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Abstract

Cognitivism, the traditional approach to understanding cognition, has argued for the essential role of symbolic computations over internal mental representations. But this view has been criticized on a number of grounds, one in particular being the assumption of amodality: that the symbols involved in processing are arbitrarily related to their referents. An opposing view—the framework of Perceptual Symbol Systems—holds that the elements of thought should be treated not as amodal symbols, but rather as modality specific, analog representations that simulate particular aspects of perceptual experience. Though this approach has been gaining in popularity from intuitively appealing theoretical accounts, and suggestive empirical support, it has suffered from a lack of specificity for key constructs. To address this problem, this paper presents a more detailed study of the foundational concept of *perceptual symbol*. The proposal builds from recent work on the skill-based nature of visual perception (the Sensorimotor Contingency Theory), and research that provides tools for representing the inseparable link between perception and action (the Theory of Event Coding). From these two sources, the characterization of a perceptual symbol as a selective re-enactment of perceptual experience, treated as a unit, will be elaborated and defended.

Introduction

Cognitive science, for much of its short history, has been dominated by a view of cognition that emphasizes the necessary role of computation, and which holds that cognitive processing is rule-governed manipulation of internal mental representations (Fodor, 1975, 1983; Fodor & Pylyshyn, 1988; Johnson-Laird, 1989; Minsky, 1975; Newell & Simon, 1972; Pinker, 1998; Pylyshyn, 1984). The symbols that comprise these representations are what codify knowledge, and indeed *are* knowledge. Under this interpretation, symbols possess several key properties, the most important of which, for the purposes of this paper, is amodality: that a symbol is arbitrarily related to the thing it represents (Barsalou, 1999; Markman & Dietrich, 2000). In addition, specific psychological theories that adopt this framework "generally assume that knowledge resides in a modular semantic system separate from episodic memory and modality-specific systems for perception, action, and emotion" (Barsalou, et al., 2003). This view of cognition has undoubtedly met with much success (for accessible overviews, see Johnson-Laird (1989) and Pinker (1998)).

There are critics, however, who have challenged this framework (Barsalou, 1999; Carlson, 1997; Clancey, 1997; Clark, 1997; Damasio, 1994; Dourish, 2001; Dreyfus, 1972; Gibson, 1979; Glenberg, 1997; Harnad, 1990; Hutchins, 1995; Lave & Wenger, 1991; Rumelhart & McClelland, 1986; Searle, 1980; Smith & Thelen, 2003; Suchman, 1987; Thelen, 1994; Thelen, Schoner, Scheier, & Smith, 2001; Thomas, 1999; Van Gelder, 1998; Varela, Thompson, & Rosch, 1992). In particular, one approach questions the requirement that the symbols used in cognitive processing should be amodal. Instead, in a Perceptual Symbol System (PSS), the symbols are modality-specific representations that do bear a principled resemblance to the things represented (Barsalou, 1999; Barsalou, et al., 2003). Specifically, these symbols are perceptual in the sense that they re-enact selective aspects of experience. But this view, though promising, remains underspecified in important ways. This paper is an attempt to clarify a fundamental construct of the PSS approach, the *perceptual symbol.*

The specific goals of this paper are: (1) to present an account of conceptual representation that is at odds with the traditional view in one important respect—that the symbols used in thought are amodal; (2) to review theoretical arguments and empirical evidence that suggest that PSS should be taken seriously as a plausible alternative to Cognitivism; (3) to show that there are certain respects, however, in which the PSS framework is underspecified, specifically with respect to the foundational concept of a *perceptual symbol;* (4) based on the assumption that to clarify the concept of *perceptual symbol* requires some understanding of what perceptual experience is, to present one type of skill theory of perception that provides a comprehensive account of how perception *and* action interact to support perceptual experience; (5) to connect this account to perceptual symbols by adopting representational structures called *event codes* that possess key properties required by a PSS; (6) to review consistent empirical evidence that the properties of event codes that hold at the fine level of basic sensorimotor interaction might also hold during higher level cognitive processing; and (7) to suggest limitations and remaining questions for future study.

Why a Perceptual Symbol System?

