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What memory is for

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Abstract: Let's start from scratch in thinking about what memory is for, and consequently, how it works. Suppose that memory and conceptualization work in the service of perception and action. In this case, conceptualization is the encoding of patterns of possible physical interaction with a three-dimensional world. These patterns are constrained by the structure of the environment, the structure of our bodies, and memory. Thus, how we perceive and conceive of the environment is determined by the types of bodies we have. Such a memory would not have associations. Instead, how concepts become related (and what it means to be related) is determined by how separate patterns of actions can be combined given the constraints of our bodies. I call this combination "mesh." To avoid hallucination, conceptualization would normally be driven by the environment, and patterns of action from memory would play a supporting, but automatic, role. A significant human skill is learning to suppress the overriding contribution of the environment to conceptualization, thereby allowing memory to guide conceptualization. The effort used in suppressing input from the environment pays off by allowing prediction, recollective memory, and language comprehension. I review theoretical work in cognitive science and empirical work in memory and language comprehension that suggest that it may be possible to investigate connections between topics as disparate as infantile amnesia and mental-model theory.

Keywords: amnesia; automatic memory; coherence; embodied meaning; inferences; language comprehension; memory; mental models; recollective memory; symbol grounding

1. Introduction

Most memory theories presuppose that memory is for memorizing. What would memory theory be like if this presupposition were discarded? Here, I approach memory theory guided by the question, "What is memory for?" The answer that I develop is influenced by three sources. The first is Lakoff and Johnson's (Johnson 1987; Lakoff 1987; Lakoff & Johnson 1980) cognitive linguistic analysis of language, conceptualization, and meaning. They propose that cognitive structures are embodied; they arise from bodily interactions with the world (cf. Harnad 1990; 1993). After a brief review of the Lakoff and Johnson program, I examine the literature on memory (the second source) for evidence that cognitive structures are, indeed, embodied, and why that is so. I will propose that memory evolved in service of perception and action in a three-dimensional environment, and that memory is embodied to facilitate interaction with the environment. The third set of ideas comes from research on mental-model theory of language comprehension. I relate mental-model theory to the notion of embodied memory by proposing that because language acts as a surrogate for more direct interaction with the environment, language comprehension must also result in embodied representations, which are in fact mental models. In exploring these ideas, I develop an approach to memory and language comprehension that suggests ways of dealing with old problems (e.g., why recollection and comprehension are effortful), as well as new concepts to replace old ideas (e.g., an association).

1.1. Why embodiment should matter to cognitive psychologists

Why should psychologists interested in language, learning, and memory care about issues such as embodiment of memory? Because, by ignoring them, we have been making a big mistake. Most theories of memory treat internal representations as meaningless symbols such as a string of zeros and ones that "encode" features (e.g., Hintzman 1986; McClelland & Rumelhart 1986; Metcalfe 1993), as pointlike objects with no structure (Gillund & Shiffrin 1984), or as propositions relating intrinsically meaningless symbols (Kintsch 1988). Two problems arise from this treatment. The first is the symbol grounding problem (Harnad 1990): How do those meaningless symbols come to take on meaning? The answer is not as simple as referring the symbol to a lexicon, because words in the lexicon must also be grounded. Also, not all of those meaningless symbols are meant to represent words or wordlike concepts; some are meant to represent complex nonverbal displays (Posner & Keele 1968; Schacter et al. 1990). The second problem is that we have not availed ourselves of a golden opportunity. By treating internal representation as meaningless symbols, we have not thought about the possibility of taking advantage of other forms of representation. Instead of meaningless symbols, suppose that representations have a structure that is lawfully related to the objects being represented. The structure of the representations might then play an important role in determining, for example, what concepts are easily associated, because their structures literally fit together. For example, it seems easy to associate "horse" and "spotted" because horses have surfaces that can be spotted, whereas it is more difficult to associate "idea" and "spotted." Note that this sort of thinking trades on the analogical nature of the representations rather than on propositional listings of content (see Palmer 1978). That is, we could just as easily assert "the idea was spotted" as "the horse was spotted." Nonetheless, one seems to make sense and the other does not.

In the next few sections I develop the case that internal

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representations are analogically structured (embodied), that this structure helps to explain memory phenomena, and that in conjunction these ideas suggest that the standard memory paradigms are ill-conceived and that standard memory phenomena may be revealing little that is important about memory. These sections are followed by a discussion of the possibilities for analogical representation underlying language comprehension.

1.2. Embodiment and the Lakoff and Johnson program

A central concern of the Lakoff and Johnson program is the concept of meaning. According to Lakoff (1987), the standard theory of meaning in cognitive science is based on the notion of truth values of propositions, and, as it turns out, this theory will not work as a theory of human meaning. Explication of why this is so requires a bit of patience, in part because the way psychologists use the term "proposition" is different from the way philosophers and logicians use it. For the psychologist, propositions are relations among symbols, that is, an assertion that a relation exists. It is these assertions that are supposed to be meaningful. Importantly, although the propositions are supposed to capture meaning, the symbols used in the propositions are taken to be, by themselves, meaningless or arbitrary: there is no intrinsic relation between a particular symbol and its meaning. Thus when illustrating propositions, a psychologist may use a word to stand for an element in the proposition, but that is just a convenience. Indeed, the meanings of the words need to be specified, presumably by other propositions. Thus we should replace any words in a psychologist's proposition with things such as "symbol X19." This state of affairs is quite useful because it allows for reasoning (the derivation of new propositions) to be based on the manipulation of propositions by syntactic rules. These rules are thought to operate independent of the referents of the elements (nodes and symbols) in the propositions.

For example, suppose that proposition 1 (P_1) asserts that element a is in relation R to element b. In shorthand, P_1: aRb. Furthermore, suppose P2: bRc. Now, if R is a transitive relation (such as "larger than"), and both P_1 and P_2 are true, then by the syntactic rules of transitive inference, P_3: aRc is also true. Thus, for the psychologist, we have created new knowledge, namely, that P_3 is true. Note that these propositions have truth values, but they fail a commonsense test of what it means to have meaning. Namely, in order for a statement to be meaningful (to us), we must know what the statement is about. In contrast, although we know that P3 is true, we have little idea what it is about, because we have no idea what a and b stand for.

The problem of what a and b stand for is the symbol grounding problem (Harnad 1990): How do we give meaning to the arbitrary symbols? To know what these propositions are about requires a mapping between the elements in the propositions (a, b, c, and R) and the world (or a possible world, or a model of the world). Without this mapping, the symbols can only refer to other symbols, which in turn refer to yet other symbols. Just like trying to learn the meaning of a word in a foreign language by using a dictionary written solely in that language, such a system of symbols will never generate meaning (Searle 1980). Most psychologists don't see a problem here, because they are happy to point to perception: the arbitrary symbols are grounded by the perceptual system. That is, what a symbol means is what it refers to in the "outside" world.

Lakoff (1987) presents (at least) three arguments against the plausibility of generating meaning by this sort of symbol grounding. First, this theory requires that categories be Aristotelian, that they have sharp boundaries. Aristotelian categories are needed so that we can successfully map between the arbitrary symbols in the propositions and the elements in the world. Thus, if a proposition is supposed to be about a horse, to give the proposition its proper meaning we must be able to map the symbol for horse (X19, perhaps) onto horses, and exclude zebras and antelopes and perhaps even ponies. In contrast to this requirement, there is a tremendous amount of empirical work in the psychology of human categorization implying that categories in the head are not Aristotelian. Instead many significant categories have fuzzy boundaries (Oden 1984; 1987), graded membership (Kalish 1995), complex structures (Lakoff 1987), or are based on prototypes (Rosch 1973). Furthermore, the extensions of even basic biological categories are less than certain, and categories based on human culture are even more fuzzy. Thus, categories such as democracy, justice, and mother (Lakoff discusses biological mothers, birth mothers, adoptive mothers, stepmothers, etc.) seem to have structures quite different from the classical Aristotelian category.

A second argument against the standard theory as a theory of human meaning is based on an analysis of Putnam (1981). This analysis, however, is directed toward the philosopher's meaning of proposition, and so it requires a bit of new terminology. To the psychologist, a proposition (like aRb) is supposed to have meaning. To the philosopher, aRb is a sentence in a formal language. The meaning of the sentence (its propositional content) corresponds to the function that determines, for any possible situation, whether that sentence is true or false. In plain language, which is not an exact equivalent but close enough, the meaning of a sentence such as "the horse is spotted" is whatever allows one to determine if it applies to particular situations. Furthermore, two sentences have the same meaning if they have the same truth values for all possible situations.

Putnam discovered a serious problem with this truth-value notion of meaning: it is not difficult to construct pairs of formal sentences whose symbols are mapped to radically different things, but that have the same truth values in all situations. In other words, even though the sentences are about radically different things on the truth-value account of meaning, because the sentences have the same truth values they are supposed to have the same meaning. Clearly, it does not make much sense to assert that sentences about different things mean the same thing. As it turns out, the problem is with the arbitrary nature of the symbols. They only mean when they are mapped onto the world, and Putnam demonstrated that it is impossible to find the one and only correct mapping.

Lakoff and Johnson's third argument against the standard theory is based on their analysis of language use and what it implies about cognition. In brief, people frequently use metaphorical language ("He's trapped in his marriage," "Your theory is airtight," "I'm really high today"). Furthermore, Lakoff and Johnson propose that metaphorical language is not just the way people talk, but accurately reflects the way people think. Given that theories cannot literally be airtight and that people's emotional states cannot literally be high, it is hard to imagine how cognition could be based on the mappings of arbitrary symbols and produce such (easy to understand) language.

Several other cogent arguments against the use of arbitrary symbols in a theory of meaning can be found in Barsalou (1993; Barsalou et al. 1993) and Shanon (1988). Barsalou and Shanon note that people have a hard time defining many familiar words, and that the definitions can vary greatly with context. This finding is difficult to explain if one believes that meaning of words is a simple list of well-formed propositions. They also note that there is no good account of how propositions composed of meaningless and arbitrary symbols might have evolved or how a child could have discovered them. As Shanon concludes,

> Specifically, it appears that the underlying substrate of mental activity is not a repertory of well-defined, well-structured abstract symbols, and that the workings of mind cannot be generally characterized as the computational manipulations of such symbols. Rather, the substrate in which mental activity takes place should be one that meets the following requirement: It should not be fixed by any coding system that is defined a priori, it should afford maximal sensitivity to unspecified dimensions and distinctions, it should be context-sensitive, and it should be embedded in the framework of the organism's action in the world. (p. 80)

That is a call for an embodied approach to meaning.

1.3. Embodiment and meaning

If we dismiss the standard theory, what is left? Lakoff and Johnson offer a theory of meaning based on the concept of embodied knowledge. Because I will be approaching the problem from the question "What is memory for?" I will develop an idea of embodied meaning that is distinct from the Lakoff and Johnson proposal. Nonetheless, the proposals are clearly related. In outline, my proposal is that perceptual systems have evolved to facilitate our interactions with a real, three-dimensional world. To do this, the world is conceptualized (in part) as patterns of possible bodily interactions, that is, how we can move our hands and fingers, our legs and bodies, our eyes and ears, to deal with the world that presents itself? That is, to a particular person, the meaning of an object, event, or sentence is what that person can do with the object, event, or sentence.

How does this approach answer the objections raised to the standard theory of meaning? Importantly, embodied representations do not need to be mapped onto the world to become meaningful because they arise from the world. In other words, embodied representations are directly grounded by virtue of being lawfully and analogically related to properties of the world and how those properties are transduced by perceptual-action systems (Harnad 1990; 1993). Thus, the meaningful, action-oriented component of conceptualization is not abstract and amodal. It reflects how bodies of our sort can interact with objects.

Given that embodied representations do not need to be mapped onto the world to be grounded, there is neither need for representations to be Aristotelian nor for the categories in the world to be Aristotelian. Furthermore, because embodied representations are not discrete, meaningless symbols, they can reflect subtle, fuzzy variations in the world. How then do categories arise? Objects fall into the same (basic) category because they can be used to accomplish the same interactive goal, such as supporting the body. Because the same object may be useful for accomplishing a variety of goals, categorization can be flexible and context dependent (Barsalou 1993).

Consider three objections to these claims. The first is that because we have different bodies, we will understand the world in different ways. In fact, that is a valid prediction. For example, what makes an object a chair for a particular individual will depend on whether or not that individual is able to get his or her body into a sitting position using the object. Thus, depending on the height of the object, the width of the flat surface, the object's strength, and so on, the object will be a chair for some people (e.g., a child) but not for others (e.g., an aging grandfather).[1] Nonetheless, bodies are substantially the same around the world and across cultures. Thus, although there will be variability around the edges, our common human endowments and our common environment ensures a great degree of common center to cognitive structure.

A second objection to the claim that cognitive representation is embodied is that the mapping problem has not been solved; there is still the problem of mapping (arbitrary) words to embodied representations so that we can talk about what we are perceiving and thinking. This is a deep problem (e.g., Harnad 1990; Plunkett et al. 1992), but it is not one that I intend to address here. The point of the above is that embodied representations allow us to understand how, except for the seriously deranged, we all know the difference between say, horses and ideas, and contrary to what Putnam's analysis shows of the standard theory, we don't ever confuse them.

A third objection is that some things are meaningful (e.g., a beautiful sunset) even when there is no apparent possibility for bodily interaction.[2] The embodied account of meaning is situated, so that action-oriented meaning can vary greatly with context. Thus, depending on the context, a Coke bottle can be used to quench thirst, or as a weapon, a doorstop, or a vase. That is, its meaning depends on the context. Similarly, a beautiful sunset is a context that combines with objects and memories to suggest actions consistent with warmth, relaxation, and a good beer.

Later I will discuss how embodied representations can be extended to represent abstract concepts and how they may provide a novel way of dealing with unanalyzed concepts such as association. For now, however, I turn to developing a particular sketch of embodied representations that arises from a consideration of what memory is for. This sketch is not a fully testable theory. The idea is to show how a type of theory that is not subject to the criticisms leveled at meaningless symbol theory can handle problems of memory and comprehension.

2. What memory is for

Except for the recent blossoming of interest in indirect memory (see sect. 5.1), the contemporary psychology of memory has been dominated by the study of memorization.[3] In part, this seems to have arisen from a failure of many twentieth century memory theorists to consider what memory is for. By the end of section 5, I will have concluded the following: memory is embodied by encoding *meshed* (i.e., integrated by virtue of their analogical shapes) sets of patterns of action. How the patterns combine is constrained by how our bodies work. A meshed set of patterns corresponds to a conceptualization. Updating memory occurs whenever the meshed patterns change (a change in conceptualization of the environment) and the updating is in terms of a change, or movement, or *trajectory* toward a new set of meshed patterns. Thus, memory records how conceptualizations blend into one another. This memory works in two broad modes. First, patterns of action based on the environment (projectable properties of the environment) are automatically, that is, without intention, meshed with patterns based on previous experience. This automatic use of memory corresponds closely to implicit or indirect memory. Second, patterns from the environment can be suppressed so that conceptualization is guided by previous experience encoded as trajectories. This is a conscious and effortful use of memory. The ability to suppress environmental patterns contributes to prediction, the experience of remembering, and language comprehension.

