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Symbolic or Embodied representations: A Case for Symbol Interdependency

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Abstract

Current directions in cognitive science suggest that language processing is either embodied or symbolic. Instead of posing the question whether language comprehension is embodied or symbolic, the question should be to what extent language comprehension is embodied and symbolic. The current study relies on the theoretical model that considers symbols as interdependent abstract systems of meaning occasionally grounded in the comprehenders' embodied experience of the world. Such a symbolic interdependency system would explain how symbolic representations are built onto embodied representations, would provide a convenient mnemonic support for language users and would explain why humans have and other species don't have language. Statistical algorithms like Latent Semantic Analysis can be considered models of mechanisms behind symbol interdependency, able to reveal some of the embodied relations captured in language.

Introduction

Over the last decade the debate regarding embodied versus symbolic representations in language comprehension has dominated areas within the cognitive sciences (Barsalou, 1999; Glenberg, 1997; Kintsch, 1998; Lakoff & Johnson, 1999; Landauer & Dumais, 1997). Center of the debate is the question whether language comprehension is primarily symbolic or whether it is fundamentally linked to embodied (perceptual and motor) mechanisms. Over the years advocates of either side of the spectrum have polemically presented their views (Barsalou, 1999; Fodor, 1980; Glenberg & Robertson, 2000; Harnad, 1990; Lakoff & Johnson, 1999; Pylyshyn, 1984; Searle, 1980). These discussions often give the impression that language comprehension involves *either* symbol processing *or* embodied simulation. The current study replaces this with the question to what extent language comprehension is symbolic *and* embodied. It is hard to imagine that logical reasoning or mathematics could exist without any form of symbolic processing. At the same time, it is hard to imagine how visual rotation and spatial orientation tasks can operate without any form of perceptual processing. It is therefore very likely that symbolic and embodied processes go together in language comprehension. This study will therefore not adopt an eliminative view[1] (Goldstone & Barsalou, 1998) that rules out a symbolic (or for that matter embodied) representation, but instead will adopt an integrative view that assumes some relationship exists between language and perception. The nature of the relationship between embodied and symbolic representations thereby is the central question. This study will argue for symbol interdependency, a dependency of symbols on other symbols and dependency of symbols on embodied experiences. The mechanism behind symbol interdependency can be represented by statistical models like Latent Semantic Analysis.

Predominantly Embodied Theories

According to embodied approaches of meaning, symbols (e.g. words) always have to be grounded to a referent in the physical world. A theory emphasizing the link between symbol and reality is obviously not new. De Saussure for instance (1916) already argued that a linguistic sign (what we will call 'symbol') is composed of a signifier (the acoustic image) and a signified (the mental representation of an external reality). That is, the basis of linguistic and non-linguistic comprehension lies in the sensorimotor experiences of actions. With every word we read or hear we are grounding that word in our perceptual experiences. For instance, we understand the word "eagle" differently when

[1] It is important to note here again that most symbolic and embodied approaches are not eliminative. For instance, symbolic approaches do not rule out perceptual experience (Kintsch, 1998; Landauer, 1999) and embodied approaches do not exclude symbolic representations (Barsalou, 1999; Zwaan, 2004).

reading the sentences "The ranger saw the eagle in the sky" than when we read "The ranger saw the eagle in the nest" (Zwaan, Stanfield, & Yaxley, 2002) because we generate different embodied representations of the two sentences.

Recently, a large body of empirical evidence has accumulated, suggesting that perceptual variables affect conceptual processing. For instance, comprehenders' motor movements match those described in the linguistic input. Klatzky, Pellegrino, McCloskey, and Doherty (1989) showed that the comprehension of verbally described actions (e.g. the phrase "picking up a grape") was facilitated by preceding primes that specified the motor movement (e.g. grasp). Glenberg and Kaschak (2002) found similar evidence measuring how much the sensibility of a sentence is modified by physical actions. When subjects read sentences like "Mark gave you a pen" and used a congruent action (press a button close to the body of the subject) reaction times were lower than when an incongruent action (press button away from the body of the subject) was applied. Kaschak et al. (2004) presented subjects with sentences describing motion in a particular direction (e.g. "The storm clouds rolled in") and simultaneously presented dynamic black and white stimuli matching or mismatching the direction described in the sentence (up, down, towards, away). Again, response times were faster for the matching cases, than the mismatching ones.