The framework of Perceptual Symbol Systems (PSS) is a perceptually-based approach to conceptual representation that has gained in popularity for many theoretical and empirical reasons. On the theoretical side, the view is more sophisticated than its empiricist predecessors. First, it appears that the rejection of perceptually oriented approaches was too hasty (Barsalou, 1999). For example, the criticism that perceptual symbols are just holistic records of perceptual experience (like internal pictures that lack any interpretation) is based on the assumption that perceptual symbols could not also be treated as discrete, componential units; and in this regard, be used productively in forming multimodal symbolic structures. But under this new construal, perceptually-based conceptual systems can acquire the power to represent a variety of concepts ranging in abstractness, and thereby possessing the desired flexibility shown by humans (Barsalou, et al., 2003).

Second, because of the analog relationship with their referents, perceptual symbols provide a great deal of implicit information about the things they represent (Zwaan, 1999). This information can then be made explicit through perceptual processes like scanning and selective attention (Goldstone & Barsalou, 1998). An amodal system requires that knowledge be expressed in terms of syntactically well-formed sentences, usually expressed in a first-order predicate calculus, or LISP-type language. This requirement places a heavy burden on a system if it must represent *all* knowledge explicitly (even the most mundane kind—for example, that cars have four wheels).

Third, the foundations of amodal symbol systems are not without problems, specifically in terms of how the symbols are acquired—the transduction problem (Barsalou, 1999)—and how the symbols relate back to the world—the symbol grounding problem (Harnad, 1990). If perception and cognition are realized by fundamentally different cognitive processes, then how does one representational language get *transduced*—that is, translated—into the other? Conversely, how does the output of cognitive processing connect with the world to enable purposeful interaction? In other words, how do the symbols become *grounded*?

Fourth, though presumed to be flexible by virtue of the (amodal) form of the symbols (such as using the symbol CAT to stand for all cats), amodal symbol systems lack the flexibility of human cognition. To get around this problem, amodal representations have been supplemented with specific episode information (Markman & Dietrich, 2000).

Fifth, amodal conceptual systems are well known to be able to account for numerous findings after the fact (Anderson, 1978; Solomon, 2001), but of far greater importance is the power of a theory to make *a priori* predictions. The amodal view cannot easily predict perceptually-motivated effects, whereas a perceptually-based view can do so with ease (Barsalou, et al., 2003).

In addition to the theoretical support, a growing body of empirical research suggests a strong influence of perceptually-based knowledge on conceptual processing. For example, in a property-listing task, people will generate response that depend on the nature of the perceptual variables involved in the simulation (e.g., listing "roots" for "rolled-up lawn", rather than for "lawn", because roots are less occluded in a rolled-up lawn)(Barsalou, Solomon, & Wu, 1999). From studies in text comprehension, in an effort to comprehend a text passage, people appear to construct online simulations of the situations described in the text. In other words, comprehension of language becomes "preparation for situated action" (Richardson & Spivey, 2000). The situation models (Zwaan, 1999) that underlie this comprehension process are fundamentally experiential, and not surprisingly, derive much motivation from the PSS framework. In research motivated by these ideas, people have been found to recognize a picture of an object (for example, a nail) more quickly if the object is in the same orientation, vertical or horizontal, implied by a text passage read earlier ("The nail was hammered into the floor/wall")(Stanfield & Zwaan, 2001). In related work, sentences such as "Open the drawer" are judged as sensible more quickly if at the same time people move in a manner consist with the implied motion (in this case, pulling rather than pushing)(Glenberg & Robertson, 2000). People also appear to re-enact the eye movements that accompanied earlier perceptual processing (Laeng & Teodorescu, 2002; Mast & Kosslyn, 2002; Richardson & Spivey, 2000). These results are just a few of the many that have provided support for the PSS framework (for a more detailed review, see Barsalou, et al., 2003)

The Structure of a Perceptual Symbol System

A PSS is a conceptual system composed of an integrated set of simulators (which in practice can be interpreted as the concepts). The simulators are composed of frames, which integrate perceptual symbols, and provide structure for event sequencing. Moreover, each simulator implies a simulation competence—the potential for producing an indefinite number, and limitless variety of perceptual simulations. Finally, processes of selective attention and memory integration provide the requisite representational power for the system to act as a fully functional conceptual system in the classical sense (Barsalou, et al., 2003; Fodor & Pylyshyn, 1988).