2.1. The function of memory in a dangerous environment

We live in a dangerous, three-dimensional world. Given the size, density, and physical capabilities of our bodies, the natural environment is hostile. We are open to predation, and our interactions with the world can lead to injury from freezing, burning, drowning, and falling. Clearly, survival requires the capability to navigate this environment and, just as clearly, our perceptual system has evolved to do just that. For example, we have developed impressive abilities to use information (e.g., optical flow fields) to guide action so that obstacles are avoided. These abilities may not require any sort of representation of the environment and they may not require memory; responding constrained by characteristics of the environment and our bodies guarantees successful action (for a review, see Bruce & Green 1985).

On the other hand, it is frequently the case that we need to differentiate. In addition to avoiding obstacles in our path, we need to pick out and follow a particular path, avoid a particular location, or approach a particular person. This sort of differentiation requires a memory system. What makes one person a particular person (to you) or one path the path to your house, is its relevance to you, that is, how you have interacted with it in the past. An optical-flow field cannot contain this information; it is the province of memory. This distinction is discussed by Epstein (1993), who uses the term "projectable" to refer to properties of the environment that can be specified by information available in the light and "nonprojectable" to refer to properties that must be signaled by other sources. Thus spatial layout is a projectable property, whereas ownership is a nonprojectable property that must come from experience.

2.2. Embodied conceptualization, memory, and meaning

To support action, the perception of projectable properties is in terms of patterns of possible action: how we can examine, grasp, shove, leap over, or move around an object. This coding depends on the capabilities of our bodies, both as a species and as individuals. Because the world is perceived in terms of its potential for interaction with an individual's body, it is proper to call the perception "embodied."

Patterns of action derived from the projectable properties of the environment are combined (or meshed, sect. 3.1) with patterns of interaction based on memory. The two patterns can combine because they are both embodied, that is, both are constrained by how one's body can move itself and manipulate objects. The resulting pattern of possible actions is a conceptualization: the possible actions for that person in that situation. For example, "turn left to get home."

Thus meaning of an object or a situation is a pattern of possible action. It is determined by the projectable features of the object molded by bodily constraints and modified by memory of previous actions. These memories provide the nonprojectable features. As another example, consider the meaning of the cup on my desk. The embodied meaning is in terms of how far it is from me (what I have to do to reach it), the orientation of the handle and its shape (what I have to do to get my fingers into it), characteristics of its size and material (the force I must exert to lift it), and so forth. Furthermore, the meaning of the cup is fleshed out by memories of my previous interactions with it: pouring in coffee and drinking from it. Those memories make the cup mine.

Note three characteristics of this sort of meaning. First, because bodily actions take place in space, embodied meaning captures spatial (or topological) and functional properties. Thus a synonym for this type of embodied meaning is spatial-functional meaning. Second, because we interact with objects via parts, conceptualization in terms of bodily interaction forms the basis for partonomies (Tversky & Hemenway 1984) and basic-level categorization. Third, conceptualization in terms of patterns of bodily interaction is very close to Gibson's (1979) notion of affordance.

Thus, what is memory for? Its primary function is to mesh the embodied conceptualization of projectable properties of the environment (e.g., a path or a cup) with embodied experiences that provide nonprojectable properties. Thus the path becomes the path *home* and the cup becomes *my* cup. This meshed conceptualization, the meaning, is in the service of control of action in a three-dimensional environment.

2.3. Evidence for embodied conceptualization

How far can this account of embodied meaning be pushed? At the least, there are intriguing results that fit this account nicely and that do not seem to have a natural explanation in cognitive accounts based on meaningless symbols. I will review some of this literature from the domains of affect, memory, and imagery.

2.3.1. Embodiment and affect. Van den Bergh et al. (1990) presented typists and nontypists with sets of letter pairs (e.g., WX and ZD). The subjects were asked to choose the one pair (from each set) that was liked the best. Typists showed a clear preference for pairs typed with different fingers over pairs typed with the same finger, whereas the nontypists showed little preference. (The typing finger was determined using AZERTY keyboards in Belgium and QWERTY keyboards in the United States.) Van den Bergh et al. argued that, for typists, part of the encoding of letters is that of a motor program or movement. The incompatible movements generated by letters typed with the same finger resulted in a negative evaluation. It is unlikely that this effect arose from associations to specific letter combinations because the effect was most robust for pairs of letters with low frequency in the language.

Berkowitz and Trocolli (1990) and Berkowitz et al. (1993) illustrate the influence of the body on affect judgments. In one experiment, subjects were asked to judge the personality of a fictitious person described in neutral terms. Half the subjects listened to the description while holding a pen between their teeth without using their lips. This activity forces the face into a pattern similar to that produced by smiling. The other subjects listened to the description while biting down hard on a towel. This activity forces the face into a pattern similar to that produced by frowning. The subjects who were smiling rated the person described more positively than did the subjects who were frowning. It is unlikely that this effect arose due to demand characteristics of the experiment for the following reason: the effect was obtained only when subjects were distracted from their activities. When they were asked to focus on the activities, the subjects seemed to compensate for the forced smile (frown) and rate the description more negatively (positively). What can account for this finding? Experienced emotion is embodied. When the body is manipulated into a state that is highly correlated with an emotion, the body constrains other cognitive (that is embodied) processing.

2.3.2. Embodiment and imagery. Montello and Presson (1993) asked subjects to memorize the locations of objects in a room. The subjects were then blindfolded and asked to point to the objects. Pointing was fast and accurate. Half of the subjects were then asked to *imagine* rotating 90° and to point to the objects again. That is, if an object was originally directly in front of the subject and the subject imagined rotating 90° clockwise, the correct response would be to point to a location toward the subject's left. In this condition, the subjects were slow and inaccurate. The other subjects, while blindfolded, were asked to *actually* rotate 90° and to point to the objects. These subjects were just about as fast and accurate as when pointing originally. Thus, mentally keeping track of the locations of objects, a task that many cognitive psychologists would suspect as being cognitive and divorced from the body, is in fact strongly affected by literal body movements.

Rieser et al. (1994) reported a similar finding for children and adults. The participants were tested for the ability to imagine (while at home) their classrooms and to point to objects from various perspectives. When the perspective change was accomplished by actually changing position (at home), the 5-year-olds were correct on 100% of the trials, the 9-year-olds were correct on 98%, and the adults on 100%. When the perspective change was accomplished solely by imagination, the 5-year-olds were correct on 2% of the trials, the 9-year-olds were correct on 27%, and the adults were correct on 100%. Even the adults showed great difficulty in terms of the time needed to accomplish the imagination-only version of the task. When actually changing position, 100% of the adult responses required less than two seconds, whereas when imagination was used, only 29% of the responses required less than two seconds.

Findings on the psychophysiology of imagery also point to a close connection between body and cognition. These findings are summarized by Cuthbert et al. (1991). Their starting point is Lang's (1979) bio-informational theory, which asserts that encoding of events includes response "propositions," and that imagery (visual and otherwise) is the activation of those propositions. Furthermore, although overt responding is inhibited during an imagery task, there may well be "efferent leakage" that can be measured using psychophysiological techniques. In support of these ideas, Cuthbert et al. note that psychophysiological responsivity is particular to the image being evoked. Thus imagining a fearful situation evokes sweating, imagining positive situations results in measurable activity in muscles associated with smiling, and imagining negative situations results in activity in the muscles associated with furrowing of the brow. There are analogous effects for imagery related to other perceptual/action systems. Thus, in imaging pendular motion, discharges in the eye muscles follow the appropriate frequency, in imaging bicep curls there are discharges in the biceps, and in imagining the taste of a favorite food there is an increase in saliva flow. These results are compatible with the notion of embodied, spatial-functional encoding. In addition, the idea of embodied encoding has an advantage over Lang's response propositions. According to Cuthbert et al. (1991), the function of imagery is to allow new behaviors to be tried out "off-line." It is not clear however, how response propositions can be integrated (other than by concatenation) to effect this rehearsal. In contrast, the integration of responses is basic to the notion of mesh (see sect. 3.1) of embodied encodings. That is, given that the information is encoded in terms of bodily interaction, effecting one action (or imagining it) necessarily constrains the operation of simultaneous and successive actions.

2.3.3. Embodiment and memory. Effects of embodiment are revealed by research on memory for subject-performed tasks (Cohen 1981; Engelkamp & Krumnacker 1980; Saltz & Donnenwerth-Nolan 1981; see also a special issue of *Psychological Research*, 1989, including Englekamp & Zimmer). The basic finding is that memory for actions (performing a command such as "open the book") is better than memory for the verbal description of the commands. One interpretation of this finding is that memory specializes in embodied information.

The nature of our bodies also controls ease of remembering. Consider a series of studies by Tversky and her colleagues (e.g., Bryant et al. 1992). In these experiments, subjects read about and memorized spatial layouts corresponding to scenes viewed from particular perspectives (e.g., in the hotel scene, "To your left . . . you see a shimmering indoor fountain"). Objects were located above, below, in front, in back, to the left, and to the right of the observer in the imagined scene. After the scene was memorized, the time taken to retrieve a particular object was measured. For equally well memorized locations, one might expect the retrieval times to be independent of location. Another hypothesis is that the times would be correlated with the degree of mental rotation needed to mentally face the object. The results, however, were contrary to both of these hypotheses. Fastest responding was to objects located on the head/feet axis, followed by the front/back axis, followed by the left/right axis. Tversky argues that these results follow from using a "spatial framework" that is sensitive to environmental asymmetries (such as gravity) and perceptual asymmetries (we generally look and attend to the front). In other words, retrieval processes appear to be sensitive to how we use our bodies.

Klatzky et al. (1989) demonstrated contributions of the body to symbolic or semantic judgments. They trained subjects to make hand shapes corresponding to descriptions such as "pinch" or "clench." The verbal descriptions were then used as primes for judging the sensibility of phrases such as "aim a dart" (sensible) or "close a nail" (not sensible). The appropriate prime, that is a prime corresponding to the hand shape used in the to-be-judged action, speeded the sensibility judgment compared to a neutral prime. Thus, the hand shape for "pinch" speeded the sensibility judgment for "aim a dart." It is unlikely that this priming effect derives from any sort of verbal mediation: the priming effect was found for subjects trained to make the hand shapes when signaled by nonverbal primes. Also, when subjects were trained to make verbal responses (but not hand shapes) to the nonverbal primes (e.g., saying the word "pinch" when shown the nonverbal signal for pinch), the priming effect was eliminated. Klatzky et al. suggest that the sensibility judgment requires a type of mental simulation using an embodied, motoric medium. Generating the appropriate hand shape "facilitates constructing the representation and/or simulating the action/object pairing" (p. 75).

3. How embodied memories are used

Consider this scenario. You have been wandering in the woods, and suddenly you are unsure of the way home. You see what appears to be a path, but you are not certain if it really is a path, yet alone the path home. You take a few steps and hunt for evidence. As you continue your exploration, you become convinced that this is the right path: the patterns of rocks, twigs, and soil align themselves to form a connected pattern that could be a path. Also, as you move along, you are able to conform your own body to the putative path. For example, the overhanging branches are not so low that you have to stoop or crawl; when you reach a stream, the distance between the rocks forms a series of stepping stones that can be used by an animal of your size and agility.

3.1. Mesh of patterns as functional constraint satisfaction

Recognition of the path as a path arises from an exploration of the environment and a fit between the environment and embodied knowledge. This fit can be conceptualized as a type of constraint satisfaction, but here the constraints are spatial and functional, not associationistic or probabilistic (cf. Rumelhart et al. 1986). Thus projectable properties of the environment (arrangement of rocks, twigs, and soil) are encoded in terms of how you (with your particular body) can interact with that environment (e.g., whether the distances between the rocks in the creek can be broached). Other patterns of interaction come from memory, for example, patterns representing goals such as "get home without getting wet." In conceptualizing the environment as a path, the spatial-functional patterns based on projectable properties from the environment are combined or meshed with the patterns from memory. The meshed pattern dictates how (or if) the body can be moved in a way that simultaneously satisfies both sets of patterns of action (e.g., "Can I, with my body, get from rock to rock without getting wet?"). This sort of mesh is a possibility because all of the patterns are embodied, that is, they are all encoded in terms of how your body constrains actions. When the patterns can be meshed into a plan for coherent action (e.g., stepping across the rocks), the rocks, soil, and twigs become (for you) a path.

I envision mesh of embodied encodings as being analogous to coarticulation in speech production. When pronouncing the initial /d/ in "dog," the articulators are shaped in part by the requirement to enunciate the following vowel, and when pronouncing the vowel, the articulators are shaped not only by the vowel, but by the preceding and following consonants. Furthermore, the constraints on articulation are not consciously imposed, but are constraints that follow from real movements of physical devices: the tongue can only be in one place at one time, and how it is going to move to the next place will depend on where it is now. Thus pronunciation of the word requires a mesh of real physical actions.

An example of cognitive meshing is borrowed from Barsalou et al. (1993). Imagine a ball; now imagine that it has yellow and white stripes; now imagine that the ball is deflated (it is a beach ball). Adding each new descriptor is not a matter of adding a simple association or adding a proposition to a list. Instead, each previously constructed representation constrains how the new descriptor is utilized. Thus, the yellow and white stripes surround the ball. Then, not just the ball, but the stripes too become deformed when the ball is deflated. The stripes and the ball deflate together because they are encoded as patterns of action subject to the same spatial-functional constraints. This meshing occurs not just in imagination, but in memory, comprehension, and perception.

It is the mutual modification of meshed patterns of action that produces emergent and creative features of thought. The deflated beach ball is not simply a deflated ball associated with an unchanging stripes feature. Instead, the fact that the stripes are deflated arises from the operation of meshing. Related concepts will mesh easily, because that is what it means to be related (sect. 7.3), and, with some effort, we can mesh arbitrary concepts. Thus a "tiger bicycle" is one designed for hunting tigers, and it consists of a mesh between the actions required to hunt and those required to ride a bicycle, whereas "colorless green ideas" are uninspired ways of dealing with environmental crises. In short, mesh underlies our ability to understand novel conceptual combinations. Note that the type of mesh I am proposing depends on the analog nature of embodied actions, not just their propositional content.

