The future of embodiment research:
Conceptual themes, theoretical tools, and remaining challenges

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Abstract

Research on embodiment suffers from the lack of a shared theoretical and conceptual basis, so that it seems unlikely that all research sailing under the embodiment flag is actually targeting comparable questions and phenomena. A better organization of the field is therefore necessary to make progress. This will require trading the often-metaphorical interpretations of available findings for systematic predictions derived from a to-be-developed theoretical framework. This chapter discusses some of the major themes driving the embodied-cognition movement and the degree to which they imply that human cognition is indeed embodied. As a theoretical framework to organize efforts to address these themes, the theory of event coding (TEC) is suggested, which provides a sufficiently rich theoretical and conceptual toolbox to systematically structure theorizing and studying, and eventually improve our understanding of embodied cognition. The chapter concludes with a brief list of important challenges that remain to be tackled, including more specific, mechanistic theorizing about the representations underlying embodied cognition and the processes operating on them.

Like many other new theoretical approaches, the embodiment movement, as I will call the total of approaches interested in embodied cognition in a broader sense, is a counter-reaction. What unites most members of the embodiment movement is the rejection of what has been captured by the term GOFAI—good old-fashioned artificial intelligence (Haugeland, 1985). What is attributed to the theoretical attitude that this term refers to is the assumption that human intelligence emerges from the mental manipulation of symbolic, amodal representations. If this were the case, as GOFAI claims, there would not necessarily be anything special about *human* intelligence, which in fact could be perfectly mimicked by symbol-manipulation operations in artificial systems, like computers or robots. Hence, artificial intelligence would be indistinguishable from natural intelligence, which is the key idea that led to the development of the Turing test (Turing, 1950). It is fair to say that the members of the embodiment movement are united in rejecting this symbol-manipulation approach as a sufficient theoretical basis for understanding human cognition.

What also unites the members of the embodiment movement is some theoretical reliance on the human body and/or the actions it is involved in. The details of this reliance is very diverse however: some consider body and action as the purpose of cognition, some as the vehicle or tool to generate cognition, some as a kind of modality or source of information, and some as a medium to generate internal simulations. The reasons for this diversity is that different members of the embodiment movement have counter-reacted to rather different developments in sometimes different fields, which makes their conclusions too heterogeneous to extract anything like a common theoretical framework or line of thinking or methodology (cf., Wilson, 2002; Hommel, 2015, 2016). Worse, many counter-reactions put forward valid arguments against their main theoretical target but the way these arguments relate to the human body or the action it generates often remain rather vague and metaphorical. Given that the approaches vary sometimes dramatically in theoretical aims, scope, and precision, I will not try to systematize the available approaches or to trace each one back to its particular theoretical context. Rather, I will try to extract a number of conceptual questions that seem to drive at least a substantial number of the available approaches. In a first round, I will go through the most salient conceptual themes and critically discuss whether and to what degree they imply a relevant role of the body in human cognition. Then I will suggest a theoretical framework to organize the discussion of these themes and briefly sketch how this organization may work. Finally, I will present a brief to-do list that I think is necessary to work through in order to better understand how human cognition is embodied.

Conceptual themes of the embodiment movement

Representation

While we will see that many members of the embodiment movement deal with some aspect of representation, other approaches are more radical in this respect in denying the need of any representation. Proponents of a radical/nonrepresentational embodied cognitive science (e.g., Chemero, 2009) took inspiration from the ecological psychology of James Gibson (e.g., 1979; Dreyfus, 2002) and the constructivist theorizing on enactivism along the lines of Maturana and Varela (e.g., Varela, Thompson, & Rosch, 1991; Clark & Toribio, 1994; for a comparative discussion and integration, see Baggs & Chemero, 2018, and Raab & Araújo, 2019). Some of these approaches have characterized themselves as relying on the idea that cognition is situated, in the sense that cognitive activity and knowledge utilization always takes place in a particular context. We will see that not all authors subscribing to this view deny the relevance of representations (e.g., Barsalou, 2008), but true proponents of radical embodied cognitive science do. The situated-cognition approach was fueled by developments (or the lack thereof: Brooks, 1999; Clark, 1997) in cognitive robotics, where authors have emphasized that much if not all information needed for behavior does not need to be stored or predicted but can be picked up from the current environment (e.g., Clancey, 1997; Pfeifer & Bongard, 2006). This is considered to be important by reducing the complexity (Brooks, 1991) and speeding up (Pfeifer & Scheier, 1999) real-world decision-making and behavior, which is seen as a strong advantage over cognitive-robotics approaches that heavily rely on stored information and world models.

Representation-skeptics commonly point out the informational richness of the environment of agents, often in a Gibsonian (Gibson, 1979) sense (e.g., Rietveld & Kiverstein, 2014; Wilson & Golonka, 2013). This reasoning is based on the intuition that the more information is provided by the environment, the less information and the less contribution to this information needs to be attributed to the perceiver/actor. Once all informational sources of the environment are understood and described, nothing would be left to the perceiver/actor, so that no representations need to be attributed to him or her. Unfortunately, this view confuses the source of information with the way it is used. On the one hand, the richness of environmental information does speak to the question of how much a perceiver/actor can rely on external information and how much internal contribution through stored memories is necessary. It is true that this remains a theoretical consideration, because even if all necessary information would be provided by the environment, it would still need to be demonstrated that the perceiver/actor indeed uses this information, rather than internally stored information. But the general line of the argument is well taken. On the other hand, however, few non-ecologists/non-enactivists would deny the need and benefit of environmental information for perception and action control, which makes it difficult to see in which sense the key claim of ecological approaches might be “exciting” or “radical” (e.g., Baggs & Chemero, 2018; Wilson & Golonka, 2013), and in which sense it might challenge the concept of representation as it is, often implicitly, used in cognitive psychology and the cognitive neurosciences.