Zwaan, Stanfield, and Yaxley (2002) measured response times for pictures matching the content of sentences and pictures that did not. For instance, they used sentences about a nail being pounded either into the wall or into the floor. Response times for pictures matching the sentence (e.g. vertically oriented nail for sentence in which nail pounding into the floor) were faster than mismatching pictures, leading to the conclusion that subjects simulated the scenes described in the sentence. Similarly, Zwaan and Yaxley (2003) showed that spatial iconicity affects semantic judgments (the word “attic” presented above the word “basement” resulted in faster judgments than the reverse iconic relationship), suggesting that visual representations are activated during language comprehension (see also Boroditsky, 2000; Fincher-Kiefer, 2001; Matlock, Ramscar, & Boroditsky, 2005).

Three theories of embodiment are currently most prominent in the field of discourse psychology (Pecher & Zwaan, 2005): Glenberg’s (1997) *Indexical Hypothesis*, Zwaan’s (2004) *Immersed Experiencer Framework*, and Barsalou’s (1999) *Perceptual Symbols Theory*. According to all three theories, knowledge is not transduced into (amodal) symbolic representations, but instead into modality-specific states (e.g. visual states). For instance, the Indexical Hypothesis states that comprehenders index words and phrases to actual objects or analogical perceptual symbols, generate affordances of these objects or perceptual symbols, and then mesh these affordances using syntax. We understand the sentence “John used his shoe to hit the mosquito” by considering all possible things one can do with a shoe, such as walking and hitting. Of all these affordances that are generated we then select the relevant one based on the syntagmatic information (one does not walk mosquitoes, but one can hit them).

Despite the overwhelming evidence for embodiment in comprehension, there are a number of questions that remain unanswered. If words are directly related to perceptual representations (e.g. images) representing those words, which in turn activate affordance of these perceptual representations, language does not seem to be an efficient communicative tool. First, it would require considerable learning and memory resources to activate perceptual information in even the simplest language task. An utterance of a few sentences would result in a combinatorial explosion of representations in various modalities. Such an explosion of options is not an impossible way to communicate, but certainly not an efficient one. Secondly, a direct relationship between symbol and perceptual representation makes it difficult to communicate about imaginative things and abstract objects. For instance, it is difficult to think of the embodied representations that are activated in reading this paper. Thirdly, with a direct link between word and embodied representation, it is not straightforward to explain language acquisition. Does a child need to learn the link between each word and its representation? If so, it is difficult to explain why children rarely attend to the word the adult talks about (Bloom, 2000). Finally, why do humans have language and other species do not? After all, other species are embodied and have the vocal tracts to communicate, but do they not have the sophisticated communicative system that humans have? These issues do not warrant the conclusion that language processing is not embodied, but at least suggest that embodiment is unlikely to be the whole story.

Predominantly Symbolic Theories

Predominantly symbolic theories assume conceptual representations are typically non-perceptual. That is, mental representations are autonomous symbolic representations. It is not surprising that the autonomy of symbolic representations became particularly popular around the cognitive revolution in the 1950s with the various information processing theories based on computational models, including predicate calculus, script and schema theories, and connectionism. A typical example of symbolic representations is propositional representations (i.e. the mental sentences that form idea units). As a shorthand notation these propositions generally consist of predicates and arguments (Kintsch, 1974; 1998). A proposition like HIT(JOHN, MOSQUITO) represents a hitting event where the agent *John* hits the object/patient *mosquito*. There is some experimental evidence for the psychological reality of these mental sentences (Bransford & Franks, 1971; Kintsch & Keenan, 1973; Wanner, 1975). Various other psychological symbolic models have been proposed to describe how human memory is organized both semantically and schematically (Quillian, 1966; Collins and Quillian, 1969; Smith, Shoben, and Rips, 1974; Minsky, 1975; Rumelhart &

Ortony, 1977; Schank & Abelson, 1977). These proposals for knowledge representation formed the origin of complex computational implementations, including FRL (Frame Representation Language) and KRL (Knowledge Representation Language) (Bobrow & Winograd, 1977; Fikes & Kehler, 1985) and CYC (Lenat & Guha, 1989). According to all these symbolic approaches, mental representations must be amodal because we cannot have an internal homunculus that can look at modality-specific mental images in our mind, (Pylyshyn, 1973). Furthermore, if symbol systems can approximate human language comprehension performance well, they must at least have some validity in modeling human language processing (Landauer & Dumais, 1997).

Three symbolic computational models of language processing are currently most prominent in the field of discourse psychology: Lund and Burgess's (1996) Hyperspace Analog to Language (HAL), Griffiths and Steyvers' (2004) Topics Model, and Landauer and Dumais's (1997) Latent Semantic Analysis (LSA). All three are statistical corpus based techniques for representing world knowledge by estimating semantic similarities between the latent semantic structure of terms and texts. Within the scope of this book we refrain from a redundant description of LSA.