3.2. Clamping projectable properties

Meshing patterns of action based on projectable properties of the environment with those from memory changes the way we conceptualize the environment. Thus, the soil, twigs, and rocks are conceptualized not just as a path, but as the path home. There is a danger, however, in allowing patterns from memory to modify conceptualization: meshing of patterns can distort the perception of the environment. Clearly, survival requires seeing the environment for what it is (soil, twigs, rocks), not just for what it means (the path home). To keep the system reality-oriented, it is necessary to ensure that patterns based on projectable properties of the environment are primary. That is, the meshed conceptualization that is achieved cannot be at the cost of distorting the environmental input. I will refer to this as "clamping" projectable properties of the environment.

Clamping projectable properties ensures that experiences are individuated or situated. We do not experience categories, but individual, particular events (cf. Barsalou et al. 1993). We cannot direct our perceptual system to ignore differences between two paths, just because they are both paths, or between two chairs just because we can fit our bodies into both. Because the projectable properties are clamped, the two chairs, although members of the same category, remain separate chairs.

3.3. Updating memory

I have proposed that embodied memory acts as a source of nonprojectable patterns of action that mesh with patterns derived from projectable properties of the environment; the mesh is possible because both sets of patterns are constrained by how the body works. If memory is to be useful, however, it must be updated. That is, new experiences must affect the system so that we come to learn the path home. Because experience is continuous (or at least the environment appears continuous to beings of our size and abilities), we must deal with how it can be captured by a system using a finite brain.

Consider this possibility. Projectable properties are clamped and then embodied memories mesh to produce a particular conceptualization (e.g., the path home). At this point, either an action is taken (e.g., a step along the path) or projectable properties of the environment change (e.g., a barrier appears). In either case, the system is forced to settle into a new conceptualization. Here is the proposal for updating memory: memory is updated automatically (that is, without intention) whenever there is a change in conceptualization (mesh). The degree to which updating takes place is exactly correlated with the degree to which the conceptualization changes.

Updating is not encoding a new memory trace. Instead, the shift from one pattern of possible actions (one conceptualization) to the next is reinforced. That is, what is updated is how one situation flows into another. I will refer to this flow as a "trajectory," using the term to imply that the change is not random. Instead, actions humanly possible under the current conceptualization are biased by what was possible in the previous conceptualization, just as pronunciation of a vowel is biased by the pronunciation of the preceding consonant.

The idea of trajectories solves several problems in the psychology of memory. It provides a way of conceptualizing dynamic information in memory that is sensitive to biological and spatial-functional constraints (Shiffrar et al. 1993). Trajectories can reflect minimal changes in conceptualization, such as from one step along a path to another, or gross changes such as from a step to a fall. The idea offers the beginnings of a solution to the problem of features. Most theories of memory are based on the idea that memories are multidimensional, consisting of a vector of features, such as "animate," "red," and "smaller than a bread box." None of these theories, however, is committed to a listing of what those basic features might be. In fact, because experience is so varied, it is hard to imagine a complete list. Also, given a feature-based system, it is difficult to understand how people can ever learn anything truly new: we must always conceptualize using the same basic features. In contrast, because embodied patterns of action can be infinitely varied and infinitely meshed with goals (also specified as patterns of action), a system based on embodied concepts and trajectories approaches the ideal of enabling memory to code the full variety of human experience.

Because updating of trajectories occurs only when there is a change in conceptualization, memory is sensitive to frequency and to novelty. To illustrate this, consider once again walking the path home. Three phenomena are associated with repeated actions: (1) memory for the repeated action (walking the path) will be an increasing, but negatively accelerated, function of frequency (e.g., Logan 1988); (2) memory for a particular typical repetition of the action will be poor (Glenberg et al. 1977; Naveh-Benjamin & Jonides 1984); (3) memory for a particular unusual repetition of the action will be good (Hunt 1995). The frequent interactions with the path will result in frequent updating (reinforcement of a particular trajectory) and, consequently, a shift toward a stable conceptualization (e.g., a shift from possibly the path home to definitely the path home). However, once the conceptualization is stable, little further updating occurs. Thus each encounter with the path will have less and less of an impact (phenomenon 1). Because typical encounters result in little new conceptualization and little updating, we have little memory for the individual steps down the path (phenomenon 2). However, if reconceptualization is required (e.g., when a log appears across the path, so that now, in terms of bodily constraints on action, the path is a blocked path) memory is again updated, leading to memory for novel events (phenomenon 3).

3.4. Prediction and suppression of the clamped environment

The meshed conceptualization of the current environment dictates what actions are possible in that environment. Prediction, however, requires simulating how an action will produce a new conceptualization, which in turn can be used to simulate the next action, and so forth. Two difficulties arise. The first is that simulated action does not change the environment. Thus, changes in projectable properties that would have resulted from a real action cannot be clamped to automatically guide further action. A second difficulty is that currently clamped stimulation provides the *wrong* constraints, because those constraints are only relevant before the simulated initial action. I believe that this is a major problem, and that it requires a radical (and dangerous) mechanism: suppression. In particular, I propose that in the service of prediction, we have developed the ability to, if not ignore, at least to suppress the overriding contribution of the current environment to conceptualization. This is a risky operation because it loosens the tie between reality (the current environment) and conceptualization. Perhaps because suppression is so dangerous, it is an effortful process. As we will see, however, suppression results in several serendipitous abilities, including conscious autobiographical memory and language comprehension.[4]

Once clamping of projectable properties is suppressed, multistep prediction arises from following trajectories guided by bodily constraints on action. For example, by following trajectories we can envision what will happen when we proceed down the path. We also have the ability to envision arbitrary events (such as what actions are possible if the path is washed out by a storm or blocked by strange creatures), not just events we have previously experienced.

Prediction for these arbitrary scenarios is based on seeking a mesh among patterns of action. Some of the patterns are based on well-learned trajectories. Other patterns (e.g., interactions with strange creatures) come from a consideration of how our bodies work. These patterns can mesh to give a coherent conceptualization because they are all based on bodily interaction. Keep in mind, however, that in prediction the mesh of these patterns may not be guided by stable and projectable features of the environment. To the extent that environmental constraints are suppressed, and to the extent that trajectories are not well-learned, the predictions will tend to be variable and inaccurate. Thus, it is easy to predict the outcome of the next step on a well-traveled path: the simulated mesh is strongly constrained by projectable features of the current environment and well-learned trajectories. It is more difficult to predict what will happen many steps down a new path when the projectable features must be suppressed and trajectories uncertain.

3.5. Mesh and connectionism

Many of the ideas and much of the terminology introduced in section 3 are borrowed from connectionist approaches to cognition. Some examples are constraint satisfaction, trajectories as paths through a set of states, and clamping of projectable features. There are two other, perhaps deeper, similarities. As I will discuss in section 6.2, an embodied conceptualization functions as a preparatory state. Given a particular conceptualization, an organism is better prepared to act when changes in the situation easily mesh with the conceptualization than when changes do not easily mesh (i.e., we are surprised). This notion of preparedness underlies priming phenomena, and it is close to connectionist interpretations of semantic priming developed by Masson (1995) and Sharkey and Sharkey (1992).

The second deeper similarity relates to ideas of context and situated representation. For example, Smolensky (1988) discusses how a distributed representation of "coffee" will depend on whether the coffee is in a cup, in a can, or in a person. Similarly, as I discuss in sections 3.1 and 7.3, action patterns based on projectable features of an object (e.g., a Coke bottle) can mesh with action patterns underlying goals in particular contexts (e.g., drinking or fighting), so that the resulting meshed conceptualization is context-dependent.

Nonetheless, there are important differences between my use of terminology and connectionist systems. For example, connectionist accounts of semantic or meaningful information are based on conceiving of meaning as activation of a limited number of features, at least at the input layer. Unfortunately, most theorists fail to specify what the features are, and they fail to specify how those features might be learned or changed as a consequence of development. In the system that I am proposing, initial coding is not featural, but analog, in terms of patterns of possible action. Furthermore, as one learns more about the interactive capabilities of one's body, objects and actions can be imbued with new meaning: what I can do with that object now.

A second important difference concerns the nature of constraints. In standard connectionist accounts, constraints are, in Palmer's (1978) terminology, extrinsic (but see Regier, 1995, for an exception). That is, a particular constraint represents statistical, or joint-occurrence, information, not a necessary feature of the operation of the system. Thus, a connectionist system would be equally happy to learn that a Coke bottle can be used as a chair or as a weapon. In an embodied system, constraints arise because of analog coding of projectable features and their implications for human action. In Palmer's terminology, these constraints are intrinsic to the operation of the system. For example, how we think about a Coke bottle is constrained not just by particular experiences with Coke bottles, but by the actual shape and heft of the bottle, too. Thus, an embodied system would have little difficulty understanding how a Coke bottle could be a weapon, but it would balk at learning that it could be used as a chair.

These differences are not unique to my proposal. Lakoff (1988) argues that connectionist systems need to be grounded in the body to give meaning to connections and constraints. As an illustration, he notes that phonology is not arbitrary; instead, it is constrained by the muscles, shapes, and control of articulation. Shepard (1988) makes a related point regarding the abilities of connectionist systems to self-organize and generalize: "[N]ontrivial self-programming can take place only if some knowledge about the world in which the system is to learn is already built in. Any system that is without structure has no basis for generalization to new situations" (p. 52). How the body can interact with the world provides just such a basis for generalization.

These comments should not be taken to mean that an embodied system cannot be simulated using connectionism. In fact, it may well be that connectionism will be the surest route to formalizing these ideas. Nonetheless, it will have to be a connectionism that differs from the sorts currently in use.

4. Memory in the long term and in the short term

The system described so far seems to be useful for negotiating the environment, and it seems to correspond to what some have called semantic (Tulving 1983) or generic (Hintzman 1986) memory. Where is episodic memory, that is, our memory for particular, personal experiences? The answer: the same place. I propose that episodic recollection is a type of pattern completion via meshed bodily constraints on action. Furthermore, the episodic character, the feeling that a memory is personally relevant, arises from suppressing clamped projectable properties of the environment. In this case, conceptualization is driven by trajectories rather than by changes in the environment.

To some cognitive psychologists, this idea will seem wrong on the face of it: it denies the difference between episodic and semantic memory; it denies the idea that episodic memory is temporally organized; it provides no distinction between short-term and long-term memory. Before describing how the idea seems right, I will briefly address why these problems are more apparent than real.

4.1. Episodic and semantic memory

I am explicitly equating episodic and semantic memory in the sense that there are no separate episodic and semantic memory systems, hierarchically arranged (Tulving 1984) or otherwise. Of course, phenomenal memories differ in content, accessibility, and so on. But those differences do not imply separate systems. Whereas this equation of memory systems may have been controversial 10 years ago, data and mainstream memory theorizing are now moving in this direction. In short, there is little data to support a distinction between a memory system devoted to personal experience and one devoted to general knowledge (McKoon et al. 1986). What appeared to be strong evidence for a memory organized by "semantic" dimensions (Collins & Quillian 1969), is now known to reflect frequency of experience (Conrad 1972). Evidence that was taken to indicate the storage of prototypes (Posner & Keele 1968) in semantic memory is now taken to reveal the operation of retrieval processes that can average experiences (Hintzman 1986; McClelland & Rumelhart 1986). Priming effects that were thought to reflect the spread of activation along permanent semantic links can be easily demonstrated for newly learned (hence episodic) information (McKoon & Ratcliff 1986a). Thus the distinction between episodic and semantic memory probably reflects a difference in the frequency with which the memories are used, the methods of assessment, and the content of the information, rather than any intrinsic differences in memory systems.

4.2. Temporal organization of episodic memory

If the framework that I have described is the only memory system, then it explicitly denies a tenet of theorizing about episodic memory: memory is a record of events that maintains some semblance of temporal order (see, e.g., Murdock's [1974] conveyor belt model or Glenberg & Swanson's [1986] temporal distinctiveness theory). Almost assuredly, the tenet that episodic memory maintains order derives from the fact that temporally distant information is harder to remember than recent information. This fact does not demand a theoretical explanation that maintains time as a dimension of memory, however. In fact, Friedman (1993) presents a convincing case that episodic memory is not organized temporally. First, there is little priming between temporally contiguous but otherwise unrelated experiences. Second, memory for time of occurrence of events is not only inaccurate; it shows nonmonotonic scale effects. That is, memory for when an event occurred may be accurate for the day, inaccurate for the month, accurate for the season of the year, inaccurate for the year, and accurate for the decade. Third, as Friedman discusses, for most of human history, memory based on a linear dimension of time would serve little useful purpose. Instead, a memory organized by functional significance or by recurrent events (seasons, migrations, life cycles) would seem to have much greater adaptive significance.

4.3. Short-term memory

The idea of a single memory system seems wrong in that there is no mention of separate processes for long-term memory and for short-term or working memory. Much of the evidential basis for a separate short-term store (or working memory, according to Baddeley, 1990) has been eroded. For example, the "recency effect" is the enhanced recall of items from the end of a list. Because it was thought to be easily disrupted by a short period of distraction, it was taken to be a hallmark of short-term store. We now know, however, that recency effects can be very long-term (Glenberg 1984; Greene 1986; 1992). Another supposed hallmark of a separate store is acoustic/articulatory encoding (e.g., Hintzman 1967). That is, short-term store was believed to code information along acoustic/articulatory dimensions, whereas long-term store coded "semantic" information. However, demonstrations of meaning-like coding in short-term situations (Shulman 1972), as well as long-term memory for articulatory and orthographic information (e.g., Hunt & Elliot 1980) deny this simple distinction. Also, the quick forgetting demonstrated using the Brown-Peterson distractor technique, is now known to reflect a combination of poor initial coding (Muter 1980) and interference from previously studied material (Keppel & Underwood1962; Watkins & Watkins 1975).

What are we to make of the impressive body of information on apparently separate short-term modules (e.g., Baddeley's [1990] articulatory loop, phonological store, and visual/spatial sketchpad)? An alternative theoretical position is to consider the evidence as indicative of skills and strategies effective in particular domains (cf. Kolers & Roediger 1984), rather than of separate modules. This skill-based alternative can easily accommodate findings that might otherwise be interpreted as evidence for new working memory modules. As one example, Reisberg et al. (1984) demonstrated an increase in "working memory capacity" by instructing subjects how to use their fingers to code numbers in a memory span task. This evidence might be interpreted as evidence for a new "finger-control" module, but it seems more sensible to view it as a newly learned skill. As another example, Carpenter et al. (1994) speculate that there may be separate working memory capacities for language production and language comprehension. Again, the alternative that different skills are involved in comprehension and production would seem to more easily accommodate the data.