For a PSS to function as a conceptual system, it should possess certain properties. (1) The conceptual system should be able to *interpret* novel experience. This is what fundamentally distinguishes a conceptual system from a simple recording system (Barsalou, 1999). A conceptual system is selective and is able to bind tokens (perceived individuals) to knowledge of types stored in long-term memory. A record (e.g. a picture), on the other hand, is an undifferentiated—uninterpreted—mass. (2) A conceptual system should allow the thinker to go beyond the information given, to use stored knowledge to make inferences. (3) Conceptual systems should have the potential for generating an indefinite number of thoughts; that is, they should be productive.

For a conceptual system to do this, it must be composed of things that have special properties. What exactly these properties are is contested, but Markman and Dietrich (2000) have provided an illuminating analysis of the issue, and their general approach will be adopted here. Specifically, they have argued that *internal mediating states* can possess certain characteristics: (1) they may be enduring; (2) discrete; (3) abstract (amodal); (4) rule-governed; or (5) they may possess a compositional structure (for more detail on these properties, see Markman & Dietrich, 2000). Internal mediating states in the cognitivist tradition hold all five. Those in the dynamical systems approach hold fewer. Relaxing one or more of these constraints can affect the representational capacity of a conceptual system.

There are two important ingredients that support the interpretive capabilities of a simulator, and as a result, the representational power of a PSS: the frames, which integrate and organize perceptual symbols; and the "potentially infinite set of simulations that can be constructed from the frame" (Barsalou, 1999). Thus, to understand what CAR means is to know, not only the perceptual symbols that comprise the representation for cars, but it is to know also how to interact with cars—to be able to organize the complex action sequences involved in effective interaction with cars. This means that the frames would be composed of perceptual symbols from several different modalities, and that a simulation could thus be considered a multimodal, selective re-enactment of perceptual experience

The importance of simulators and simulations for supporting the conceptual functions of the PSS cannot be overstated. However, given the role of perceptual symbols in supporting simulations, much work remains to be done in specifying their properties (such as how the symbols are encoded, stored, and used). There are difficulties, however, in getting a clear sense of what a perceptual symbol is, and how it fits in with the functional architecture of a PSS.

Most definitions of a perceptual symbol tend to emphasize the neural substrate, and specifically, that perceptual symbols are "records of the neural states that underlie perception" (Barsalou, 1999). But a limitation of this approach is that it captures just one aspect of the information contained within perceptual symbols. Though much current research tries to incorporate properties of classical cognitive architectures into neural networks, what is needed is a more explicit account of the functional structure to complement the neural description. What is needed, then, is a better sense of what information goes into a perceptual symbol and how that information is stored so that it can support the conceptual functions of a Perceptual Symbol System. In other words, we need a theory of perception, and a theory of how the products of perception are represented.

Perception as a skill

The perspective in this paper holds that perception is a skill: that it is the ability to engage in purposeful and effective interaction with the world (Ballard, 1983; Clark, 2002). The approach outlined is just one of many types of "skill" theories of perception, but it is one of the most elegant and best developed. Specifically, this Sensorimotor Contingency Theory holds that to perceive is to engage in skilled exploration of an environment, with the exploration mediated by the implicit knowledge of the lawful dependencies that hold between actions and sensory consequences (O'Regan & Noë, 2001). Thus, these lawful dependencies are assumed to play an essential role in providing content for perceptual symbols.

The SCT

The main goal of the Sensorimotor Contingency Theory (SCT) is to provide an answer to the so-called "hard problem" of visual consciousness: to explain how physical or informational processes could give rise to the qualitative character of experience (Chalmers, 1996). The solution to the problem is framed in terms of an interpretation of visual perception as a "mode of exploratory activity that is mediated by knowledge of sensorimotor contingencies" (O'Regan & Noë, 2001). This idea is in opposition to views, such as Muller's Doctrine of Specific Nerve Energies, in which what makes one sensory modality different from another is due to the nerve pathways that gather information. Rather, what makes modalities differ is that each is supported by different sets of sensorimotor laws: the dependencies between motor outputs, and the sensory consequences of those actions. In other words, the laws are the implicit, *procedural* knowledge of the expectancies derived from an agent's interaction with an environment. For more details, and supporting evidence, see O'Regan & Noë (2001),

According to this view, sensorimotor contingencies are a key ingredient in most, if not all aspects of cognition. As the authors describe it, "To see is to explore one's environment in a way that is mediated by one's mastery of sensorimotor contingencies *and* to be making use of this mastery in one's planning, reasoning, and speech behavior" (O'Regan & Noë, 2001). How to scale up to these behaviors remains to be seen, however. It is this role that the PSS should fill—to account for the emergence of abstract thought from this fundamental perception-action interface.