LSA is undoubtedly the model that has received most attention and is most widely used in computational psycholinguistic research. It automatically grades essays (Landauer, Foltz, & Laham, 1998). It performs equally well as students on the Test of English as a foreign language (TOEFL) tests (Landauer & Dumais, 1997), measures the coherence of texts (Foltz, Kintsch & Landauer, 1998; McNamara, Cai & Louwerse, this volume), classifies authors and literary periods (Louwerse, 2004). Recently, LSA has also been used in Coh-Metrix (Graesser, McNamara, Louwerse, & Cai, 2004; Louwerse, McCarthy, McNamara, & Graesser, 2004), a web-based tool that analyzes texts on over 50 types of cohesion relations and over 200 measures of language, text, and readability. LSA has also been used in intelligent tutoring systems like AutoTutor and iSTART (Graesser et al., 2000; McNamara, Levinstein, & Boonthu, 2004). LSA is able to understand metaphors (Kintsch, 2000), and can assist in problem solving (Quesada, Kintsch, & Gomez, 2003). The current volume provides sufficient evidence for the variety of LSA's cognition-based applications.

In fact, the performance of LSA is so impressive that some have argued LSA's potential as a model of language comprehension (Landauer, 2002, this volume; Landauer & Dumais, 1997; Louwerse & Ventura, 2004). However, the enthusiasm for LSA as a model of a mechanism of human comprehension should be downplayed by the fact that LSA is not embodied (Glenberg & Robertson, 2000). LSA presumably cannot differentiate between drying your feet with a t-shirt (acceptable) and drying your feet with glasses (unacceptable). LSA presumably cannot 'understand' how laptops can be used to protect oneself from an attack, but napkins cannot. Though it is indeed hard to argue that LSA is embodied, the question can be raised to what extent symbols have to be grounded and how this grounding process takes place.

Symbol Interdependency

Embodiment theories (Barsalou, 1999; Glenberg, 1997; Pecher & Zwaan, 2005; Searle, 1980; Zwaan, 2004) have argued that symbols must be grounded before they can have any meaning. Because the mechanism of LSA does not allow for grounding of symbols, LSA cannot subsequently be a model of language understanding. Landauer (2002, this volume) has argued that if sensory information were to be added to the LSA space, LSA could become an embodied system. Though it seems feasible that higher-order relationships can emerge from sensory data, the question should be raised whether the problem of symbol grounding in LSA requires that sensory information is added to the training corpus. Does a direct relation between symbolic and embodied representations exist?

In fact, Deacon (1997) has argued that the relationship between symbol and embodied representation is of a secondary nature. His answer to the question why humans have language and other species do not is that humans have the symbolic mind for it. Deacon argues that humans have the mental ability to represent complex abstract entities of meaning and the relations between these entities. Other species simply do not have that capacity, though some approach it (e.g. chimpanzees). Deacon's proposal of the special mental abilities humans have is a model of symbolic transduction, loosely based on Peirce's (1923) theory of signs. Peirce identifies three different kinds of signs: icons, indices and symbols. Icons are mediated by a similarity between the sign and the object it refers to, like a portrait representing a person. There is a physical similarity between the portrait and what it represents (the person). Indices are mediated by contiguity between sign and object, like smoke indicating fire. An index represents an association of correlation between icons. It needs to be learned that where smoke is, there is fire. In fact, if we were to live in an environment with continuous smoke, but no fire, we would lose this indexical association. The third level of representation is symbolic. Symbols are mediated by an arbitrary, conventional relationship between sign and object, like wedding rings being symbols of marriage. A symbol is a relationship between icons, indices and other symbols.

Different levels of interpretation can now be formed based on the hierarchical relationships of this classification. Indexical relationships consist of iconic relationships. For instance, the iconic relationship between the icon smoke and what this icon represents needs to be associated with the icon fires and what this icon represents. Note that indexical relationships are temporally and spatially contiguous. If they do not occur at the same time in the same place, the relationship disappears. This is different for symbolic relationships: they occur outside time and space and exist by means of convention. In other words, an arbitrary relationship exists between the symbol and what it represents. Most animals are able to form iconic and indexical relationships, but they cannot reach the higher-order symbolic relationships. Only humans can, because of their unique brain structure (Deacon, 1997).