Nonetheless, one must come to grips with our intuitions of immediate access to some information and difficulty in recovering other information. Consider this proposal. Memory and the perceptual/action system are designed to produce a meshed conceptualization (possible actions) for current stimulation. It is this constantly changing conceptualization (changing because the stimulation changes in response to action) that gives the illusion of a short-term memory. Because the current conceptualization updates memory and provides the starting point for future conceptualization, it will have a strong influence on performance over the next few moments (as does a short-term memory). Distraction (a changing environment) does cause a disruption in short-term behavior because it produces a forced change in the current conceptualization. Limits on the "capacity" of a short-term store are simply the limits on coherent conceptualization.

This framework also rationalizes some aspects of rehearsal and control of thought. In particular, it seems that some sort of cyclical activity is needed to maintain information in the forefront of consciousness. Baddeley (1990) discusses this as an articulatory loop that must reactivate the decaying contents of a phonological store. But if memory is like a box that holds items of information, why should cyclical activity be necessary? The answer comes from the nature of trajectories. They are not static memory traces; they are reinforced changes from one conceptualization to the next. Thus, there is no holding of trajectories in mind. Instead, to maintain a thought or a conceptualization in the absence of clamped projectable properties, it is necessary to reuse a trajectory, or to replay the same scene over and over.

5. Memory in two modes: Automatic and effortful

The major function of memory is to mesh constraints on action based on nonprojectable properties with constraints from projectable properties. This is an automatic function of memory in the sense that it is not under conscious control, and it corresponds rather directly to recent work on indirect or implicit memory. There is also an effortful mode of memory. Effortful suppression of projectable properties allows conceptualization to be guided by trajectories. The resulting conceptualization is what underlies personal, autobiographic, conscious recollection.

5.1. Memory's automatic contribution to conceptualization

When we are walking the path home, we do not need to consciously recall which way to turn at each intersection; when we recognize our children in a crowd, it is not because we have subjected each face to a conscious check; and as we read each word in a sentence, there is no need to try to remember back to when we might have last encountered a similar-looking pattern in order to ascertain the meaning of the word. Memory is automatically, that is, without intention, creating a mesh between the projectable properties (the path, the faces, the letters) and patterns of interaction controlled by nonprojectable properties. Research on indirect or implicit memory (Roediger 1990; Roediger et al. 1994; Tulving & Schacter 1990) is tapping this automatic mode of functioning.

Indirect tests of memory do not require conscious decisions that something is remembered. Instead, the tests often measure some form of repetition priming, that is, the extent to which previous exposure to a stimulus facilitates current processing. For example, a list of words (or pictures) can be presented in phase 1 of a repetition priming experiment. In phase 2, subjects are asked to identify degraded stimuli, some of which occurred in phase 1. Repetition priming is the phenomenon that identification of stimuli actually presented in phase 1 is superior to identification of stimuli presented for the first time in phase 2. This finding occurs whether or not the subjects are attempting to remember anything about phase 1 (e.g., Jacoby & Dallas 1981; Weldon & Roediger 1987). A more conceptual form of indirect memory can be measured by, for example, presentation of a word and the later choice of that word as an answer on a test of knowledge (Blaxton 1989). Among the many interesting findings generated by this research, several may be particularly important. First, repetition priming can be of very long duration. It is not unusual to be able to demonstrate positive effects over weeks and months (Sloman et al. 1988). Second, repetition priming effects are often sensitive to presentation and test modality. For example, pictures prime pictures more than pictures prime words, and vice versa (Weldon & Roediger 1987). Third, people with dense amnesia often perform equivalent to nonamnesics on indirect, repetition priming tests (e.g., Musen & Squire 1991). I address this last finding in section 5.2.4.

Jacoby (e.g., Jacoby et al. 1993) has made the case that much of repetition priming is due to an automatic component. Jacoby characterizes this component as "familiarity" that arises from "perceptual fluency." In the embodiment framework, the automatic component of memory is the contribution of embodied memories to conceptualization of the current environment. It is a type of perceptual fluency in that it affects how aspects of projectable properties are conceptualized. Because embodied memories do not change the clamped environment, the automatic operation of memory does not help one to literally see more clearly (that is, with greater acuity): it helps one instead understand the environment. That is why repetition priming has negligible effects on accuracy (in the signal detection sense of ability to discriminate) while affecting interpretation (or bias; Ratcliff & McKoon 1993; Ratcliff et al. 1989).

Repetition priming is modality specific because it is often based on clamped projectable properties. For example, consider an experiment in which both pictures and words are presented and later subjects must identify the objects in fragmented pictures. To identify the pictured object, subjects must use their memories to mesh with the projectable fragments. Clearly, features of the letters used in spelling the name of the pictured object are irrelevant to this task, so little priming is expected or found between reading words in phase 1 and identifying pictures in phase 2 (Weldon & Roediger 1987).

Use of trajectories may underlie conceptual forms of repetition priming as well. For example, presentation of "Amazon" in phase 1 will facilitate answering "What is the longest river?" in phase 2. Clearly, words are more than just marks on a page. In reading "Amazon" we think about what rivers are in terms of swimming, fording, and so forth. This cognitive activity reinforces trajectories from the word "Amazon" to these activities. Later, in comprehending the question "What is the longest river?" we may create a similar conceptualization of rivers. Given the previously reinforced trajectories, the embodied conceptualization of Amazon is easily reachable (that is, meshes with) the embodied conceptualization of "longest river."

5.2. Effortful memory

In section 3.4, I discussed the idea that multi-step prediction requires suppression to loosen control of projectable properties on conceptualization. I suggested that suppression is dangerous because projectable properties that should be controlling action (such as walking) are ignored. This analysis leads to several suggestions. First, because suppression is dangerous, it is effortful. The effort is a warning signal: Take care; you are not attending to your actions! Also, the effort forces us to use suppression conservatively. Second, there are behavioral indices of suppression. For example, when working on a difficult intellectual problem (which should require suppression of the environment), we reduce the rate at which we are walking to avoid injury. Third, autobiographical memory arises from suppressing the environment: once the environment is suppressed, conceptualization is controlled by trajectories and bodily constraints on mesh rather than the projectable features of the environment. Thus recollection is similar to prediction. Both are effortful, both depend on trajectories, and both are constrained by the body. On this view, conscious recollection is a type of pattern completion that is inherently reconstructive (Bransford 1979).

The effort in suppressing the environment can be used to explain standard and nonstandard facts of episodic memory. As an example of the latter, consider the phenomenon of averting one's gaze when engaged in a difficult memory task. When recollection is difficult and unrelated to the current environment, clamping of the environment must be suppressed to allow internal control over conceptualization. Closing one's eyes or looking toward a blank sky are actions that help to suppress the environment by eliminating projectable properties that would normally be clamped. Glenberg et al. (1995) have demonstrated that people avert their gaze when working on moderately difficult recollection tasks (but not easy ones) and that this behavior enhances accurate remembering.

5.2.1. Encoding paradigms. How people are instructed to think about (i.e., encode) to-be-remembered stimuli greatly affects success in conscious recollection. Interactive imagery (e. g., Bower 1970), levels of processing (Craik & Lockhart 1972), and generation paradigms (e.g., Slamecka & Graf 1978) all illustrate this phenomena. As an example, consider the use of interactive imagery to memorize arbitrary pairings such as "lamp – 88." Success in remembering the pairing is greatly enhanced by imagining, say, a neon light shaped to form the digits 88, compared to rote rehearsal of the words.

Standard analyses based on the notion of abstract, amodal symbols have difficulty with these effects because the abstract propositional description of the to-be-remembered stimuli are the same regardless of the encoding task. That is, for both rote rehearsal and imagery one must remember the same thing, "lamp – 88." On an embodied account, constructing an image requires meshing a conceptualization of a lamp with that of 88. The changes in conceptualization from the orthographic stimulus to the meshed image update memory trajectories. Later, partial information such as "lamp" may be given as a cue for the pair. Reading and conceptualizing "lamp" will be along the lines of the reinforced trajectory. Importantly, the analog shapes of the successive conceptualizations increasingly specify the final conceptualization of the neon 88. (Interestingly, the ability of young children to use this sort of strategy depends on those children manipulating the objects [Varley et al. 1974].) Contrast this with a situation in which the encoding task is not interactive imagery but simply reading the two words or engaging in rote rehearsal. There is little mesh created by reading the words: the words are pronounced separately so that there is not a physical mesh such as that produced by coarticulation. Furthermore, there is no conceptual mesh in terms of the patterns of interaction between the two objects named by the words. No wonder that little can be reconstructed from the cue "lamp" alone.[5]

5.2.2. The feel of memory. Why is there a phenomenal feel to conscious recollection? Why does the content of memory appear to reflect personal experience? Why doesn't perception or automatic uses of memory feel that way? The feel of memory comes from the effort of suppressing the environment and the consequent knowledge that conceptualization is being driven by previously created trajectories. This process has the feel of personal memory because of our belief that the achieved conceptualization is free from domination by the projectable properties of the environment.

5.2.3. Suppression and amnesia. To the extent that skill in suppressing the environment develops, it suggests explanations for several related phenomena. Consider first infantile amnesia. There is now good evidence that the phenomenon is not as dramatic as initially proposed. In particular, there is evidence for good early retention when it is tested nonverbally. To the extent that a test trades on the automatic operation of memory, it should reveal substantial memory for the infants. In addition, both Howe and Courage (1993) and Nelson (1993) have suggested that what changes around ages 2–3 is the child's ability to code and retrieve information in ways understandable to adults. For Howe and Courage, this amounts to developing a self-concept useful in organizing and retrieving memories. For Nelson, this amounts to learning how to use narrative structures to organize and relate the child's narrative (i.e., self) experiences. Nelson notes that this learning is typically guided by interactions with adults.

Consider the following explanation for the correlation between development of self-concepts and the emergence of recollective experience. Recollective experience requires (1) suppression of environmental input, (2) use of self-generated information (trajectories) to drive the conceptual system, and (3) an attribution that the resulting conceptualization is due more to internally-guided than externally-guided construction. I suspect that a major factor in the development of a concept of self is just the ability to suppress environmental information. Until that skill is mastered, conceptualization is controlled by the clamped environment; after that skill is mastered, conceptualization can be guided by oneself. That is, one can control what one is thinking about. Furthermore, development of language (by interacting with adults) may well be an important experience in learning how to control suppression and recollective experience: development of language facility is tantamount to learning to use words to guide conceptualization. Thus skill in suppressing the environment is facilitated by language, and this same skill supports recollective experience and the development of a notion of self.

If recovery from infantile amnesia requires learning to suppress the environment's control of conceptualization, perhaps adult anterograde amnesia results from a traumatically induced reduction in the ability to suppress. Two findings are consonant with this speculation. First, amnesics exhibit poor performance on explicit tests of memory requiring conscious recollection, but not on implicit tests of memory (e.g., Musen & Squire 1991). According to the framework developed here, it is the explicit, recollective tests that require suppression of the environment, not the implicit, automatic tests. Second, although there are numerous explanations of amnesic abilities and disabilities, none provides any explanation for the feel of memory. That is, when it can be demonstrated that amnesics are using past experience as effectively as normal rememberers (on implicit or automatic tests), why don't the amnesics have any sense that they are remembering? Of course, the same question can be asked of the normal rememberers: When they perform well on an implicit (automatic) memory task, why do they lack the experience of remembering? For the normal rememberers, the feel of memory comes from an effortful suppression of environmental input and the attribution that conceptualization is controlled by the self. When conceptualization is controlled predominately by the environment, as when performing implicit memory tasks, it does not feel like memory. And, this is the usual state for amnesics.

5.3. The Kolers-Roediger program

Other memory researchers have proposed ideas similar to the framework outlined here. A particularly good example is the "procedures of mind" approach (Kolers & Roediger 1984). In fact, the similarities between the approaches are striking. Kolers and Roediger suggest that many distinctions popular in memory theorizing reflect different skills rather than different memory stores. Importantly, while championing a symbolic account, Kolers and Roediger note that abstract, meaningless symbols will not do. Instead, they prefer symbols that retain characteristics of how they were acquired: "We claim that knowledge of objects is specific to the means of experiencing them" (p. 419). Thus the symbols are in some ways analogical, as I have advocated. Kolers and Roediger also object to modeling knowledge using psychologists' propositions because "descriptions of events rarely if ever tell a person what to do about the events described" (p. 439). Of course, conceptualization in terms of patterns of interaction with the environment was designed to overcome this problem. Finally, Kolers and Roediger eschew the idea that memory is purely a conscious experience. They propose instead that the most important contribution of memory is to the automatic execution of skills.

Given the similarities between the Kolers-Roediger program and the embodiment framework, are there any differences? One is my emphasis on meaning, that the meaning of an object or event is a meshed pattern of possible action. A second difference is the idea of mesh itself. The mesh between the projectable features of an object and nonprojectable features from memory can dramatically change the meaning of an object or event (see sect. 7.3). This sort of combination is made possible by considering both the projectable and the nonprojectable features to be patterns of action that can combine as physical, bodily actions can be combined. If separate patterns of action can be forced into a coherent pattern of bodily movement, then we can comprehend the combination; in this way rocks, twigs, and soil combine to form a path for a particular person. It is not clear how the skills described by Kolers and Roediger can be combined except through concatenation. Finally, I am attempting to extend the analysis to language comprehension.

6. Language comprehension

I have argued that the same memory system underlies perception, semantic memory, and episodic memory. The meaning of a situation is given by a meshed pattern of possible actions, and that is an embodied conceptualization. The system is updated whenever there is a change in conceptualization. Thus, the environment is comprehended as a series of transformations of embodied conceptualizations. I propose a similar characterization of language comprehension. Language comprehension, like comprehension of the environment, is the successive transformation of conceptualizations that are patterns of possible action.

Like recollective memory, language comprehension requires suppression of the environment, but in two ways. First, the content of the language may have nothing to do with the physical environment in which the language is expressed. Lectures, for example, have little to do with the lecture hall. Thus, we must suppress projectable properties of the environment to comprehend language. Second, and perhaps more difficult, we must also suppress the projectable properties of the language signal itself. That is, to understand the language, we cannot focus on the shapes of the letters, the patterns of spaces between the words on the page, or the chirps and squeaks of the speech signal.