Cognitive psychologists commonly speak of a representation if there is some functional internal state that is correlated with some external state of affairs, and cognitive neuroscientists do the same with respect to neural internal states. Hence, if it is the case that every time a perceiver sees a cherry, or a particular cherry, he/she can be demonstrated to generate some functional or internal state, this state is considered to represent the cherry—irrespective of whether this state is used or perceived by someone or something, and whether this use is considered “mental”. From a functional perspective, assuming such representations is useful because it identifies the function of the state as reflecting a relationship between some external state of affairs, the particular perceiver/actor, and some processes that are affected by this relationship. It is also useful by helping to understand how and why a perceiver/actor can carry out internal or external operations with or on the represented state of affairs even in the absence of that state of affairs. For instance, people can simulate picking a cherry from a tree without seeing the tree or the cherry, which would be hard to understand if these people could not somehow reproduce internal states that are similar to the states that a real cherry and tree would produce. Obviously, the same holds for neural states: if perceiving a real cherry and imagining seeing a cherry generates the same or similar neural activity, which we know they do, it is hard to see what would be wrong by calling this activity a representation of the cherry or of seeing the cherry.

These issues are commonly not addressed by radical anti-representationalists, who systematically restrict their examples to tasks that are likely to rely on substantial amounts of environmental information, like grasping an object, but entirely ignore tasks that do not and cannot, like grasping when blindfolded, or writing an article, or singing a song. Anti-representationalists are also reluctant to provide concrete processing models that explain how environmental information eventually moves a muscle to generate the action under discussion. If they would, they would need to explain how the perceiver/actor reconfigured him- or herself in order to pick the cherry, rather than playing soccer, say, and how the environmental information is actually brought into contact with, and how it controls the activation of the muscle driving the action. In other words, anti-representationalists choose to not touch theoretically what happens between people's ears, which makes it feasible to do without representations.

However, the main target of the theoretical criticism does not seem to be representations in the trivial sense that I have discussed so far. Rather, anti-representationalist papers often construe some kind of contradiction between the concept of "mental representations" on the one hand and the idea of "perceptually guided motions through the world" on the other (Wilson & Golonka, 2013). And yet, while one can argue about the usefulness of the widespread custom to qualify representations as "mental", it is hard to see why the representation concept as such should be incompatible with attempts to account for perceptually guided action. Generating perceptually guided action requires environmental information to get in touch with muscles moving the respective limbs, which in turn requires the channeling of perceptually extracted information from the sensory surface through to action control. On this way, the information needs to be coded and frequently recoded, which means that the external information needs to be internally re-presented—and it is this trivial necessity that most cognitive psychologists and neuroscientists have in mind when speaking about representations (e.g., Raab & Araújo, 2019). This is even more obvious if the environmental information is no longer available, such as if one closes one's eyes before starting to reach for an object: how could one ever achieve this if one wouldn't be able to represent the previously available information off-line? The ability to re-present or recode external information does not necessarily suggest any high cognitive work, consciousness, or understanding, it simply refers to the obvious fact that information needs to be transported through the central nervous system to do its job. Apparently, this concept of representation is much more trivial than what anti-representationalists argue against. Anti-representationalists also seem to believe that assuming the existence of representations implies that cognitive content and cognitive processes are disembodied (e.g., Chemero, 2011; Wilson & Golonka, 2013; for a broader discussion see Dove, 2011). However, it is hard to see how assuming that external states of affairs are systematically correlated with internal states of affairs, as cognitive psychologists and cognitive neuroscientists do, necessitates the assumption that cognitive processes have nothing to do with the body. Indeed, we will later see that a number of theorists that subscribe to the embodiment movement are explicitly discussing that and how representations bring the body into play—which seems to undermine the basic assumption that representations and embodiment are incompatible concepts.

To summarize, the representations that anti-representationalists are against seem to be different kinds of representations than those assumed to exist by modern cognitive psychologists and cognitive neuroscientists, so that the actual target of the criticism remains to be identified. For mainstream cognitive psychology/neuroscience, the assumption of representations in a trivial sense (i.e., internal states that systematically correlate with external states of affairs) does not seem to rule out the possibility that human cognition is embodied, and does not even seem to be related to the question of whether and how the embodiment of human cognition works. Worse, the systematic reluctance of anti-representationalists to develop concrete mechanistic models that explain how the environmental information they are interested in actually drives the movements that they emphasize stands in the way of further theoretical developments that would help us to understand how and in which sense human cognition is embodied.

