facing sensors each projecting a single line of sight, like a beam of light that might be broken by a passing object. The sensors are arranged so that as the agent moves back and forth, the falling shapes will break the seven lines of sight in distinctive ways. The agent's nervous system then processes the information from the lines of sight, and adjusts the agent's motion so that it ends up beneath a circle but away from a diamond.

Beer's analysis of the agent's capacity to distinguish the circle from the diamond begins with an assignment of state variables that describe different features of the system comprising the agent, its nervous system, and the environment. For instance, one variable indicates the height of the falling object, another the relative horizontal distance between the agent and the object, and another still the activity of a given neuron in the agent's nervous system. Because the agent is always moving, its horizontal distance to the falling object is always changing and so the activity in its nervous system is also undergoing constant change. The system resembles the governor in this respect – all parts of the system are in motion at all times, and the change happening in each part is a function of the change taking place in other parts (in the falling objects in the world, in the motions of the agent, in the agent's nervous system).

The differential equations Beer devised to describe the patterns of change taking place in the system provide the means to explain why the agent behaves as it does. For instance, they explain why the agent has difficulty catching a circle if it begins to drop from a position directly above the agent; why the agent adopts a scanning pattern involving zig-zagging motions; how the agent would behave given any starting point for a falling object, and so on. The explanations, moreover, are counterfactual supporting in the sense that they can predict the agent's behavior if a diamond were to fall at a speed that it never actually does, or were the agent to be a relative distance from a circle that it never actually is, or were the falling object to have a shape somewhere between that of a circle and a diamond.

Beer contends that his account of object categorization in his simulated agent, like the explanation of the governor's behavior, is non-computational. The agent, object, and nervous system are analogous to components of the governor. They are in constant contact, influencing each other and in turn having the nature of their influence shaped by the influences they exert on each other. As such, the system appears poorly suited to a computational description that strives to impose on its elements an algorithmic description consisting of sequential operations over discrete representational states. No such states exist, Beer insists, and certainly nowhere is there a memory in which are stored rules that a CPU applies to representational states in order to perform a categorization operation.

Philosophers and psychologists have divided over whether the dynamical approach to cognition succeeds in its effort to do away with representation (see, for instance, van Gelder, 1995; Bechtel, 1998; Prinz and Barsalou, 2000). Much of the debate turns on how one conceives of representations. Beer might be right that nothing in his agent corresponds to the kind of symbolic structures present in standard computers, but this does not preclude the possibility of states of other sorts that play the "standing-in" role associated with representations. Ward and Ward (2009), for instance, subject an agent like Beer's to a form of analysis that reveals a correspondence between states of the agent's nervous system and particular shapes. Perhaps this discovery justifies the claim that even within agents as simple as Beer's, representations make an appearance.

Also worth considering is whether agreement with Beer with respect to the representation-free status of his agent entails a commitment to representation-free cognition *tout court*. Might some cognitive tasks require representations while others do not? Clark and Toribio (1994) have explored this idea, suggesting that some tasks, like planning, counterfactual reasoning, and problem solving are "representation-hungry." These are the tasks that seem to require abstraction from particular cases, or imagery, or memory. Whether a dynamical systems approach to these capacities can succeed without use of representational states seems unlikely.

Extending Cognition

Computationalists, recall, adopt an overt solipsism. The brain is separate from the body and world, receiving information about these things via channels from the sensory systems. Having received this information, it draws on its various computational programs in order to make sense of it all, producing as output the perceptions and actions necessary for survival. The brain is the locus of cognition; its boundaries mark the boundaries of thought.