Several predictions follow from the claim that language comprehension requires suppression of projectable properties. The first is that good language comprehenders should be good at suppressing the environment. Second, good language comprehenders should be good recollectors, given that both require suppression. Third, unavoidable or nonsuppressable properties of the environment should disrupt language comprehension. Of course, distracting noise or sights will impair comprehension, but a more subtle effect is discussed by Sanford and Moxey (1995). They note that many types of regularity seem to disrupt language comprehension, and hence those regularities are classified as instances of poor style. Repeating patterns of articulation (McCutchen & Perfetti 1982), phonemes (e.g., "Crude rude Jude chewed stewed foods," from Baddeley & Hitch, 1974), and excessive repetition of particular sentence structures all seem to slow comprehension. Sanford and Moxey propose that these regularities contribute to the computation of coherence, but because the regularities "are irrelevant to the writer's message," the processing rapidly runs to a halt. Here is a different (but related) suggestion. The regularities are regularities in the projectable properties of the environment. The regularities capture attention and contravene the suppression required for conceptualization and comprehension of what the language is about. That is, instead of paying attention to the meaning of the language, we start to pay attention to the language itself.

Fourth, because language comprehension is seen as a general skill, performance in language comprehension tasks should correlate with performance in other comprehension tasks. Gernsbacher et al. (1990) have demonstrated just this.

6.1. Mental models in language comprehension

Suppose, as Taylor and Tversky (1992) claim, that at least one of the functions of language is that "language is a surrogate for experience" (p. 495). If language is to be a useful surrogate, it must make contact with the sorts of embodied representations that we use to characterize the world, and I propose that language does this relatively directly: we understand language by creating embodied conceptualizations of situations the language is describing. In fact, this is the only reasonable story for how we can manage to learn from language.

This story works when language is being used as a surrogate for events that are completely absent and when language is being used to enhance current experience. Consider a situation in which a mother is instructing her child. Representations derived from the language must smoothly integrate (mesh) with representations derived from other aspects of the environment. Thus, being told "That plate is hot" must modify the embodied representation of the plate in order to modify interactions with the plate. Tannenhaus et al. (1995) demonstrated just this sort of smooth and immediate integration. Their subjects responded to verbal commands (e.g., "Put the apple on the towel in the box") to move actual objects arrayed before them. Eye movements were monitored during the task. Movement of the eyes to referent objects was very closely time-linked to the verbal command. Additionally, the environment was used to smoothly disambiguate the language. For example, when considering the language alone, the phrase "on the towel" is temporarily ambiguous. It may describe the location of a particular apple (the apple that is on the towel) or where an apple is to be put. Indeed, when there was only one apple in the array, the eye movements indicated uncertainty. When the array contained two apples (one on a towel and one on a napkin), however, then the phrase "on the towel" will almost certainly be meant to specify a particular apple, not a location in which to put the apple. In the two-apple case, the eye movements indicated no uncertainty. Thus, understanding of the sentence made virtually immediate use of the context, in contrast to notions of modularity of syntactic analysis. This sort of integration is possible if both the environment and the language are understood as embodied patterns of action.

This sort of reasoning is compatible with work on mental-model theory. The basic claim of mental-model theorists is that language comprehension results in representations of what the language is about, not representations of the language itself (e.g., chirps, words, sentences, or propositions). Johnson-Laird (1989, p. 488) writes that a mental model is a representation of a situation such that "its structure corresponds to the structure of the situation that it represents." With an important emendation, this definition can apply to the sorts of representations I have been describing. It seems unlikely that the literal, in-the-head structure of the representation could actually be isomorphic to the structure of the situation (in contrast to Glenberg et al. 1994).

6.1.1. Mental models from language and perception. Embodied mental models are "models" in the following sense: a model is useful if it can be used to predict the effect of an action in the real situation being modeled. One way to ensure accurate prediction is to build into the model spatial-functional constraints analogous to those of the real situation. For example, a useful model of an airplane will have wings that generate lift when it interacts with air currents, much like a real airplane's wings generate lift. Similarly, a mental model built from language incorporates embodied constraints on action like those derived from comprehension of the environment. This sort of mental model is useful to the extent that it incorporates enough constraints on action to derive predictions.

One difference between embodied models derived from language and those derived from perception is how completely the meshed pattern of possible actions constrains further action and prediction. The multiple projectable properties of the environment, because they are clamped, tightly constrain conceptualization and action. In language comprehension, the patterns of possible action that contribute to a meshed conceptualization are much looser. That is, language is ambiguous in not specifying exact parameters of spatial layout, force, and so forth (Talmy 1988). Thus, conceptualizations derived from language do not constrain action as effectively as conceptualization derived from the environment. This is one reason for differences between expert and nonexpert comprehension. The expert's model incorporates tighter constraints on action based on trajectories derived from experience. Given the same text, the expert is able to take (appropriately constrained) actions that leave the nonexpert baffled. This effect of expertise in language comprehension parallels the expert guide who can spot the trail (based on trajectories derived from experience) while the novice sees only twigs, soil, and rocks.

6.2. Comprehension, prediction, and priming

I have argued that embodiment in terms of action patterns is just what is needed to facilitate interaction with the environment and prediction. Is prediction an important component of language comprehension? Clearly, language would be of little use if it did not enable better prediction of the environment. But, the question asked in the literature on comprehension is different: Does a mental model serve as a source of "on-line" predictions about the upcoming text? In response to this question, one might ask "Should it?" If the point of language is to be a surrogate for experience, that is, to help us take appropriate action in real situations, it makes little sense to expect the representation to predict upcoming text: it should predict changes in the situation. In fact, McKoon and Ratcliff (1992) reached the conclusion that there is little evidence that people make predictive inferences while reading.

Nonetheless, Keefe and McDaniel (1993) presented convincing evidence for what appeared to be just those inferences. Using the standard logic based on psychologists' propositions, Keefe and McDaniel reasoned that pronunciation of a probe word would be faster if the word were part of a recently made inference than if not. For example, subjects read a sentence such as "After standing through the three-hour debate, the tired speaker walked over to his chair." Following the sentence, subjects pronounced the probe word "sat." Supposedly, pronunciation of the probe word would be facilitated by its having been incorporated into an inferred proposition such as "The speaker sat down." In the control condition, for which an inference including the word "sat" is unlikely, subjects read a sentence such as "The tired speaker moved the chair that was in his way and walked to the podium to continue his three-hour debate." Indeed, pronunciation of the probe word was faster in the predictive condition than in the control condition. In fact, pronunciation of the probe following the predictive sentence was as fast as when the sentence explicitly continued with "and (he) sat down." Murray et al. (1993) used a similar methodology and produced a similar effect when the "to-be-inferred event was in focus at the time of test" (p. 464). Why is evidence for predictive inferences found only shortly after the predicting sentence? Does this evidence demonstrate that subjects were attempting to predict the upcoming text?

Consider an interpretation of these findings from the point of view that the goal of language comprehension is the creation of a conceptualization of meshed patterns of action. In this case, interpretation of a word, phrase, or sentence consists of meshing the actions consistent with that bit of language with the patterns of action derived from previous text. After comprehending Keefe and McDaniel's predictive sentence (" . . . the tired speaker walked over to his chair"), only certain actions can be easily meshed with the conceptualization. For example, the actions implied by

"He began to rake the leaves" does not mesh. In contrast, the action of sitting will mesh, and hence interpretation and pronunciation of the probe word "sat" is quick. After comprehending Keefe and McDaniel's control sentence (" . . . walked to the podium to continue his three-hour debate"), the action of sitting meshes about as well as the action of raking, and so pronunciation of the probe word "sat" is slow.

This interpretation of the results is radically different from that used in standard propositional accounts of inference making. In the standard account, an inference corresponds to encoding a new proposition, something akin to "He sat down," and one would expect some effect of this proposition well after it was encoded. The embodied account is that no "inference" in the standard sense is made. Instead, the action of sitting in the chair is temporarily compatible with the embodied conceptualization. When the situation changes, some actions are no longer compatible with the embodied conceptualization and the "inference" is no longer operative. This notion of temporary compatibility (how well the probe will mesh with the other constraints) may well underlie McKoon and Ratcliff's (1986b) data for "partial" encoding of predictive inferences, and the temporary effect noted by Keefe and McDaniel (1993) and Murray et al. (1993). Of course, this is not to say that language comprehenders might not make forward inferences if induced to do so (e.g., one might be asked to "guess what happened next"). These sorts of inferences are just the sort of predictions discussed in section 3.4. However, given that language, unlike the environment, only loosely constrains action, it is more reasonable to wait until what happens next is described.

The procedures used by Keefe and McDaniel (1993) and Murray et al. (1993) follow from the more general notion of "semantic priming." The standard idea is that processing causes activation to spread along permanent links to semantically related information, and this spread of activation speeds processing of the related information. Thus, reading the prime, "doctor" speeds the decision that the target "nurse" is a word (Meyer & Schvaneveldt 1971). The standard interpretation of semantic priming is embarrassed by demonstrations that priming need not be due to permanent links (McKoon & Ratcliff 1986a), and that the effective relation between the prime and the target may have little to do with the presumed semantics of categories (Sheldon & Martin 1992). Might semantic priming be another instance of the operation of mesh? Assume that language comprehension is an attempt to mesh action suggested by the current word or phrase with the pattern of actions already established. Thus, in thinking about what a "doctor" is (the actions taken by a doctor and how one interacts with a doctor), one sets up a conceptualization in which the actions suggested by "nurse" will mesh. Hence, processing of "nurse" is facilitated relative to the case when it is preceded by an unrelated prime word such as "rake."

A report by Hess et al. (1995) strongly suggests that semantic priming reflects something akin to mesh rather than spread of activation along permanent links. Their subjects read a sentence describing a local context, such as "To complete the assignment, the English major wrote a . . . " and they then read a target word such as "poem." The question of interest was whether the local context ("English major") would facilitate reading of the target ("poem") regardless of the global situation. This would be expected if priming reflects activation along permanent links such as between "English major" and "poem." In one global situation, the English major was working on a writing assignment, and, indeed, reading of "poem" was facilitated relative to a neutral condition. In another global situation, however, the English major was working on a computer program. In this case, reading the target "poem" was not facilitated. The implication is that priming reflects ease of integration (mesh) of concepts, not spread of activation along permanent links.

6.3. Space in language comprehension

If embodied conceptualization is a pattern of possible actions, then it must incorporate information about spatial layout, because actions are played out in space. The data from several research projects investigating spatial coding in mental models provide this evidence. First, there have been investigations of how language can lead to accurate, analogical representations of a described layout. For example, Denis and Cocude (1989) had subjects read texts describing the layout of objects on a circular island. After several readings, they were asked to mentally simulate scanning from one object to another. The main finding was of a correlation between distance (if the objects had actually been arrayed) and simulated scanning time. Morrow et al. (1989; see also Rinck & Bower 1995) had their subjects memorize the layout of the rooms in a building (and objects in the rooms) before reading a passage describing the movements of a protagonist throughout the building. Morrow et al. measured time to verify that particular objects were located in particular rooms as a function of the protagonist's described movements. Interestingly, when a described movement (e.g., from Room A to Room C) required passage through an unnamed room on the path of the movement, verification of objects located in the unnamed room was faster than verification of objects in other unnamed rooms off the path. Apparently, subjects were using the spatial information in the building layout while comprehending the text.

Glenberg et al. (1987) demonstrated the contribution of spatial information to language comprehension without prememorization. Subjects read texts describing a protagonist and a target (e.g., a jogger and a sweatshirt) that were either spatially dissociated (the jogger took off his sweatshirt before jogging) or spatially associated (the jogger put on his sweatshirt before jogging). After a sentence or two in which the protagonist was kept foregrounded but the target was not mentioned, accessibility of the target (e.g., the sweatshirt) was greater in the associated condition than in the dissociated condition. (McKoon and Ratcliff, 1992, have argued that this effect may reflect a type of salience. See Glenberg and Mathew, 1992, for a counter to this interpretation.) Along similar lines, O'Brien and Albrecht (1992) demonstrated sensitivity to spatial location of characters in a text well after the spatial information was introduced. Thus, several sentences after reading, "As Kim stood outside the health club, she felt a little sluggish," readers would balk at the sentence, "She decided to go outside . . . "

One interpretation of these findings is that they reflect a representation that is analogical with respect to space, that is, that the mental model is constructed in an inherently spatial medium. This seems unlikely. Langston et al. (in press) have demonstrated that spatial contiguity, in the absence of other relations, does not have strong functional consequences. In these experiments, subjects read (or heard) texts describing the spatial layout of four objects. In outline, the texts read, "B is to the right of A, C is under B, D is to the left of/right of C." The last sentence in the "close" condition was "D is to the left of C," so that the spatial layout of the objects has D under (that is, close to) A. The last sentence in the "far" condition was "D is to the right of C," so that object D is separated from A. After reading, subjects were tested for availability of the target object, A. If space is represented analogically, and if closeness in that space has functional consequences, then the target should be more available in the "close" condition than in the "far" condition. We tested for availability of A using speeded recognition of A and time to read a sentence referring to object A. Availability of A was never reliably affected by the condition ("close" versus "far"), even though memory for the spatial layout was well above chance.

How are we to understand the contrast between Langston et al. (in press) and the other research that clearly points to an appreciation of spatial relations during comprehension? One possibility builds on the distinction between mental models encoding space in a spatial medium and mental models encoding spatial-functional action and thereby representing space incidentally. Consider a reinterpretation of Glenberg et al.'s (1987) jogger on this spatial-functional account. When the jogger puts on the sweatshirt, there is a mesh between the jogger and the sweatshirt: wherever the jogger goes, the sweatshirt goes too. Then, later facilitation in reading "sweatshirt" is not due to spatial closeness of the jogger and the sweatshirt, but their functional relatedness. On this account, the texts used by Langston et al. (1995) resulted in encoding patterns of action between the reader (projected into the situation) and each object (A, B, C, and D). Given that spatial layout is not encoded directly, there is little reason to suspect that availability of object A will depend on its spatial distance from object D. In other words, spatial distance only matters when it corresponds to functional distance.

The proposal that embodied mental models reflect a structured space (that is, a space structured by possible actions) rather than a uniform space, is consistent with several research programs. McNamara (1986) and McNamara et al. (1989) adduce evidence that spatial memory is structured and perhaps hierarchical. Bryant et al. (1992) argue that the time needed to answer questions about memorized spatial layouts reflects an embodied encoding. They find that retrieval of information aligned on the head/feet axis is faster than for the front/ back axis, which in turn is faster than for the left/right axis. They interpret these differences as reflecting asymmetries of the body.

6.4. Comprehension of nonconcrete descriptions

If language comprehension is in terms of meshed action, how is it that we come to understand abstract language that is not about concrete objects or situations? Here I adopt a version of Lakoff's (1987) spatialization of form hypothesis. Namely, we understand abstract situations by conceptualizing them in concrete ways.