Cognition

Some authors are less interested in issues related to representation in general, but focus on the role of cognition in decision-making and action control. Again, some of the pioneering authors were motivated by their disappointment about progress in cognitive robotics (e.g., Brooks, 1999; Clark, 1997), while others relied on research on human thinking (e.g., Gigerenzer et al., 1999). The key intuition is that cognitive processes are slow and often too comprehensive, or more comprehensive than necessary, which implies that truly effective decision-making and action control should not rely on cognitive processes at all, or at least not in time-critical situations. This obviously raises the question of what the alternative might be, and here the answers are rather different. While some authors have brought overlearned habits, generic biases, or spontaneous heuristics into play (like Gigerenzer et al., 1999), others have considered sensorimotor processes (e.g., Körner, Topolinski & Strack, 2015)—which implies a closer connection to the embodied-cognition idea. The main conceptual problem in these approaches is that they fail to define the concept of cognition, which makes it difficult to judge whether this concept is truly independent from the alternatives it is put into opposition with.

The term goes back to Greek for "I know, perceive" and, according to a typical definition, refers to "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses" (www.oxforddictionaries.com, retrieved 1.2.2020). This implies a very active role of the person who is busy with knowledge acquisition and understanding, and the definition seems to be relatively "disembodied"—if one neglects the fact that the senses belong to, and are carried by a body that also mediates the experience. Engaging in cognitive processing is also often explicitly or implicitly associated with conscious representation, as for instance implied by the work of Gigerenzer et al. (1999), Kahneman (2011), or Dijksterhuis and Nordgren (2006). Given that the buildup of conscious states is notoriously slow and sensitive to biases (Kahneman, 2011; Hommel, 2013), it makes a lot of sense to assume that relying on such states slows down information processing to a degree that stands in the way of fast and efficient decision making and action control.

However, since the cognitive revolution in the 1960s and 70s, when Neisser (1967) defined cognitive psychology as “the study of the mental processes involved in acquiring knowledge”—a definition that is still very close to the Greek roots of the term cognition, the semantics have slowly but consistently liberated the term from such roots. Both cognitive psychology and the cognitive neurosciences are interested in the processes *underlying* cognition, without the requirement that each process shares all the characteristics that the emerging property the process contributes to is assumed to have. Hence, there is no reason to assume that the processes generating cognition are as conscious and as slow as the cognitive act that they are assumed to contribute to. Unfortunately, cognitive psychology and the cognitive neurosciences tend to label the processes underlying psychological phenomena according to these phenomena, which is why theorists speak of memory processes, attentional processes, perceptual processes and, indeed, cognitive processes. As I have elaborated elsewhere (Hommel, 2019a, in press), this is unfortunate for two reasons: it blurs the line between the explanandum (such as cognition) and the explanans (the interaction of processes explaining the emergence of cognition), and it falsely suggests that the respective processes are dedicated and reserved for the psychological functions the label of which they carry (e.g., implying that a “memory process” cannot also be an “attentional process”). Importantly, if we correct for these terminological inaccuracies by translating “cognitive processes” into “processes that contribute to the emergence of human cognition”, there is no reason to believe that all processes contributing to cognition are necessarily slow or too comprehensive. There is also no reason to believe that the processes underlying human cognition, defined in whatever way, shows zero overlap with the processes that one assumes to underlie the conceptual alternative, be it a habit or a sensorimotor process.

Taken altogether, anti-cognitivist critics may well be right in assuming that efficient decision-making and action control does not rely on conscious representations. However, given that few, if any mechanistic models of decision-making an action control suggest such a reliance, it remains unclear against which approaches such critics are arguing. It is possible that much of the respective controversy rests on a misunderstanding of the term cognition, and in particular on its in accurate application to the processes that are assumed to generate human cognition. The key question that remains is whether, and to what degree these processes relate to the human body and the activities it unfolds. But even if they strongly rely on the body and its activities, there would be no contradiction in assuming that they also underlie human cognition—which is indeed what the term embodied cognition implies. Hence, anti-cognitivism does not seem to be a logical theoretical motive to favor the idea that human cognition is embodied.

Format

Some authors of the embodiment movement are less skeptical with respect to the general idea of representations but more interested in the format of representations. In contrast to the symbolic view suggested by GOFAI, embodiment theorists tend to assume that cognitive representations are distributed and modal, that is, still capturing aspects of the sensory or sensorimotor activity that served to pick up the respective information. Authors differ with respect to the degree to which they allow for symbolic, abstract, and amodal representations in addition to less abstract or modal representations, and the degree to which action-related information is considered to be part of modal representations, but the unifying assumption is that abstract symbols cannot be all there is (for an overview, see Barsalou, 1999, 2008).

Even though many embodiment theorists assume some degree of modal representation, not all proponents of modal representations are necessarily embodiment theorists (this depends on their definition of "modal", on which there is no consensus: Haimovici, 2018). Modal representation has also been put forward as a means to provide a better grounding of internal representations. For instance, the assumption of abstract symbols has raised the question of where symbols are coming from in the first place and exactly how they actually acquire their meaning (Harnad, 1990). To really understand what the term red means arguably requires some exposure to something red, which brings in perceptual experience, and representations reflecting that experience, as an important mediator of symbol grounding. If representations carry concrete aspects of their acquisition history, the grounding problem could be reduced and eventually be solved (Barsalou, 1999). While this theoretical move might include information about the body and about action, they may not always be necessary ingredients, which implies that not all evidence supporting modal representation necessarily requires the assumption that cognition is embodied (Barsalou, 2008).