But there are a number of problems to be overcome in attempting to extend these principles to the PSS framework. The main limitation is that no indication is given for how sensorimotor contingencies should be represented, or even whether they should be represented at all. For reasons given in Markman and Dietrich (2000), it is too early to abandon representation as an explanatory construct in theories of cognition. So, to be able to characterize a perceptual symbol as a selective reenactment of perceptual experience, to be treated as a unit, not only must there be some sense of what perception consists in, there must also be a way to represent the information that supports both perception and cognition. In addition, the representation should possess the right properties to support the functional requirements of a conceptual system. The Theory of Event Coding (TEC), and specifically, the *event code,* is proposed to fill this role.

The TEC

The Theory of Event Coding (TEC) addresses the relationship between perception and action planning. In opposition to traditional approaches, the TEC does not assume independence between the two processes, but instead emphasizes that both functions are supported by a common representational medium. At the heart of the TEC is the notion of an *event code*, which "consists of the codes that represent the distal features of an event" (Hommel, et al., 2001). These codes, then, are what underlie perception-action dependencies, but also, more generally, cognitive processes. In their words, "The theory holds that cognitive representations of events (i.e., of any to-be-perceived or to-be-generated incident in the distal environment) subserve not only representational functions (e.g., for perception, imagery, memory, reasoning) but action related functions as well (e.g., for action planning and initiation)" (Hommel, et al., 2001). The principle of common coding is a core assumption of the theory. The other—the principle of effect cause of actions—places special emphasis on the roles of specific types of feature codes within the event code; that is, the feature codes for actions are initiated by the resultant changes in sensory input caused by the actions.

As representational constructs, the event codes are discrete, compositional, and the individual elements retain an identity, even when they participate in more complex structures (Hommel, personal communication, Feb. 2004). In all, these considerations implicate an important functional role that event codes may play as representational constructs within the PSS.

Scaling up

Because the TEC has focused on fine sensorimotor interactions, such as "arrows or circles that come and go on a screen, or hand and fingers that go up and down on a key pad" (Hommel, et al., 2001), how are these event codes integrated to produce more complex event structures? Why start with the TEC rather than, say, with CHREST (Lane, Cheng, & Gobet, 2000) or PLAN (Chown, Kaplan, & Kortenkamp, 1995)? There are several reasons. First, the TEC is compatible with CHREST (as a model of active perception) and PLAN (a model of navigation that uses cognitive maps), and indeed they may all share a common logic (Hommel, et al., 2001). Second, the TEC was adopted primarily for practical reasons: It seemed to bear most closely on the issues addressed in the SCT, and would prove the shortest leap to make from non-representational to a representational description of sensorimotor dependencies. Third, it appeared that the best bet was to start small, at the principled "bottom", and then to work up. But associated with this is a riskier bet: that because of the recursive nature of the event codes, the integrative mechanisms operating at the lower-levels worked also at the higher levels. Fourth, the connection from the TEC to PSS had already been suggested by other researchers, specifically Richardson and Spivey (2001). Finally, some recent evidence in word learning suggests that the principles operating in the TEC might also hold at higher levels. Specifically, Terry Regier and his colleagues have suggested that more attention is paid to the *endpoint* than to the beginning of a spatial event (Regier & Zheng, 2003). Furthermore, as evidence of this, Regier and Zheng found that finer semantic distinctions are present in spatial terms at the endpoints of spatial events than at their beginnings. Specifically, in a task that required participants to judge whether two events, presented very briefly, were the same or different, fewer errors were committed in a "joining" task (e.g., where a lid would be put either on or in a container) that required attention be devoted to the endpoint, than in a "separation" task, in which a lid would be taken either off or out of a container, and attention would be required at the starting point. These results are consistent with the potentially important role of *goals,* and the principle of effect cause of actions, in encoding event sequences at a more general level.