Talmy's (1988) analysis of force dynamics is a good example of how abstract concepts can be given a bodily interpretation. He notes that we can conceptualize forces as one entity (an agonist) acting against another (an antagonist) and that the entities may have different strengths and different tendencies (either toward action or toward inaction). Importantly, these basic entities and relations can be based on bodily experiences such as pushing and being pushed, moving objects, and so forth. Talmy suggests that our understanding of causal terms (e.g., "because") reflects an agonist's tendency (toward action or inaction) being overcome by an antagonist. Thus, we understand the sentence "The ball kept rolling because of the wind blowing on it" as an agonist (the ball) with a tendency toward inaction being overcome by the stronger antagonist, the wind. Talmy also demonstrates how this analysis can be extended to psychological instances of causation, social references, and interpretation of modals such as can, may, must, and should. Thus, interpretation of "John cannot leave the house" comes about from assigning John the role of an agonist whose actions are blocked by the unmentioned but stronger antagonist of social or physical constraint. In the case of "should not" the antagonist is a value or belief, and so on. The point is that what has traditionally been treated as prototypically abstract (e.g., cause, force, modality), can be conceptualized in embodied terms, and in so doing brings out important similarities in our understanding of these concepts.

Bowerman (1982; 1985) discusses a number of cases of children's late speech errors that imply an understanding of the more abstract in terms of the concrete. Bowerman classifies an error as a late speech error when it occurs after a linguistic form has been used correctly and when the error does not mirror adult usage. She argues that, given these constraints, the error arises from an overextension of the adult-sanctioned relation between domains. Typically, the spatial domain is extended, so that the pattern of errors is asymmetrical across domains. For example, children import spatial terms into other domains, but rarely vice versa. Bowerman reports that children use the spatial verbs "put" and "take" to describe state changes, such as "put the door locked." Also, it is commonplace to use spatial terms when describing time, for example, "the week before" or "between spring break and finals week." Is this just a convention, or does it reflect a conceptualization in which we understand time by using spatial dimensions? The late error "behind the dinner" for ("after the dinner") would seem to imply the latter (Bowerman 1982; 1985). Finally, Bowerman describes the use of spatial terms to speak of nonspatial dimensions, such as looseness of teeth ("They're all the same length of loose") and temperature of water ("I want it the same size as Christy's was").

One final example should suffice. Suppose that we conceptualize abstract trait information (e.g., that Marta is energetic) as a meshing between the person and the trait. That is, the actions that Marta might perform are meshed with "energetic" so that her actions are constrained to be energetic. To test this notion, Fernandez and Saiz (1989) had subjects read texts describing the association or dissociation of a main character and a trait. In a text about Marta, an expert in international business, the critical sentences in the associated condition read (in translation from the Spanish):

(1) She has just been appointed to a government position. Almost everybody considers her an especially energetic person.

Whereas the critical sentences in the dissociated condition read:

(2) She has just been appointed to a government position. Almost nobody considers her an especially energetic person.

After reading one or two filler sentences in which Marta was kept foregrounded (but her energy never mentioned), accessibility of "energetic" was evaluated by speeded recognition of the probe "energetic." On average, responding in the associated condition was over 100 milliseconds faster than responding in the dissociated condition. Thus, readers may well have been conceptualizing abstract trait information as embodied and meshed with an embodied conception of Marta.

6.5. Embodiment and coherence

Some texts make sense; others do not. The ones that make sense are judged coherent. But, what produces that sense of coherence? A standard answer is that it arises from the connectedness of the psychologists' propositions underlying the text; when the propositions are connected (or can be made connected through bridging inferences; Haviland & Clark 1974) then the text is coherent. When the propositions do not connect, either bridging inferences need to be made to connect them or the text will appear incoherent.

This interpretation of coherence is wrong in several respects (see Sanford & Moxey 1995). Importantly, the account is wrong because whether or not propositions connect and how they connect depends first on interpreting the propositions against a situation. Consider the following example adapted from Sanford and Moxey:

(3) While measuring the wall, Fred laid the sheet of wallpaper on the table. Then he put his mug of coffee on the wallpaper.
(4) After measuring the wall, Fred pasted the wallpaper on the wall. Then he put his mug of coffee on the wallpaper.

A propositional analysis does not reveal that (4) is odd, and thus a propositional analysis cannot indicate "local incoherence" and cannot trigger bridging inferences to maintain coherence (see also O'Brien & Albrecht 1992). Noticing that (4) is odd arises from a consideration of the situation, that once the wallpaper is on the wall, under normal conditions, it cannot not support a mug of coffee. To state it differently, coherence is a relationship among ideas, and texts do not have ideas – only readers do.

An impressive counter to the claim that coherence derives from connecting propositions can be found in Barton and Sanford (1993). Their subjects read about an airplane crash that occurred in the Pyrenees between France and Spain. The subjects were asked for advice on where the survivors should be buried. In fact, the subjects readily offered advice; that is, they understood the text, judged it as coherent, and were ready to suggest where the survivors should be buried. Nonetheless, only about 60% of the readers noticed that "survivors" are not buried. In a second experiment, when readers were asked where to bury the "surviving dead," only 23% noticed a problem. Clearly, the readers were not forming propositions and checking them for sensibility, because "surviving dead" cannot make a sensible proposition.

An alternative account of coherence is twofold. First, coherence is a matter of degree, and in fact no bit of language is completely incoherent. Second, the degree of coherence can only be computed from the mesh of a situational representation of what the language is about.

The claim that no bit of language is completely incoherent rests on the analogy between understanding language and understanding the environment. Consider, for example, a percept of a drawing of an "impossible object." There may be no three-dimensional object that could project that two-dimensional outline. Nonetheless, the percept is not incoherent; the percept is of a drawing that has no corresponding three-dimensional realization. Percepts may be unusual or bizarre, but never incoherent because the perceptual/action system is designed to transduce patterns of possible interaction. Similarly, a random collection of words (or even phonemes or features) will be perceived coherently, perhaps as chirps and whistles, and a random collection of sentences will be perceived coherently (correctly) as a random collection of sentences.

Nonetheless, we do get the sense that some collections of sentences are not random. Sentences cohere to the extent that they produce continuous transformations (trajectories) of a meshed set of possible actions. Consider (4) again. The second sentence seems incoherent in that it cannot be incorporated into the the standard situational interpretation of flat wallpaper on a vertical wall in a gravitational field. However, if the initial model is changed so that any of these presuppositions about the situation are eliminated (e.g., the wallpaper has niches in it, the wall is not yet vertical because it will be incorporated into a doll's house, etc.), then the sentences are coherent. Another example is also adapted from Sanford and Moxey:

(5) John ate a banana. The banana was brown. Brown is a good color for hair. The hair of a dog is drunk to counteract a hangover.

Sanford and Moxey use this snippet of text to illustrate that sentences that incorporate cohesion markers (e.g., anaphoric reference) can, nonetheless, be judged incoherent. The problem is that the sentences do not update a mental model. That is, the patterns of action suggested by each sentence do not admit to smooth transformation of the mesh from one sentence to the next. Note, however, that as with the previous example, a change in the initial situation can render the sentences (more) coherent. Imagine that John engages in free association whenever he eats fruits. Then the list of sentences, as descriptions of his free-associations, seem (more) coherent. Similar examples can be constructed for film (e.g., the sequence of cuts seem incoherent unless one has the appropriate model of the film) and for events in the world (e.g., changes in the weather seem incoherent unless one has the appropriate model of weather systems). In short, coherence is a property of models (the ideas that people have), not a property of snippets of language.

A final example was taken from the abstract of a talk given in a computer sciences seminar at the University of Wisconsin–Madison.

(6) The talk will concentrate on the design of the communications subsystem [of the Meiko CS-2 MPP System]. This utilizes a "fat tree" network constructed from high performance crosspoint switches. Processing Elements interface to this network via a communications coprocessor which contains intelligence to handle virtual addressing and ensures very low message start up times.

This text may well be very coherent for its intended audience, but it is at the low-end of the dimension for me. The problem is not that the propositions do not connect. The propositional relation between "fat tree" networks and crosspoint switches is virtually transparent; similarly, it is quite clear that a coprocessor intervenes between the "Processing Elements" and the network. The problem is that I do not know what a "fat tree" network is, or what "crosspoint switches" or "Processing Elements" are. I do not know the literal shapes of these things, nor do I know the actions they can take or how I can interact with them. Because I lack that knowledge, I cannot build a coherent spatial-functional model. Presumably, crosspoint switches can be arrayed or interconnected in some way so that they make up a "fat tree" network. But for me, the mesh is missing.

The ideas (1) that coherence is a function of the mesh in an embodied model, (2) that the embodied models constructed to understand language are the same as those that underlie comprehension of the natural environment, and (3) that the purpose of perception and memory for the natural environment is to guide action, all lead to a suggestion about how to assess comprehension. Most laboratory comprehension tests require verbatim reproduction of a text, reproduction of "idea units," or speeded responding to words or phrases. A more sensible comprehension test, however, is one that requires action. To what extent can the reader take sensible action (or make sensible predictions) on the basis of the text? (6) is relatively incoherent for me because I can make so few predictions. For example, if the type of switches were changed, I don't know if that would change the network from a "fat tree" network to some other kind; if the communications coprocessor was not intelligent, I do not know if the message start up times would be slower or faster. On the other hand, (6) is not completely incoherent because there are some predictions that I can make. For example, based on knowledge of part-whole relations, I can predict that if the crosspoint switches are eliminated, there will be no "fat tree" network.

7. Conclusions

I began with a consideration of the Lakoff and Johnson program and the problem of meaning. In applying their insights to a theory of memory and mental models, the concept of embodiment becomes central. The basic claim is that an individual's memory serves perception and action. Memory meshes nonprojectable features with projectable features of the environment to suggest actions for that person in that situation. These patterns of action are what make the environment meaningful to that person. This framework provides a way to address meaning, symbol grounding, recollective and automatic uses of memory, and language comprehension.

7.1. Summary of interpretations and predictions

The framework provides alternative accounts of standard phenomena and it makes new predictions. Here is a brief review. The concept of embodied knowledge is used to address the problem of meaning and symbol grounding (sect. 1.3), why people interpret the world differently (1.3), effects of bodily activity on emotions (2.3.1), imagery (2.3.2), memory for actions (2.3.3), sensibility judgments (2.3.3), short-term behavior (4.3), and understanding in abstract domains (6.4). Mesh of patterns of action is applied to emergent features of thought (3.1), recollective memory (5.2), interactive imagery (5.2.1), interpretation of semantic priming phenomena including forward inferencing (6.2), and coherence (6.3). Suppression of projectable properties of the environment is seen as critical to multistep prediction (3.4), the feeling of memory (4.0), the decrease in physical activity when thinking (5.2), amnesia (5.2.4), correlation of language comprehension with recollection (6.0), and effects of incidental patterns on comprehension (6.0). Finally, trajectories are applied to frequency effects in memory (3.3), the nature of rehearsal (4.3), automatic uses of memory (5.1), and expertise (6.1.1).

7.2. Embodied knowledge, emotions, and social behavior

Can embodied patterns of action underlie all conceptualization? Our experiences of music, taste, and emotions all seem to have aspects that do not fit well into a spatial-functional straitjacket, and one suspects that aspects of these experiences are represented in addition to action patterns. Nonetheless, given the ease with which these sorts of experience combine with spatial-functional experience (consider the contribution of music and mood to the understanding of the action depicted in a film), it is not inconceivable that they may eventually be covered by the same sort of analysis.

Missing from the discussion is a consideration of hedonic valence and motivation to act. It is not as yet clear how pleasure and pain should be represented in an action-oriented system (but see Lang 1979). What is clear, however, is that hedonic valence affects action and how experiences become meaningful. Our understanding of pleasurable experiences is in part action-toward those experiences, whereas our understanding of aversive experiences is in part action-away. Several ideas follow. Given that action-away does not necessarily specify what the action is directed toward, it ought to be more diffused and variable than action-toward. Also, on this analysis, approach and withdrawal are not poles of a single dimension: withdrawal from one situation does not imply approach toward another. Thus our understanding of emotional experience should reflect at least two dimensions (e.g., Schneirla 1959).

Malter (in press) applies these ideas to consumer research, in particular, to impulse buying. He proposes that projectable features of a product automatically mesh with affectively charged memories (perhaps imparted by advertisements) to produce an irresistible approach-dominated conceptualization. Thus the consumer experiences a strong desire to approach and manipulate the object, and in most cases that can only be accomplished after purchase. Furthermore, Malter notes that overcoming this urge to buy requires effortful suppression of the projectable features in order to deliberately evaluate the purchase. In the face of a strong impulse to buy, however, that effort may be viewed as unattractive or not considered at all.

There is also reason to believe that an embodied, action-oriented analysis has implications for social psychology. Fiske (1992) traces the history of action-oriented theories of social cognition from James ("My thinking is first and last and always for the sake of my doing," as quoted in Fiske) to Heider (1958) to current "pragmatic" research. Fiske defines pragmatism as a framework in which "meaning, truth, and validity are determined by practical consequences [and] concrete goal-relevant actions" (p. 886).

Fiske's own analysis of social cognition is compatible with the ideas I have described, and her analysis suggests an important extension. According to Fiske (and Heider 1958), the key to social cognition is to view others not just as objects that we can affect, but as beings who can effect us in turn. Consonant with this premise, Fiske proposes that our ability to infer traits is in the service of interaction with others.

7.3. Mesh

Among the interpretations that stem from a consideration of embodied representations, the notion of mesh seems most important. Ideas mesh to the extent that the pattern of action underlying one idea can be integrated with the pattern of action underlying another. The patterns mutually modify and constrain one another because the conjoint actions must be possible given our bodies. This mutual modification of patterns of action is what underlies the construction of meaning from words whose senses are jointly modified by the contexts in which they occur.

Meshing patterns of action provides a new way of thinking about componentiality and productivity in language. As an example, consider the Coke bottle. Its shape, and thus its affordances for human action, allow it to mesh with many physical situations and goals. It can be used for storing liquid, as a cup, a doorstop, a weapon, a vase, and so on. Thus the meaning of a Coke bottle (how we can interact with it) is not fixed, but infinitely varied, depending on the context of use. Importantly, however, the meaning is in no way arbitrary or unconstrained: the meaning of the bottle is constrained by its shape (heft, fragility, etc.) and the implications of that shape for action. Thus the spatial-functional meaning of a coke bottle is componential in that it will mesh with many human contexts. Because that mesh can transform the meaning, however, its use is creatively productive.

This type of componentiality helps us to understand what Barsalou et al. (1993) term "linguistic vagary." When people are asked to describe the features of a category such as "Coke bottle," there is tremendous variability both across people and from time to time in a particular person's descriptions. Linguistic vagary should be the norm if the meaning of a concept is determined by its mesh with the context.