Given that embodiment theorists agree in rejecting radical symbols-only approaches, it is not surprising that all embodiment approaches that include specific assumptions regarding representations have opted for what one may call compositional representations—integrated bindings of codes that represent information about the sensory features of the represented event, perhaps in addition to action-related features and other information. The exact nature and the format of these codes is not yet clear, however. Some authors assume that these codes represent the sensory modality used to extract the respective feature (Barsalou, 1999), and there is quite some evidence that relating information that was extracted by the same sensory modality is easier than relating information extracted by different modalities. However, if modality-specific codes would be all there is, one would need to explain how the same information in two or more sensory modalities (like the smoothness of an object extracted by vision and by touch) is related to each other, and how perception can inform action control. As pointed out by Prinz (1992), effective communication between perception and action requires some kind of common currency or common coding that both can relate to, which is not provided by codes representing modality-specific perceptual and action-related state of affairs (e.g., the way visual neurons are coding for a round object has no resemblance to the way muscles are controlled to reach for a round object). Communication between perception and action requires a distal reference (Heider, 1926/1959: i.e., information about the external object and the external interaction with it) rather than a proximal reference (as provided by modal codes). This does not rule out the possibility that some representations of external events are modal, but other representations need to be as amodal as their distal reference requires—in addition to being compositional (Hommel et al., 2001a; Hommel, 2009).

Taken altogether, there is widespread agreement that the representations that embodied cognition relies on need to be compositional in one way or another. Minimally, representations need to represent perceptual characteristics of the represented events, possibly in addition to codes representing the action related to that event. These representations may include modal information, but some more amodal (but still feature-based) codes are important to understand inter-modal integration and communication between perception and action.

Simulation

Various authors of the embodiment movement have suggested that both perception (Barsalou, 1999) and action planning (Gallese & Goldman, 1998) are not only associated with, but even require, some sort of internal simulation to operate properly. Simulation theorists see evidence for their claims in studies that for instance show that people respond faster to pictured objects if the shape of these objects is implied by a sentence that they read before (Zwaan, Stanfield & Yaxley, 2002). Along the same lines, planning an action has been observed to activate brain areas that are similar to those that are activated when merely imagining performing the action (Gallese & Goldman, 1998). What remains unclear in simulation views is what purpose the simulation may have. What would it be good for to generate visual images of objects described in a sentence when reading it? Some authors escape this question by arguing that simulation is automatic (e.g., Körner et al., 2015), which seems to render the possible functionality irrelevant. Others have explicitly asked the functionality question and either could not identify a particular purpose (e.g., Bergen, 2015) or explicitly considered simulation epiphenomenal (Mahon & Caramazza, 2008).

A key problem of the simulation view is causality. In order to demonstrate that simulation is a necessary requirement for meaningful perception and action planning, it would be necessary to show that preventing simulation makes perception and action planning impossible. While there are a few studies showing that introducing secondary tasks or interfering events that are assumed to hamper simulation (or the processes assumed to rely on simulation) significantly impairs performance (e.g., Grade, Pesenti & Edwards, 2015; Witt & Proffitt, 2008), finding delays of a couple of milliseconds or a slight drop of accuracy is a far cry from showing that perception and action planning no longer works without simulation. Another problem is that it remains unclear what the term simulation actually implies. For instance, Bergen (2015) traces the concept back to Wernicke (1874/1977, p. 117), who claimed that the concept of the word "bell… is formed by the associated memory images of visual, tactile and auditory perceptions". Note that this assumption does not go anywhere beyond the claim that objects are represented by codes that relate to feature information provided by different modalities, as discussed above. Wernicke's idea may thus simply come down to the assumption that representations are composites of feature codes, so that facing an object is likely to reactivate codes that represent different kinds of features of this object. Calling this a simulation may or may not be semantically meaningful but it seems to create quite a bit of unnecessary interpretational overhead, such as implying someone or something that is doing the simulation and someone or something for which it is done. Someone is indeed implied by considering simulation a "reenactment of previous experiences" (Pecher & Winkielman, 2013, p. 396)—which seems to imply a person having had an experience and now having it again.

To summarize, claims that perception and action planning involve internal simulation are still in need of convincing evidence that simulation is an integral part of these processes, and even if such evidence could be provided, it remains unclear in which sense simulation renders cognition embodied (especially if one considers that even simulations *about* the body do not actually involve it). Very likely, a feasible definition of simulation will turn out to be going not much beyond the assumption that perception and action planning involves the reactivation of feature codes that represent earlier-acquired, modality-specific object or event information.

Bodily states

Some authors of the embodiment movement have focused on the role of bodily states in human cognition. For instance, Körner et al. (2015) have argued that the potency of sensations and actions to "directly alter a person's state of mind, feelings, or information processing" represents a mechanism underlying embodied cognition. Empirical examples assumed to indicate such a potency derive from various attempts to prime all sorts of internal states, often by means of task-unrelated stimuli (for an overview, see Janiszewski & Wyer, 2014). Many of these demonstrations have been challenged just recently, and they seem to be difficult or impossible to systematically replicate (e.g., Chivers, 2019). More interesting for present purposes are the theoretical implications of these approaches, however, and in particular their relevance for embodied cognition.