Discussion

Much talk is made in this paper about perceptual symbols being "selective", suggesting that not all information from perception is used during cognitive processing. But what exactly does this mean? That the components of cognitive processing are less vivid, in the sense that *all* information carried over is less definite, less certain? Or does it mean that only specific kinds of information are carried over, such as spatial information, but that the information is no less definite, no less certain than when it was originally processed?

What are the laws of sensorimotor contingency that describe particular core aspects of experience, such as our experience of space, or time? Already much fascinating work has addressed the problem of doing this for space (Philipona, O'Regan, & Nadal, 2003), but then how might that knowledge map onto cognitive psychological research on space? And perhaps of even greater interest, how does our more abstract notion of time map onto that (Boroditsky & Ramscar, 2002; Gentner, Imai, & Boroditsky, 2002)?

What implications does this view have for the problem of reference—determining how cognitive structures connect with the external world (Evans, 1982)? On the one hand, it seems that there might be no such problem, since in both cases, the thing representing, and the thing represented are one and the same. Truly, the "external world" is itself an assortment of mental entities. In other words:

> Despite the importance of realism in many philosophical theories of concepts and meaning, this assumption seems superfluous and unempirical, and it introduces a number of additional problems to be dealt with that could be avoided without it. Rather than making a realist assumption, it would be easier to adopt a *coherence-based* framework. That is, the only information that any person has about the outside world comes from perceptual representations, which are themselves mental entities. Thus, rather than being concerned with whether a particular concept correctly refers to all and only proper extramental entities, it would be better to generate a theory in which the use of the concept attempts to remain consistent with other representations in the system. (Markman & Stillwell, in press)

But to someone still wary of the potential problems this (apparently) neo-idealistic position might suggest, the claim isn't so risky: we need not take on the assorted difficulties a Berkelyian idealism might, since we wouldn't be making claims about ontological status of the world (and whether it still would exist even if one were not immediately perceiving it), but only claims about what is psychologically efficacious—that is, about the cognitive structures that matter to the thinker. But is this true? If it is the case that only a *subset* of information is carried over from perceptual processing to cognitive processing, though derived from the same source, might there still be a problem of reference?

Also related: what information is carried over from perceptual to conceptual processing? Isn't this "selection/extraction" problem eerily similar to the transduction problem faced by amodal theories of cognition? What are the principles that determine which sets of sensorimotor contingencies will be exercised during, say, activation of the perceptual symbol for DOG, and deducing from a perceptual simulation that a dog, if it wags its tail, is happy?

What implications does this view have for understanding "meaning"? Might it be the case that "meaning" is a quale, much like the "redness" of red, or the "hotness" of hot? That is, could the meaning of, say, "apple" be the qualitative feeling of what-it-is-like to interact effectively with apples, based on the implicit, procedural knowledge of the sensorimotor contingencies that define the actual and allowable interactions with apples? Given that O'Regan and Noë (2001) claim that the knowledge of sensorimotor laws, and the current exercise of that knowledge, determine the qualia of experience, is it too much of a leap to claim that the meaning of objects arises from the whole stretch of competent engagement with them? Admittedly, the problem of meaning and reference is a difficult one—beyond the scope of this paper—but the hope is that this discussion will serve as an "intuition pump" for more detailed analyses.

Conclusion

The main goal of this paper has been to elaborate a link between three deeply related, and mutually enriching areas of study. However, much of the difficulty still remains in determining how exactly the (putative) underlying processes (such as how event features are integrated into event codes) give rise to the functional properties of a PSS. But clearly, the possibility that sensorimotor contingencies, event codes, and perceptual symbols comprise the fundamental components of thought further suggests a deeper result: that now we might be more assured that suggestive correlations between perception and cognition (Goldstone & Barsalou, 1998) could now be given a principled causal basis for their interaction. We might now be in a better position to understand just in what respects perceptual processes might hold at the conceptual level; and accordingly, how we as researchers, and possessors of minds, might broaden and enrich our investigations.

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