The idea of mesh may prove to be a concept that can replace "association." Although association has played a central role in theories of cognition, the term carries little theoretical weight. What we mean by an association is little more than a conditional probability; if B is associated with A, then $P(B|A) > P(B)$. There is little or nothing in our theories to help us understand when "laws of association," such as frequency and recency, hold, and when they do not. In contrast, the notion of mesh can, like an association, be used to relate concepts, but the nature of the relation is deeper: when patterns mesh, they modify each other because they must conjoin in a way that respects constraints on bodily action. Thus, "Coke bottle" is difficult to mesh with "chair."

Mesh provides a rationale for Thorndike's (1932) concept of belongingness (see also Ohman et al. 1976) as well as various ideas put forward by Gestalt psychologists. Furthermore, mesh may help to explicate species-specific differences in associability of stimuli. Rats find it easier to associate a novel taste with illness than to associate a novel sight with illness (Garcia & Koelling 1966). In contrast, pigeons find it easier to associate a novel sight, rather than a novel taste, with illness (Wilcoxin et al. 1971). If learning comes about through meshing patterns of bodily action, then, given species differences in anatomy, physiology, and possible actions, the fact that stimuli will mesh differently for different species is a foregone conclusion.

7.4. Standard memory paradigms

If knowledge is embodied, then commonly used laboratory paradigms for studying memory may well be missing the mark. Many of these paradigms use random lists of words as the objects of memory. Whereas there are reasons for using lists of words, these are reasons related to history and convenience, not to any analysis of the design of memory. A favorite argument to justify the verbal list format is that each word corresponds to a mini-event, and from memory's point of view these mini-events are similar to other events in the world. This argument loses much of its force, however, if memory is embodied and designed for negotiating a three-dimensional environment.

The discrepancy between the design of memory and the design of the tools used to analyze it may account for undesirable characteristics of memory research. Importantly, memory researchers have not made much progress in understanding the nature of memory. We know about many phenomena (Greene 1992), but there is little agreement as to the interpretation of those phenomena, how they fit together, or whether a particular phenomenon is of any importance. Even with something as basic as the effect of repetition, the theoretical diversity is astounding: we have theories in which repetitions enhance the strength of a single representation (Gillund & Shiffrin 1984), theories in which repetitions are individually preserved (Hintzman 1986), and theories which treat memory much like a hologram (Metcalfe 1993). We have multi-store theories and single-store theories; single-system theories and multiple-system theories. All of these positions receive support from some aspects of the literature. I suspect that this diversity of positions arises because in using inappropriate tools we obtain incompatible views of memory much like the views of the blind men touching the elephant.

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NOTES

1. The argument is not that grandfather is unable to interpret a platform as a suitable chair for his granddaughter. Instead, the argument is that the grandfather knows perfectly well that the platform is not a suitable chair for himself. Thus, when the young child refers to the narrow platform as a chair, the grandfather may have some difficulty in knowing what the child is talking about. It is only when the grandfather adopts the child's perspective (i.e., how the child's body can interact with the world) that he comes to appreciate how the platform can be a chair for the child. (Adopting another's perspective requires suppression, as discussed in sect. 3.4) the main point is that words and events do not have set meanings for all times, places, and people. Words and events have meanings to individuals because of their individual bodies and experiences in the world.

2. Thanks to Alan Baddeley for raising this objection most forcefully.

3. Thanks to Tony Sanford for this observation.

4. Furthermore, Gärdenfors (1995) proposes that the ability to form "detached" representations, that is, those unconnected to current environmental stimulation, is a significant evolutionary step. Bloom (1994) discusses how the ability to manipulate such representations motivates language acquisition.

5. This account is very similar to that given to explain how thinking about "Amazon" can facilitate answering the question "What is the longest river?" That example, however, was used in the context of the implicit, or automatic, mode of memory. Given that automatic and effortful memory are clearly dissociable, how can the same processes apply? Although dissociable, tasks designed to tap these two modes of memory share many subprocesses (cf. Jacoby et al. 1993). On the embodied account, both modes make use of trajectories to develop a meshed conceptualization: the memory. The purest automatic case is when the trajectories apply to clamped projectable properties, such as fleshing out a fragmented picture. This is what Roediger et al. (1994) call a data-driven task. The purest effortful case is when nothing in the current environment is related to the sought-after information so that all projectable properties must be suppressed. This is an instance of Roediger et al.'s conceptually-driven tasks. The "Amazon" and "lamp" examples are intermediate in terms of suppression. We cannot completely suppress the projectable properties because we need to read the words. Nonetheless, the orthography of the words is of little use; what matters are the trajectories they invoke.

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Functional memory versus reproductive memory

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Abstract: A functional theory of memory has already been developed as part of a general functional theory of cognition. The traditional conception of memory as "reproductive" touches on only a minor function. The primary function of memory is in constructing values for goal-directedness of everyday thought and action. This functional approach to memory rests on a solid empirical foundation.

> The function of memory is to bring past experience to bear on present action. This function is manifest in our everyday judgments and decisions of family and work and in our personal mental life. Memory in everyday life may thus be called *functional memory*. Functional memory is barely recognized in the traditional perspective of *reproductive memory*. (Anderson 1996, p. 363; see also Anderson 1991b)

Glenberg hit the nail on the head with the criticism that "contemporary psychology of memory has been dominated by the study of memorization" (sect. 2, para. 1). Reproductive memory – memorization – is only a small part of what memory is for. Memory is mainly for goal-directed thought and action.

The opening quote of this commentary comes from a functional approach to memory in a spirit similar to that of Glenberg, but one based on a very different foundation. Whereas Glenberg seeks a foundation in spatial-perceptual function, the present approach is founded on the goal-directed approach-avoidance of everyday life. This rests on an exceptionally solid base of experimental applications in almost every area of psychology (e.g., Anderson 1991a; 1991b).

Approach and avoidance, the dynamics of everyday life, depend on values. One main function of memory is for the construction of values. Values are not generally memorized or reproduced, but constructed, because they depend on specifics of the operative situation. Once constructed, of course, they may be stored for use in future construction. Neither of these two functions has much to do with reproductive memory, however.

It is not necessary to "start from scratch in thinking about what memory is for" (abstract), because a respectable start has already been made. The present functional approach to memory is not a promissory note. It has a cutting edge in the form of *cognitive algebra*. Experimental studies in numerous areas have revealed the operation of algebraic laws of cognition (see contributors to Anderson 1991a). These algebraic laws have provided a validated theory for the psychological measurement of values. As one contribution, a dissociation between memory for given verbal stimuli and memory for an integrated response constructed from those stimuli has been demonstrated (Anderson 1991b, pp. 9–13, 40–46).

One can concur with Glenberg that "commonly used laboratory paradigms for studying memory may well be missing the mark" (sect. 7.4, para. 1). They are indeed missing the mark – because they have prejudged memory as essentially reproductive. The grip of this preconception appears even in critics such as Neisser (1982, p. xii), who comments that traditional approaches have been "accumulating the wrong *kind* of knowledge." Despite his emphasis on everyday memory, however, Neisser has remained bound by the reproductive conceptualization of memory.

Glenberg begins too narrowly. His attempt to base memory on visual perception recognizes the goal-directedness of cognition only in one respect. Even at the sensory level, many senses besides vision – especially affective senses such as taste and sex – govern much of everyday life. These and other affective senses do not generally provide the accuracy criteria Glenberg requires in the visual sense.

The difference between visual perception and affective senses is basic. The visual sense does best when it apprehends the external world as it really is. Affective senses, in contrast, are primarily concerned with an internal world that has a value-based concern with the external world. Externalist accuracy of taste is denied by idiosyncratic taste aversions. Similarly, the affective value of sex is clear, whereas the idea of its accuracy seems strained and unreal.

A related reservation about Glenberg's approach arises from results obtained with the functional theory. The external world does not suffice to explain the internal world of cognition. In particular, algebraic laws of intuitive physics differ from the laws of physics in the external world. Glenberg's emphasis on veridical spatial cognition is too narrow because it leaves little place for nonveridical cognition.

A similar reservation is raised by Glenberg himself, in his comment that "hedonic valence and motivation" do not fit his "spatial-functional straitjacket" (sect. 7.2, paras. 2 and 1, respectively). A memory theory adequate to account for everyday thought and action cannot be expected to emerge from this "spatial-functional straitjacket."

A theory of memory should indeed begin, as Glenberg's does, with the issue of what memory is for. At the most general level, the function of memory is to bring past experience to bear on present thought and action. To make this specific requires an understanding of the nature of thought and action. Few would disagree that thought and action are mainly goal-oriented. Goal-directed thought and action embody a fundamental approach–avoidance axis. At bottom, approach and avoidance depend on values. Without a theory of value, memory theory has limited significance. An effective approach to the value problem, far from complete but demonstrably effective under certain conditions, has been developed along with cognitive algebra. These algebraic rules embody and provide functional measurement of psychological value, providing a new way of thinking about memory.

Glenberg has rightly stressed the need for a functional approach to memory. His visual–functional approach certainly seems to bring out significant aspects of functional memory. The present functional approach is in the same spirit.

Problematic aspects of embodied memory

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Abstract: Glenberg's theory is rich and provocative, in our view, but we find fault with the premise that all memory representations are embodied. We cite instances in which that premise mispredicts empirical results or underestimates human capabilities, and we suggest that the motivation for the embodiment idea – to avoid the symbol-grounding problem – should not, ultimately, constrain psychological theorizing.

Glenberg issues a powerful call-to-arms to anyone who is serious about understanding basic issues in human memory. We applaud aspects of his analysis, including his emphasis on the form of mental representations and his effort to account for phenomena as diverse as dead reckoning, language comprehension, and occasion-setting phenomena. In particular, his concept of "mesh," which provides an index to gauge the successes and failures of arbitrary associations, seems an important idea. The phenomena he cites demonstrate convincingly that association formation is *not* – at least in many instances – arbitrary.

Certain implications of Glenberg's theory, however, seem inconsistent with empirical findings, or seem to predict that humans should not have certain cognitive–motor abilities they clearly have. These implications, examples of which we cite below, derive primarily from the theory's exclusive reliance on "embodiment" as the mechanism by which mental representations take on meaning. The embodiment mechanism is adopted by Glenberg to avoid the symbol-grounding problem (Harnad 1990), which he portrays as the most damning feature of present models of human memory, but we see that problem as more apparent than real – an argument we embellish at the end of this commentary.

One finding that seems problematic for the theory is that mere exposure to a stimulus can alter subsequent performance on certain perceptual or cognitive tasks (often without the performer's awareness). Such stimulus-driven processing, typically independent of a subject's tasks or goals at the time, suggests functions and operations of memory that do not fit neatly in the embodiment framework. In fact, Glenberg's explanation of implicit-memory priming effects seems to contain buried within it an implicit assumption that prior exposure can have automatic-activation (task-independent) effects on memory.

At a more detailed level, the finding that prior generation of a word, as opposed to simply reading that word, leads to a *lower* probability of being able to produce that word when it is presented tachistoscopically (Jacoby 1983) – or with letters missing (Blaxton 1989) – also seems problematic. It seems integral to Glenberg's analysis that bodily actions (such as speaking or writing) result in stronger memory representations than do nonphysical actions; guidance of action, after all, is "what memory is for."

With respect to human cognitive–motor capabilities that seem difficult to reconcile with the theory, musicians are one source of examples. Consider a trained musician, proficient on two instruments, who attempts to execute on the clarinet a simple piece originally learned on the piano. An experienced musician will do this with ease, and even a novice will show some positive transfer. In such cases, however, the overlap in the physical aspects of the two sets of actions is minimal. A more trivial example is that musicians can hum a new piece they have learned on some instrument, such as a guitar, yet the requisite movements of the vocal apparata do not overlap the physical actions performed on the instrument. If all memory is truly embodied, such transfer should be minimal.

Imagine another musician who, after a long delay, is unable to play a piece once played well. Here Glenberg's theory, as we understand it, makes an odd prediction: the musician should not even be able to hear the piece mentally. The ability to predict how the piece *would* sound derives, in Glenberg's theory, from the capacity to suppress projective characteristics of the environment and to "mentally" follow the trajectory that the embodied actions would otherwise dictate. A failure to access those embodied memories for the purpose of action implies a de facto inability to access them recollectively. Both abilities, according to Glenberg, rely on the same embodied trace, which is "designed" to serve action, not recollection.

The symbol-grounding problem, which renders current memory models inadequate in Glenberg's view, seems a much less serious problem to us, for two reasons.

First, current models are not quite as bad as they may seem with respect to their representational ability. "Meaningless" strings of 0s and 1s represent their environment in a crudely analog manner. Thus, two traces have the potential to be analogous to the degree that the codable features are indigenous to the representational system present in the organism. This constraint is not, in our view, arbitrary; it seems, in fact, more tractable than the notion of representations serving action patterns in an infinitely variegated way. We grant, however, that the nature of the features involved in the representational assumptions of current models remains poorly specified.

Second, the use of an atom that is maximally atheoretical in the representational system approximates the ultimate implementational ends of such a theory: to describe its working in terms of hardware preinstalled in the human brain. Neurons and synapses are no less arbitrary in their symbolic values than nodes or connections, and the use of such "meaning-weak" symbols forces our theories to describe representations in terms of patterns of activation – much as the brain is likely to. In this sense, it is the engineer, and not the psychologist, who must face the symbol-grounding problem.

Glenberg's work is laudable in its scope, coherence, and emphasis on meaningful representations. The singular emphasis on grounded meaning, however, seems to underestimate the flexibility and functions of human memory and to ignore certain process considerations. Whether the innovative and potentially powerful concept of mesh – the process that guides the combination of symbols and the combination of symbols with immediate environmental input – is actually tractable, for example, remains to be seen. Ultimately, Glenberg's theory does not remedy the current deficiencies in computational theorizing as to the nature of mental representation, but it does demonstrate that a serious theory, at least in its early stages, can confront such problems head-on.

Meshing Glenberg with Piaget, Gibson, and the ecological self

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Abstract: Glenberg's rethinking of memory theory seems limited in its ability to handle abstract symbolic thought, the selective character of cognition, and the self. Glenberg's framework can be elaborated by linking it with theoretical efforts concerned with cognitive development (Piaget) and ecological perception (Gibson). These elaborations point to the role of memory in specifying the self as an active agent.

Glenberg's ambitious target article suggests a major rethinking of memory theory, and I am very sympathetic to its general direction. Glenberg's proposal seems to have several weaknesses that limit its generality, however. My goal in this commentary is to offer some friendly suggestions for linking Glenberg's efforts to rethink memory theory with other theoretical work.