For many of the findings of priming studies, a connection to embodied cognition is anything but obvious. For instance, the ability of attended or unattended, conscious or unconscious stimuli to trigger a particular behavior seems unrelated to the question of whether and in which sense cognition is embodied, and the same holds for stimuli that may activate a particular goal or motivational orientation. Depending on the theoretical background, these kinds of priming effects might even be consistent with a GOFAI-compatible view that is based on symbol manipulation. Similarly, observations of what one may call metaphorical associations, like when being exposed to physical warmth promotes interpersonal warmth (e.g., Williams & Bargh, 2008; but see Lynott et al., 2014), are likely to require the assumption of compositional, feature-based representation (so that one representation can prime another based on feature-overlap) but have no obvious bearing on any involvement of the human body. More relevant seem to be priming effects caused by experimental manipulations of bodily states, such as demonstrations showing that assuming a particular posture systematically or activating muscles that are involved in smiling affects the affective judgment of objects (see Laird, 2007; Neumann, Förster & Strack, 2003). On the one hand, these kinds of demonstrations provide clear-cut evidence that bodily states can have an impact on human cognition. On the other hand, however, there are several reasons why they do not speak to the question of whether cognition is embodied.

First, because demonstrating that changing bodily states *can* affect cognition does not necessarily imply that bodily states are involved in and represent a necessary ingredient in *all* kinds of cognition. Second, because bodily states need to be *perceived* in order to impact cognition; so that it eventually is perceptual information that has the impact, and that cognition is affected by perceptual information does not seem to be a unique theoretical assumption. For instance, there is evidence that people differ substantially with respect to their interoceptive abilities (Schacter, 1971), suggesting that some people's cognitive processing is affected more strongly by interoceptive information than other's. This implies that cognitive processing is affected by information provided by multiple sensory modalities, as many authors assume (see above), with interoception representing just one of many informational sources. Accordingly, there is no reason to assume that interoceptive informational sources have a privileged access to perception and action control, which in turn suggests that the bodily states that interoception informs about do not play a particularly dominant role in human cognition. Third, even the most hard-nosed symbolic approach is unlikely to deny that people sense and represent interoceptive information, and that this information may become associated with, and be taken to represent particular internal states. If so, it is hard to see why the demonstration that bodily states can impact cognition might require a particular kind of non-symbolic representation, as the embodied cognition movement claims.

To summarize, the available evidence suggests that interoceptive information has an impact on perception, decision-making, and action control. However, it is hard to see why these observations require the assumption that the sources of this information have a particularly dominant or theoretically noteworthy role in human cognition.

Action

Some authors of the embodiment movement have emphasized the role of action in representing external objects and events. The way and the degree to which action is considered to contribute to cognition differs substantially, however. Some have emphasized that the purpose of human cognition does not consist in amassing information about the world but, rather, in informing action control (e.g., O'Regan & Noe, 2001), even though it is not always clear how this basically evolutionary insight guides further theorizing. For instance, Milner and Goodale (1995; authors that might not consider themselves as part of the embodiment movement but that are sometimes cited in this context: e.g., Wilson, 2002) have argued for a dual-pathway model, according to which at least visual information is channeled through to a slow, central system that integrates the information with already available world knowledge, and to a fast system that feeds more or less uninterpreted information into ongoing motor control. This model is consistent with claims of those authors of the embodiment movement that have argued for a direct, not cognitively mediated impact of sensory information on action control (e.g., Körner et al., 2015). Others have taken the cognition-for-action principle to imply that representations are sensorimotor in nature and mainly created for action control, rather than for a valid internal reconstruction of the environment (O'Regan & Noe, 2001). Note that these two examples differ substantially, in that the assumption that cognition is for action is taken to imply a particular neural architecture in the first case and to imply a particular format of cognitive representations in the second. These two perspectives need not be incompatible, but they are very different in nature and regarding further theoretical and empirical implications. Even other authors have linked the cognition-for-action perspective to the assumption of internal simulation. For instance, Gallese and Goldman (1998) argue that perceiving events leads to the internal simulation of their motor implications, and that this forms the basis for the ability to imitate and to understand actions and intentions of others. Again, this perspective is entirely unrelated to the dual-route idea of Milner and Goodale (1995) and the sensorimotor-representation claim of O'Regan and Noe (2001).

Critical discussions of cognition-for-action approaches are just as incoherent as the available approaches themselves. For instance, Wilson (2002) questions these approaches because, as she argues, there is evidence that representations may contain more information than strictly necessary for a particular action, that they may contain non-physical information, and that a non-direct system exists in the Milner and Goodale approach. Not only is this criticism missing the point of other authors, like O'Regan and Noe (2001) or Gallese and Goldman (1998), but it also dismisses the possibility that even the most direct information processing can leave traces behind that can used for other purposes than the control of the ongoing action. To engage in a more fruitful discussion requires the distinction between at least three different issues that different cognition-for-action approaches have put forward.