Deacon's hierarchy of relationships is not straightforward and allows for different interpretations. What follows is one such interpretation: A sign can be an icon, index or symbol. It is therefore not the case that a word is a symbol. It can be an icon as is the case with onomatopoeias like "oink", an index as in deictic expressions like "there", or symbol like "morning". Let's consider a child learning the meaning of words. The child first sees the icon of a dog and what that icon represents, the sheepdog walking around in the house. By the time the child is about a year old it is able to associate the word "dog" it has frequently heard to the icons of that particular dog. Note that the word "dog" solely means this one particular sheepdog walking around in the house: there are strict temporal and spatial constraints. By the time the child gets older different indexical relationships ("dog" for his sheepdog, "dog" for the neighbor's Labrador, "dog" for his uncle's Dachshund) become the symbol "dog". Note that the symbol "dog" represents the various indexical relationships, but also the relationships between the various symbols. That is, by being able to build the hierarchy of indexical relations, the child is able to built interdependencies between symbols. In Deacon's words "The correspondence between words and objects is a secondary relationship, subordinate to a web of associative relationships of a quite different sort, which even allows us to reference to impossible things" (Deacon, 1997: 90).

The ability to build these higher order relationships is certainly not unique for language comprehension and production. For instance, it can also be found in logic and reasoning where relationships operate at a higher, more abstract level. Interestingly, this higher-order relationship can be found in an ability that children need prior to learning language: theory of mind, the ability to ascribe mental states that are often not directly observable to him/herself and to others (Bloom, 2000).

Symbol interdependency provides a cognitive mnemonic device. Information gets recoded. Comprehenders do not have to activate every single detail of the indexical relationship of iconic relations of icons representing objects, but can use a simple shorthand. In a neural-network fashion all nodes related to these symbols – including indices and icons – get some activation, but for default communicative purposes not enough to be processed in working memory. Symbols can therefore always be grounded in our experience of the physical world, but in language comprehension they do not always have to be grounded. Much of their meaning can come from relations to other symbols. That is, in default conversation and reading setting, comprehenders do not ground each and every word they encounter. When a situation arises where such grounding is desirable, comprehenders do not take the short-cut of relying on the meaning from other symbols, but also use embodied representations.

Symbol Interdependency argues that symbols are built onto embodied representations and that interrelations between symbols can capture meaning to a large extent, though not completely. This would lead to the prediction that language, being built onto embodied representations, should be able to capture some of the relations. LSA would be a good tool to reveal these relations.

Embodiment and LSA

Various studies have raised doubts about the claim that LSA cannot capture embodied representations (Kintsch, this volume; Louwerse, Hu, Cai, Ventura, & Jeuniaux, 2006). In a number of studies Louwerse et al. showed that LSA simulates categorization and prototypicality reasonably well, replicating Collins and Quillian's (1969) and Rosch (1973). Furthermore, they showed that LSA ranks concepts of time in a temporally appropriate order. This is true for days of the week, moths of the year and other concepts of time, like seconds, minutes and hours. Louwerse et al. (2006) also showed that by just using higher-order co-occurrences LSA correlates with real distances between places, independent of the type of city (US cities or world cities), corpus (TASA or encyclopedia), or language (English or French). Louwerse et al.'s method differed in one important respect from other methods: they did not compare one word to another words, but instead looked at the interrelations of words belonging to a semantic field.

A similar method can be applied to Glenberg and Robertson's (2000) study that showed LSA cannot reveal embodied relations. Glenberg and Robertson gave a compelling case against LSA and in favor of embodiment theory by selecting sentences like the following:

1a. *Setting*: After wading barefoot in the lake, Erik needed something to get dry.

1b. *Related*: He used his towel to dry his feet.

1c. *Afforded*: He used his shirt to dry his feet.

1d. *Non-afforded*: He used his glasses to dry his feet.

The authors showed that LSA cosines for the comparison between target sentence and setting sentence could not distinguish between non-afforded and related/afforded sentences. In other words, for LSA the related/afforded sentence was the same as the non-afforded one. Sensibility and envisioning data from human subjects however did show a difference between related/afforded and non-afforded sentences with lowest scores for the latter. Glenberg and Robertson (2000) thus drew the conclusion that LSA cannot capture the meaning of novel situations, while humans can.