Some in the embodied cognition community reject this picture of the locus of cognition. The brain no doubt plays a central role in cognitive processing, but it hardly operates on its own. Further clarification of this claim requires resolution of an ambiguity. On occasion, advocates of extended cognition suggest that cognitive processing takes place outside the brain. Adams and Aizawa (2001) suggest a helpful analogy for understanding this claim. Some spiders, rather than having to do all their digesting within their own bodies, inject an enzyme into their prey that begins to break it down into more easily digestible materials. The spider then needs merely to suck the pre-digested matter from its catch. Digestion, in this case, is *extended*. Some of it happens outside the spider's body. If cognition extends in an analogous manner, we ought to expect to find cognitive processes happening outside the brain.

Consider, though, a second sense in which cognition might extend. The system in which cognition takes place might include components that are outside the brain. On this way of conceiving extended cognition, cognition does not take place in distinct locations, as does the spider's digestion. Rather, cognition occurs in just one place, within the confines of a single system, but the system extends beyond the brain. Analogously, time-keeping does not take place in a single gear within the mechanism of a grandfather clock. Instead, time-keeping is a product of the system of gears working in close interaction. On this view, cognition extends when the brain cannot "do it" on its own, but only in close interaction with things outside itself.

The first interpretation of extended cognition generates more controversy, and critics such as Adams and Aizawa (2001, 2008) have offered a number of trenchant criticisms. We shall focus our attention on the second, although it suffers hardly less controversy than the first. The most significant obstacle to defending the second sense of extended cognition involves attention to the distinction between causal influences *on* a system and constituents *of* a system. The solar system, for instance, consists *of* eight planets and the sun. However, other celestial bodies light years away might, due to their mass, have causal influences *on* the motions of the planets. To take another example, the presence of food and oxygen surely have causal influences on cognition. Cognition could not occur without them, but this does not entail that psychologically complete descriptions of the systems that perform cognition must include references to food and oxygen.

The distinction between cause and constituent may not always be determinate (see (Shapiro, 2011, p. 158-161, for further discussion). Of pressing need is justification for judging of some thing that it is a genuine component of a system rather than just something that contributes to a system of which it is not a part. Clark and Chalmers (1998), for instance, argue that the entries in a diary kept by an Alzheimer's victim might, when meeting certain conditions, count as constituents of the person's memory. They might count as beliefs the person has about the locations of various buildings, or the names of various individuals. On this view, the cognitive system of the Alzheimer's victim includes the diary. But alternatively, why not understand the diary entries not to be constituents of the person's cognitive systems, but external "prompts," the exposure to which creates "real" memories in the person's head – the genuine locus of cognition?

An interesting approach to defending the possibility of extended cognition focuses on systems that depend on feedback loops for their operation. Clark (1997) for instance, discusses turbo charged engines. Most automobile engines produce exhaust that simply disappears into the atmosphere. Turbo charged engines, in contrast, use the exhaust they produce in order to force more oxygen into their cylinders, which in turn cause bigger explosions, which then provide more power to the engine, resulting in more exhaust, which then is forced back into the engine. Given the relationship of the various pieces involved in this loop, Clark insists that the exhaust must count as more than a mere contributor to the engine's capacity – it is a constituent in the system that produces the engine's power.

If Clark is correct, then cognition will extend when the brain interacts with the body or environment in a similarly "loopy" way. There must be a flow of information from brain, to world, and back to brain in which each part of the loop "helps" the others, resulting in a product that emerges as a consequence of this mutual interaction. As an illustration, consider recent work on the use of gesture in spatial reasoning. A number of studies have shown that when subjects are asked to perform tasks that require spatial reasoning, their accompanying hand gestures play a critical role. Their performance decreases when prevented from using gestures, and in some tasks subjects seem to explore one solution with the use of gesture while simultaneously "talking" through a distinct solution (Rauscher *et al*., 1996; Ehrlich *et al*., 2006). If future studies show that information about spatial reasoning becomes structured through the use of gesture, which in turn shapes how the brain processes the information, which in turn then shapes future gestures, then some instances of spatial reasoning would seem to fit the model of the turbo engine. If one agrees that engine exhaust is part of the system that powers the engine, then one might for the same reason think of gestures as part of a cognitive system for spatial reasoning.