First, if cognition is for action, one might expect a particular functional *architecture* of the cognitive system. For instance, Allport (1987) has taken the cognition-for-action principle to argue against information-processing models that have interpreted performance limitations of informational transfer to processing bottlenecks, as evident in the attribution of selective processing to attentional overload. Considering that information is processed for the purpose of action control brings other interpretations into play, such as the fact that each effector can be involved in only one action at one time. The architecture suggested by Milner and Goodale (1995) is also derived from functional considerations that try to account for the human ability of both slow off-line reasoning and fast online acting.

Second, if cognition is for action, one would expect a closer linkage between representations of, or plans for action and representations of objects and other action-relevant information than standard information-processing stage models imply. This is an argument that relates to the *format* of cognitive or cognitively relevant representations and that is also consistent with many of the already mentioned approaches suggesting that representations are multimodal, distributed, and/or composites of feature codes that include action-related information.

Third, cognition for action might provide the basis for *using* functional or neural representations used for action control for cognitive purposes. Whether the activation of motor structures is sufficient to subserve these purposes, as suggested by Gallese and Goldman (1998) and other simulation theorists, remains to be seen. For one, there is very little evidence that can be taken to provide unequivocal support for the claim that cognitive functions like understanding other people is impossible without motor simulation (see Galetzka, 2017). For another, there is no mechanistic model that would explain why mimicking motor states of other individuals translates into understanding them better. Finally, there is no mechanistic model explaining how motor states can be perceived by the individual having them. One might argue that activating motor states leads to the activation of the expected reafferent outcomes of the actions these states are able to drive, and it may be the representations of these outcomes that provide the perceiver/actor with the information necessary for understanding others. But this would imply that it is actually the representations of the expected outcomes that are doing the trick, while activated motor states may be just one of perhaps many ways to activate these representations. Whatever the eventual conclusion, using action-related representation for cognitive purposes does not necessarily imply a particular format of these representations or a particular neural architecture of information processing, which renders these three applications of the cognition-for-action principle relatively unrelated.

Towards a mechanistic theory of embodied cognition

What I tried to show is that the embodied cognition movement is indeed very incoherent and driven by many different, sometimes unrelated issues and theoretical lines of reasoning. This remains a real problem that stands in the way of a smooth development of the underlying ideas. At the same time, however, the different approaches that are part of the movement do show some family resemblance in the sense of Wittgenstein (1953/2001), and they more or less agree on the rejection of exclusively symbolic representation, a preference for compositional, distributed representations, and at least some reliance on action. Hence, even though the widespread lack of agreement with respect to details might be disappointing and discouraging, there is too much overlap and agreement to take the current incoherence as a reason to dismiss the entire movement. However, what is strongly needed is more mechanistic theorizing. It is mechanistic theory that helps operationalizing the often airy and metaphorical theoretical claims of embodied cognition approaches and translating them into concrete, causal mechanisms and well-defined representations on which these mechanisms operate. Elsewhere (Hommel, 2015, 2016) I have argued that a first step towards a mechanistic embodied-cognition account might borrow from the Theory of Event Coding (TEC: Hommel et al., 2001a), which not only addresses the main conceptual themes that are motivating embodiment approaches, but that also addresses them in a way that is compatible with many of them. Given that it is a theory that considers the concept of representations (in the above-explained trivial sense) useful, using TEC to operationalize embodied cognition will not satisfy radical anti-representationalists, but even for theorists from this camp TEC may represent a concrete and motivating challenge for improving the mechanistic aspects of their own theorizing. For others, TEC provides a basic framework and a conceptual toolbox that I believe can help to organize discussions about more specific mechanisms and representations, which eventually may lead to a truly mechanistic embodiment theory. It is important to emphasize that TEC is not a specific theory about a specific phenomenon, but rather a meta-theoretical framework that helps to organize the construction of more specific, mechanistic, and empirically testable models and, most importantly, of alternative models that can be directly pitted against each other.

TEC was developed to account for various empirical phenomena suggesting a much closer link between perception and action than previous stage models would allow for, such as stimulus-response compatibility, response-stimulus compatibility, interactions between action planning and attention, and action imitation. It was motivated by ideomotor theorizing (for a review, Shin, Proctor & Capaldi, 2010), with which it shares the idea that people continuously pick up and store contingencies between their movements and the sensory, re-afferent effects that these movements generate—similar to the approach of O'Regan and Noe (2001). The binding between the motor pattern driving the movements and the codes of the effect of the movement is called an event file (Hommel, 2004), and sensorimotor event files are considered to be the core unit of the cognitive system. More specifically, TEC makes four basic assumptions (Hommel et al., 2001a; Hommel, 2015): (1) perceptual events and planned actions are cognitively represented by event codes; (2) event codes are integrated assemblies of feature codes (event files); (3) which can be taken to represent cognitive or brain states that correlate with perceived or self-generated features; (4) so that the basic units of perception and action can be considered sensorimotor entities that are activated by sensory input—a process commonly called perception—and controlling motor output—a process commonly called action. Hence, according to TEC, "perception" and "action" are not just related, associated, or intertwined but, rather, two terms that refer to the exact same thing: while perception consists in the process of actively generating input that informs about environmental states of affairs and its relation to one's own body, action consists in the process of actively generating environmental states of affairs that the agent is intending. That is, both perception and action consist of moving to generate particular input, only that the term perception is used to emphasize the input-generating function while the term action is used to refer to the intention-realization function.