According to the Symbol Interdependency Hypothesis, symbols can be grounded and in peculiar cases of novel situations are likely to be grounded. But the Symbol Interdependency Hypothesis also states that language is structured according to embodied experiences and that LSA should therefore be able to capture the meaning of the novel situations. According to the same Symbol Interdependency Hypothesis words elicit meaning through associations with other words. That is, the semantic relationship between text units (e.g. words) is not dependent on the relation between these two units, but on the interdependency of these units in relation to a web of interdependent units. In other words, instead of comparing the relation between the sentence (1a) (setting) and a target sentence like (1d) (non-afforded target) in the previous example, the symbols interdependent on 1a and those interdependent on 1d should be compared. Here, this is operationalized as follows. First, the relevant words in each of the three target sentences were selected, in the example above dry, towel, shirt and glasses, using the Touchstone Applied Science Associates (TASA) corpus. Similar to Glenberg and Robertson's (2000) study, distinguishing concepts were chosen (e.g. "dry", "towel", "shirt", "glasses") rather than the full sentences. For each of these distinguishing four concepts the five nearest LSA neighbors (words most similar to the target words) were selected. In the example, the near neighbors for "glasses" are "glasses", "bifocals", "eyeglasses" "spectacles" and "nearsighted". As a working hypothesis, these five words together form the closest interdependencies between each target word. Next, for the four groups each consisting of five words a similarity matrix was computed. These matrices were each supplied to an ALSCAL algorithm to derive a Multidimensional Scaling (MDS) representation of the stimuli (Kruskall & Wish, 1978). That is, the matrix of LSA cosine values was translated into a matrix of Euclidean distances. This matrix is compared with arbitrary coordinates in an *n*-dimensional space. The coordinates are iteratively adjusted such that the Kruskall's stress is minimized and the degree of correspondence maximized. Coordinates on a one-dimensional scale for each matrix were saved and used for comparison purposes.

As expected, no significant differences were found between the related and the afforded sentences (t (32) = 1.47, p = .15). An expected difference was found between the related sentences and the non-afforded sentences (t (32) = 3.44, p < .01) with the related sentences yielding higher scores (M = .13, SD = .87) than non-afforded sentences (M = -.80, SD = .69). Unexpectedly, the afforded and non-afforded sentences only resulted in a marginally significant difference (t (32) = 1.70, p = .09), but with the expected pattern (M = -.32, SD = .93 and M = -.80, SD = .69). A correlation between the non-afforded sentence and the setting (*dry – glasses*) however showed a strong negative correlation (r (18) = -.72, p < .01), suggesting that these are furthest away in a Euclidean distance. An explanation for not finding a significant difference may lie in the dimensionality. Because of the comparison, the number of dimensions was limited to 1, despite high stress and low R^2. Furthermore, several of the items were homonyms (e.g. *glasses*) or syntactically ambiguous (e.g. *dry*).

When the MDS coordinates were compared with Glenberg and Robertson's sensibility and envisioning ratings a positive correlation was found (r (54) = .328, p = .01; r (54) = .31, p = .02 respectively. Means are presented in Table 1. Though these results may not be conclusive, they at least raise doubts about the claim that LSA cannot model embodied relations.

TABLE 1 ABOUT HERE

Conclusion

The results of the various simulations presented in this study and other studies (e.g. Kintsch, this volume; Louwerse et al., 2006) do not yield a final conclusion that symbolic systems do not represent perceptual information, but instead conclude that symbols can convey embodied information. This is what we have called the symbolic interdependency hypothesis: Symbolic relations exist between indexical relationships and ultimately iconic relationships, as well as between other symbols. Symbols are thereby interdependent abstract systems of meaning that are occasionally grounded in the comprehender's iconic experience of the world, and symbolic systems are structured after these iconic relations. Algorithms like LSA allow us to reveal some of these relations. This study has shown that by taking near neighbors of target words embodied relations that are presumably hidden for LSA can in fact be unraveled.

The interdependency of symbols allows us to ground some words without the necessity to ground others, providing comprehenders with a convenient mnemonic support for language processing. That perception and cognition structure language is not surprising. If language was at some point used by our ancestors as a tool to convey perceptual experiences, the tool was likely conveniently shaped to fit the objects it must operate on (Anderson, 2005). The fact that language consists of phrasal structures (Chomsky, 1957), subjects always precede objects (Greenberg, 1963), and categories are determined by the way we perceive the structure of the world (Rosch, 1978), are clear examples how thought structures language.

But what about the rich empirical evidence that activation of language leads to activation of perceptual information? This study has argued that symbols can be (and are occasionally) grounded in perceptual experiences, but do not always have to be. It has thereby replaced the question whether language comprehension is symbolic or embodied by the question to what extent language comprehension is both symbolic and embodied.

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Table 1. MDS coordinates and Glenberg and Robertson (2000) findings

	MDS coordinates	Sensibility ratings	Envisioning ratings
Related	.15 (.85)	6.02 (.85)	6.13 (.76)
Afforded	-.40 (.96)	4.41 (1.13)	4.92 (1.15)
Non-afforded	-.71 (.77)	1.31 (.56)	1.47 (.74)

Note Standard deviations between parentheses