Conclusions

The previous section introduced three illustrations of the kind of work embodied cognition researchers presently conduct. Each purports to challenge the current computational orthodoxy in various ways. Glenberg believes that computationalism cannot explain the emergence of linguistic meaning because, he argues, meaning cannot arise from mere symbol manipulations of the sort that computers perform. Meaning derives from the perception of affordances, and affordances reflect properties of an organism's body. Hence meaning is embodied. Beer contends that dynamical systems theory rather than computer science provides the best model for cognition. Cognition, on his view, is the product of interactions between a nervous system, a body, and a world. Because each of these things undergoes constant change, and changes in each influence changes in the others, differential equations stand a better chance of describing the behavior of such a system than does a step-by-step algorithm. Insofar as the concept of representation contributes nothing to dynamical explanations of such systems, cognitive science can do without it. Finally, some embodied cognition theorists reject the suggestion that cognitive systems are cranium-bound, taking place in a computer in the skull. Instead, as work in dynamical approaches to cognition also intimates, cognitive systems incorporate elements from outside the brain. An organism's body and environment might be crucially involved in the production of cognition.

No doubt each of the three research programs described above has deepened our understanding of cognition. Glenberg's discovery of an action-sentence compatibility effect shows that human beings seem to anticipate the actions that sentences describe and perhaps rely on these anticipations to interpret the meaning of a sentence. Likewise, Beer has shown that an agent's interactions with its environment can reduce the computational burden on its nervous system: perceptual tasks like categorization can be assisted by the kinds of scanning motions that Beer's agent adopts. Discussions of extended cognition make a similar point, revealing the extent to which cognitive systems incorporate extra-cranial components in ordinary cognitive activities. Each of these points raises the profile of the body's significance in cognitive processing.

However, far less clear is whether the tried and true methods of computational cognitive science must step aside as embodied cognition advances. One reaction to findings of the body's role in cognition is to assign it a more prominent place in computational descriptions of cognition. For instance, why not take Glenberg's finding of an action-sentence compatibility effect to show that a computational account of sensibility judgments must factor in the subject's interpretation of the sentences. The account would go like this: the subject computes the meaning of the sentence. This then initiates a motor command to produce the action entailed by the sentence, which then, presumably, is extinguished prior to the subject actually taking such an action. However, the command suffices to inhibit the action the subject is instructed actually to take (e.g. pulling the lever towards himself)? In short, Glenberg has not shown that a computationalist cannot account for the action-sentence compatibility effect, and indeed cognitive scientists have often run across instances of priming and inhibition similar to those which Glenberg's studies uncover.

In a similar vein, computationalists might not express much concern over the claims of extended cognition. As Rob Wilson (2004) has argued, the computational paradigm does not in fact entail the brand of solipsism that many computationalists have simply assumed. Computationalism, broadly, is the view that cognitive processes are best conceived as computational. But where, exactly, these computations take place, and whether they might span the brain and the surrounding world, are questions about which the computationalist may remain silent. Important to explaining cognition is the discovery of algorithms that produce the desired outputs given the available inputs. That parts of the body or world might participate in the execution of these algorithms is an empirical issue not to be eliminated from consideration merely on the basis of having adopted a computational perspective.

Finally, the growth of dynamical approaches to cognition raises interesting questions about the very nature of cognition. One might suspect that such approaches have assumed a conception of cognition so alien to that which computationalists have traditionally pursued that they do not truly mark a challenge to computational cognitive science (e.g. Chemero, 2009). Dynamical cognitive scientists tend to be interested in the behavior of whole organisms, and offer as explanations of this behavior equations that might fit non-cognitive systems as well as purportedly cognitive ones. Hence, one response to the dynamical "challenge" is to see it as not a challenge at all, but instead as a hopeful approach to understanding a range of phenomena that has so far not received adequate attention from cognitive scientists.

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