How does TEC relate to the conceptual themes favored by embodied-cognition theorists? This is not the place for an overly detailed assessment of this issue, the more so as I have already elaborated elsewhere how TEC relates to various aspects of embodied cognition (Hommel, 2015, 2016). I will also not go into mechanistic details but refer the interested reader to computational implementations of TEC (Haazebroek, Raffone & Hommel, 2017; Kachergis, Wyatte, O'Reilly, de Kleijn & Hommel, 2014) and to a number of recent extensions of TEC to cover cognitive control processes and representations of self and social events (Hommel, 2018, 2019b). I will instead restrict myself to a brief sketch explaining how and in which sense TEC can be taken to address the conceptual themes that the embodiment movement is interested in (see Table 1 for a brief summary of the respective concept, the most extreme arguments, possible solutions, and corresponding TEC mechanisms). As already mentioned, TEC claims that perception and action control are based on feature codes and event files, which are intermodal, sensorimotor representations. This will not address any radical anti-representationalist criticism, but is consistent with the large majority of the more representation-friendly embodied-cognition approaches. At the same time, TEC is not sensitive to any criticism of cognition-skeptic theorists. For one, because TEC is agnostic with respect to the possible contribution of conscious awareness. There is strong evidence that event files can be activated in a very short time, irrespective of whether the activation is or is not task-relevant (Kühn et al., 2011), which rules out arguments that “cognitive” representations are too slow to make meaningful contributions to effective action, at least with respect to the representations that TEC considers relevant. The representations of TEC are also not disembodied, because the representation of each object or event is assumed to contain information about the action that was carried out to sense or generate the object or event, or to interact with it. Hence, object or event representations are shaped by, and reflect the action it relates to and the agent carrying it out.

TABLE 1

TEC assumes that event files represent distal information (Hommel, 2009, Hommel et al., 2001a), which means that the codes these files contain reflect characteristics of the event they represent but not the characteristics of the modality that provides information about the event. As Prinz (1992) has pointed out, it is this distal reference that provides the common code for relating perception and action, that allows perception and action to talk to each other. This implies that feature codes are amodal, which seems to be inconsistent with claims of embodiment and grounding theorists, like Barsalou (1999). However, as explained above, I believe that this inconsistency is only apparent. For one, because the main goal of modal theorists, the construction of sub-symbolic representations that keep some of the flavor of the sensory or sensorimotor activity used to acquire the represented information, is still achieved. And, for another, because modal and amodal information about sensory and action features may simply represent different kinds or integrative levels of a more complex representational scheme (Haazebroek, Raffone, & Hommel, 2017).

Given the sensorimotor nature of TECs core units of the cognitive system, being exposed to an object or event is not unlikely to activate motor patterns. Whether that actually happens depends on the context, and in particular on what TEC calls intentional weighting (Memelink & Hommel, 2013). According to TEC, features are organized into feature maps and the contribution of activations from a particular feature map are weighted according to the (actual or assumed) task-relevance or contextual salience of the respective feature dimension. The weighting of feature contributions implies that not all ingredients of a given event file contribute equally to action control, and that the contribution of each feature and feature dimension can vary over time in context. This also implies that the degree to which facing an object or event spreads activation to motor information contained in the event file can vary. This means that TEC shares the assumption of the more action-related simulation theories that perceiving an event can lead to corresponding motor activity (e.g., objects may activate a grasping movement it “affords”; see Tucker & Ellis, 1998), but it does not share the assumption of some theorists that priming motor activity is obligatory or necessary to penetrate the meaning of the event (cf., Galetzka, 2017). Moreover, TEC provides the theoretical guidance needed to systematically vary the amount and degree of motor activation through appropriate instruction and task settings. Finally, TEC logic suggests that “event-file activation” might be a more appropriate and less homunculoid theoretical term than “simulation”.

TEC allows for codes of features derived from interoception to be integrated into event files but does not consider these codes particularly dominant or relevant for action control. TEC does emphasize the role of action in human cognition, and actually considers action to be the key tool to generate knowledge about environmental conditions, about oneself (Verschoor & Hommel, 2017), and about the goals one might consider achieving in the future (Verschoor, Weidema, Biro & Hommel, 2010). With respect to architecture, TEC is consistent with Milner and Goodale’s (1995) distinction between a fast and direct sensorimotor route and a more cognitive route, but it would suggest a change in conceptualization and terminology. In particular, TEC suggests that setting up and planning goal-directed action calls upon what Milner and Goodale have termed the perception route, which thus seems to be a misnomer from a TEC perspective. Rather, TEC can be seen as an implementation of Milner and Goodale’s cognitive route, which creates and establishes action plans that are then driven by Milner and Goodale’s direct route (Hommel et al., 2001b).

Taken altogether, TEC seems to provide a sufficiently rich conceptual toolbox to speak about the main conceptual themes discussed by the embodiment movement. This toolbox makes it possible to construct otherwise comparable alternative models that can be tested against each other, which is likely to advance our insight into how cognition is embodied and how embodied cognition actually works. Hence, TEC is likely to better organize the work to be done, but it does not take away the efforts needed to meet the challenges ahead, to which I will now turn.

Challenges ahead

A relatively fundamental challenge with strong theoretical implications has to do with the relationship between radical anti-representationalists and the majority of embodiment theorists that are less afraid of the concept of representations. Theorists relying on representations need to become more specific with respect to how they understand this concept. I have suggested that using the concept to refer to the obvious fact that information needs to be transmitted from the environment, through the receptors, to motor systems, and back is unlikely to cause any theoretical harm and is unlikely to provide the basis for an interesting theoretical discussion. Once anti-representationalists begin going beyond very high-level, descriptive models that try to capture the dynamics of some aspect of human action and dig deeper into causal mechanisms that generate this behavior, they will need to develop some concept that explains how the environmental information gets from A to B, and it is not hard to predict that this concept will look very similar to the trivial use of the representation concept. However, some representationalist theorists seem indeed to entertain richer interpretations of the representation concept that seems to include some degree of understanding or other “mental work”. It seems to be this use of the concept that represents the real target of anti-representationalists. Encountering this part of the criticism requires the respective representationalist theorists to provide mechanistic models that operationalize this richer representational concept. Truly mechanistic models require a detailed specification of the structure and origin of representations, and of the processes operating on them (Hommel, in press), and this degree of specificity is commonly missing especially in the cognitively richer and/or more metaphorical embodiment approaches.

A related challenge consists in the development of mechanistic explanations of where representations are coming from. One of the major criticisms of the assumption that human cognition relies on symbol manipulation was that this assumption raises the grounding problem, that is, the question of where the symbols are coming from. Embodiment theorists agree that allowing for compositional representations helps reducing this problem, but really eliminating it requires a better understanding of the acquisition process. This will call for more developmental and experimental proof-of-principle studies demonstrating the acquisition of representations of new, unfamiliar events. The neuroscientific monitoring of the acquisition process would also provide interesting converging evidence.

Another challenge relates to the role of modal information. As explained above, if all compositional information would be modal, we would need to explain how the intermodal integration of feature codes works and how perception can effectively communicate with action control. This suggests the existence and important role of compositional, feature-based information that is amodal in nature. Do modal and amodal codes coexist? How do they relate to each other, how are they acquired? More systematic experimental strategies need to be developed to investigate this issue and, again, neuroscientific methods may provide interesting converging evidence.

Yet another challenge relates to the role of action. One possibility is that action represents the essential ingredient of the representation-acquisition process, as for instance suggested by ideomotor theories and TEC: by actively exploring his or her environment, the perceiver/actor integrates motor codes of the movements with their sensory consequences. Once this integration is completed, the integrated representation can be used both online, as in mimicry or imitation, and off-line, as for instance in action planning. However, this perspective would not necessarily require the action-related ingredients of the representation to be active all the time, irrespective of the current task and purpose. Simulation accounts would in contrast maintain that activating these ingredients is obligatory and difficult or impossible to prevent, and perhaps even necessary to really understand the perceived event. In other words, there is a range of possibilities regarding the role action-related codes can play off-line and online, and more systematic empirical strategies are necessary to identify the most plausible ones. This requires going beyond proof-of-principle demonstrations and calls for more systematic, theory-guided experiments digging into concrete mechanisms and their contextual and individual variability.

A related question is whether there is a strong need for the concept of simulation. It does carry quite some homunculoid baggage by implying someone who carries out the simulation and someone for which it is carried out. Alternatively, it is possible that the available evidence is sufficiently well explained by assuming that, due to the compositional nature of representations, being exposed to a perceptual event may, depending on task and circumstances, activate action-related ingredients of the representation. If this is all there is, there need not be any particular purpose of this activation, it simply reflects the compositional nature of the representation. Calling it activation or priming, rather than simulation, seems more appropriate in this case, which would help to avoid theoretical overhead and anti-cognitivist suspicions. It also seems important for simulation theorists to develop a more mechanistic idea about what is meant by “meaning” and “understanding”, and whether these concepts go anywhere beyond mere activation of representations.

To conclude, to reach the next level of understanding where, whether, and how human cognition is embodied, more systematic and more mechanistic theorizing is necessary, and more theory-guided experimenting with the aim to become more specific with respect to the representations underlying embodied cognition and the processes operating on them. TEC may provide a useful framework to organize these endeavors, but substantial theoretical and empirical efforts will still be required.

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Table 1

Concept	Purist claim	Rich claim	Possible solution	TEC mechanism
Representations	do not exist	explain cognition	functional interpretation: mere correlates of environmental information	event files: bindings of feature-specific (amodal) codes
Cognition	too slow to intervene, bypassed	intervenes between and controls perception and action	treat cognition as explanandum, not explanans; focus on processes underlying it	generated/expressed through sensorimotor interaction
Format	modal, distributed	symbolic	consider feature-based, hierarchical coding with modal codes as basis	feature-specific (amodal) codes
Simulation	all action relies on	artifact or byproduct	treat as (not strictly necessary) option, identify contingencies	activation of to-be-expected sensory action effects
Bodily states	mediate access to body, action	coded in abstract form	treat as one code among many	coded as any other modal information
Action	purpose of perception, cognition	causally irrelevant consequence of cognition	consider perception and action as two sides of same coin	emphasizes the generative (rather than receptive) aspect of sensorimotor activity