I see three major limitations to Glenberg's framework. First, it is hard to see how his scheme works for abstract symbolic thought, or for the perception of events and objects that do not support direct bodily interactions. How could the memory representations involved in abstract, symbolic thought be embodied and thus grounded? Second, the target article does not adequately address the selective character of cognition, perception, and action. A staggering number (however counted) of projectable properties of the environment are presently available to my perceptual systems, but it seems that at a given moment only a small fraction of these could be meshed with information available from memory. If we must suppress environmental input to allow cognition to serve its functions in guiding activity, wouldn't suppression also be necessary to select *which* projectable properties are currently meshed or clamped? Third, like representational theories of mind in general, Glenberg's framework focuses on representation of the environment, neglecting the informational basis of the self. Where is the agent whose possible actions provide the basis for mesh?

Unlike standard theories of memory, Glenberg's does lend itself to elaboration in ways that address these issues. Two of Glenberg's central ideas are that (1) mental representation is grounded in perceptuomotor activity, resulting in embodied meaning, and (2) information from the environment is encoded in terms of possible actions. Both of these ideas contrast dramatically with views that have been standard, if often implicit, in memory theories based on laboratory memory paradigms. However, these central ideas echo important themes in the work of Piaget and Gibson. Drawing on these resources, I briefly suggest possible answers to the questions raised in the previous paragraph.

A possible approach to reconciling the hypothesis that all meaning is embodied with the facts that we (1) do use arbitrary symbols and (2) do engage in abstract thought can be found in Piaget's ideas about the development of mental operations (see Chapman, 1988, for a review). Piaget argued that the mental operations that manipulate symbolic representations share formal structures with sensorimotor activity that is constrained by the laws of physics. For example, the reversibility of logical operations that serves to guarantee noncontradiction and logical coherence in symbolic thought develops from – and is thus grounded in – the empirical reversibility of displacements in space. This point is compatible with Glenberg's observation that memory representations are, like current perception, structured in terms of possible actions. Studying Piaget reminds us, however, that it is not just representations, but also mental operations – not just symbols, but symbol systems – that must be grounded in activity in a three-dimensional environment. And as Shepard (1984) points out, it is a significant question which regularities in cognition are supported by information currently available to perception and which are supported by internal representations fixed by individual learning and development or by evolution.

Glenberg notes that his view of conceptualization in terms of possible actions is very similar to J. J. Gibson's (1979) concept of *affordance.* Considering some other aspects of Gibson's ecological view of perception would help to address the selectivity of perception and cognition. Gibson noted that selective attention need not require suppression (or "filtering") of information. Instead, he argued, perception is a process of actively picking up information. There are two related points here: First, we might consider how current purposive activity serves to select those projectable properties meshed in a particular conceptualization. This seems to me a more plausible general approach to selection than effortful suppression. Second, when we consider perceptual exploration (e.g., looking) as a patterned activity (E. J. Gibson 1993), the problem concerning how conceptualization can include objects that don't support bodily interactions is at least reduced if not eliminated. For example, Glenberg's "beautiful sunset" (sect. 1.3) might be more convincingly unpacked in terms of the *informational* interactions we have with it –which are no less patterns of action than walking along a path or drinking from a coffee cup.

Finally, Glenberg's framework seems well-suited for relating the function of memory to an implication of Gibson's views that Neisser (e.g., 1991) has called the "ecological self." Consider Gibson's (1979, p. 234) statement that "What we see *now* refers to the self, not the environment." That is, the information available to the visual system specifies both objects in the environment and the (typically moving) point of view of an active agent. This perceptually specified point of view is the ecological self. Similarly, the information available from memory should be understood as specifying not just nonprojectable properties of objects in the environment, but the experienced self who interacts with these objects. Developing this relation could be an important step toward relating memory theory to questions about the nature of consciousness (Carlson 1992).

I believe that Glenberg has posed a very important challenge to standard theories of memory, although I am skeptical about some of his specific proposals, such as the central role of suppression. Meshing Glenberg's ideas with other theoretical proposals points the way toward integrating memory theory with theories of cognitive development, perception, and consciousness.

Glenberg's embodied memory: Less than meets the eye

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Abstract: We are sympathetic to most of what Glenberg says in his target article, but we consider it common wisdom rather than something radically new. Others have argued persuasively against the idea of abstraction in cognition, for example. On the other hand, Hebbian connectionism cannot get along without the idea of association, at least at the neural level.

Our commentary title is deliberately provocative: the fact is, we approve of and second much of what Glenberg has to say about memory. Our title is fair enough, however, because Glenberg himself has chosen a title with some provocative grandeur to go above ideas that we thought had become quite commonplace, if not common wisdom.

The essence of his framework, a general argument against abstraction, is a case in point (sect. 1). Although probably not popular in some circles at Carnegie-Mellon University, this attitude is not unanticipated among modern workers (Brooks 1978; Hintzman 1986; Jacoby & Brooks 1984; Medin & Schaffer 1978; Nosofsky 1988). Accepting that memory lacks well-defined abstract symbols indeed favors the idea of embodiment as Glenberg asserts. But this argument (sect. 1.2) sounds much like a restatement of Tulving's (1983) encoding specificity principle (so a word is not an abstract concept after all, but rather is encoded according to a momentary context, which must be part of the retrieval cue for good recall).

What are we to make of the accusatory and dismissive charge that much of modern memory research has been about *memorization* (sect. 2)? Some of us proceduralists maintain that memory is the delayed aftereffect of mental operations (and we appreciate Glenberg's approving appeal to the proceduralist manifesto of Kolers & Roediger 1984). But regarding the field of memory as memorization seems to shift this field back to the days when we (almost invariably) used intentional rather than incidental learning procedures, as was typical before the levels-of-processing work. Moreover, a view of conceptualization in terms of patterns of interaction with the environment "meshes" closely with that same proceduralist notion of means-specific representation. Embodied representation might more parsimoniously be considered such means-specific representation with an emphasis on the physical body and its ecological setting.

Glenberg's main answer to his question of what memory is "for" is that memory is designed to mesh the embodied conceptualization of projectable properties of the environment with embodied experiences that provide nonprojectable properties (sect. 2). He says that this process is updated by shifting from one pattern of possible activations to another, thus establishing a flow among successive situations. The "streaming" of cognition is and has been a salient phenomenon since the time of William James, but any such continuous process can be (and has been) described as a series of very fine-grained symbols. Current exemplar models of memory can simulate mesh with an ongoing retrieval process that continuously retrieves multiple representations acting in concert. Suitable assumptions about the granularity of the encoded "traces" and the time span each covers would deliver predictions much like those cited in favor of the idea of mesh.

Likewise, we hold Glenberg's summary of work on long- and short-term memory (sect. 4) as perfectly justified by the evidence but not any sort of radical change (Cowan 1995; Crowder 1993). We too are attracted by the emergence of connectionism in today's theoretical landscape (sect. 3.5) and by the wisdom of many of Gibson's (1979) insights about cognition (sect. 3.2).

Others will undoubtedly argue in defense of the concept of the association, whose refutation Glenberg surely intended to be among his most stunning rejections of our past. The age of this (should we say "Aristotelian"?) concept is of course not relevant to its value as an axiom now, but we wonder whether Glenberg rejects association equally at all levels of analysis, including its Hebbian incarnation at the neural level (Hebb 1949/1961). And how can he express sympathy for connectionism without being repelled by its associative flavor? Perhaps he would suggest that associationism is valid for the neural level of analysis but not for the "cognitive" or "psychological" levels. It would thus be the opposite of an "emergent" principle (for such principles are evident at higher levels of analysis but not at lower levels). For this, we modestly propose the designation "Vanishing Principle."

Embodiment in language-based memory: Some qualifications

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Abstract: (1) Non-projectable properties as opposed to the clamping of projectable properties play a primary role in triggering and guiding human action. (2) Embodiment in language-mediated memories should be qualified: (a) Language imposes a radical discretization on body constraints (second-order embodiment). (b) Metaphors rely on second-order embodiment. (c) Language users sometimes suspend embodiment.

Glenberg's target article gives a fresh approach to human conceptualization by emphasizing its embodied nature as a way to overcome the symbol grounding problem (Harnad 1990). However, the notion of embodiment should be qualified to avoid the danger of a theoretical *deus ex machina.* I find the idea convincing that embodied (projectable) properties from the environment are meshed with embodied memory-based (nonprojectable) knowledge in our sensorimotor experience. I do not think, however, that the clamping of projectable properties of the environment is *primarily* "to keep the system reality-oriented" (sect. 3.2, para. 1). Projectable properties (the physical environment and the design of our bodies) impose ontological constraints on our actions, but they are not sufficient to determine specific courses of action. Accepting that the environment is usually full of affordances (chairs to be sat on, windows to be opened, etc.), the competition among them would be so complex that they would not grant any particular action. Using Glenberg's terminology, there would be many ways to clamp projectable properties for a given environment. Our situation would thus be similar to that of Buridan's proverbial donkey, unable to chose among equally attractive courses of action.

On occasion, some projectable properties may be immediately clamped to produce *reactive* actions, such as avoiding an obstacle, but these are not sufficient to determine *agentive* (self-generated, hierarchically organized, intentional) action. Agentive action requires that projectable properties become subordinate to active nonprojectable states such as intentions, goals, emotions, and the like. For example, because I have the goal of cutting a strip of paper, I look for the scissors in my room (an environment involving many potentially affordable objects) and, after finding the scissors, I cut that particular piece of paper instead of any other object in the environment that can be cut. Thus, the projectable properties of the environment do not by themselves specify particular patterns of action. Instead, nonprojectable properties are the primary ones for human action.

Glenberg shares with other authors (Lakoff & Johnson 1980; Talmy 1988) the intuition that abstract nonprojectable concepts are also embodied because "we understand abstract situations by conceptualizing them in concrete ways" (sect. 6.4, para. 1). This assumption is necessary for the theory because accepting nonembodied properties again would bring us to the symbol grounding problem (Harnad 1990). However, I found some problems in the notion that nonprojectable memories are embodied, namely: (a) the problem of discretization, (b) the lack of an explanatory theory of conceptual metaphor, and (c) the phenomenon of suspended embodiment.

Discretization. An important function of memory is to reduce the flow of events to manageable and meaningful parameters. One way to reduce information is to discretize it, which is obviously done in language-mediated experience and mental models. Some of Glenberg's observations are germane to the notion of information reduction and discretization: He realizes that neither space nor time is continuously (analogically) encoded in our memory. Space is encoded by language into a few discrete topological regions (front, left, etc.), and time is encoded in terms of gross categories (now, after, before, etc.). This contrasts with the fine-grained spatiotemporal tuning with objects we need in our sensorimotor experience (e.g., to move among objects or manipulate them safely).

In comparison with the analogical perceptual experience, discretization has a cognitive cost. Thus, language-based spatial representations are computed in ego-centered or object-centered frameworks that involve a relational parsing of space absent in sensorimotor experience (de Vega et al., in press). Thus, the verbal description of an object's position involves a sentence that relates the target object to a framework object (e.g., A is below C), whereas the equivalent deictic gesture of pointing to an object does not require relating the pointed object to any particular framework.

In conclusion, there should be a first-order embodiment (continuous, analogical) corresponding to sensorimotor experience and a second-order embodiment (discretized and relational) corresponding to language-based memories. To what extent is the second-order embodiment really an embodied experience? Do *all* of our memories involve implicit motor and visuospatial patterns, for instance? The answer to these questions may be crucial for Glenberg's theory and they deserve urgent empirical research.

The lack of an explanatory theory of metaphor. The fact that many abstract concepts are metaphorical supports Glenberg's insightful notion of embodied conceptualization. But we need to know more about how metaphorical conceptualization is possible and what its functional consequences are. Again, I would like to know what sort of embodiment, if any, remains in metaphor. Notice that embodiment should not be a metaphorical notion itself in order to retain its theoretical appeal. This means that the metaphors based on embodied experience should involve real bodily constraints. However, metaphors do not seem to rely on first-order embodied conceptualization (continuous and analogical); instead, they are built on the reduced and discrete concepts provided by language. Thus, some of the spatial metaphors described by Lakoff and Johnson (1980) are built on gross topological dimensions (e.g., top-down), rather than on a Euclidean metric space, and the psychosocial causality metaphors explored by Talmy (1988) rely on the schematic conceptualization of force dynamics.

Suspended embodiment. The most important limitation to the notion of embodied representations is that language users are apparently able to suspend embodied constraints. For example, to understand the sentence, "*Mary flew from Madrid to New York*," we need activate neither the mental (embodied) pathway nor the body actions and sensations typical of flying. Of course, we can make a quite detailed simulation or "mental traveling" from verbal description if we are required to do so (e.g., Denis & Cocude 1989). But in most cases mental traveling seems a superfluous use of mental resources, unnecessary for ordinary comprehension (conceptualization). What probably happens in those cases of "suspended embodiment" is that we implicitly *know* that we can instantiate the sensorimotor trajectory but we do not need to do it on that particular occasion (just as we know that a check means money but we do not need to cash it immediately). In conclusion, comprehension involves a potential embodiment rather than an actual embodiment in some cases.

All three issues – discretization, metaphors, and suspended embodiment – are manifestations of the same general principle: the compacted nature of language-mediated conceptualization. The data reduction processes in language and mental models should not be neglected in a theory of memory. The ways our body constrains our conceptualizations are probably relaxed or modified in language because memories are not built on sensorimotor experience, but on a schematic reduction of such experience.

Action patterns, conceptualization, and artificial intelligence

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Abstract: This commentary connects some of Glenberg's ideas to similar ideas from artificial intelligence. Second, it briefly discusses hidden assumptions relating to meaning, representations, and projectable properties. Finally, questions about mechanisms, mental imagery, and conceptualization in animals are posed.

I'm a proponent of the action selection paradigm of mind (Franklin 1995, Ch. 16), whose first tenet is that "The overriding task of Mind is to produce the next action." Or, as William James puts it, "My thinking is first and last and always for the sake of my doing." Thus, I find myself quite in tune with Glenberg's view that "memory evolved in service of perception and action" (sect. 1, para. 1). The action selection paradigm also views mind as operating on sensations so as to create information for its own use. Information is seen, not as taken from the environment and processed, but as created by the individual agent. This assumes embodiment in the sense of "structural coupling" (Maturana 1975; Maturana & Varela 1980; Varela et al. 1991). Glenberg's notion that "the world is conceptualized (in part) as patterns of possible bodily interactions" (sect. 1.3, para. 1) can be taken as a partial implementation of this structural coupling.

Connections with artificial intelligence. "[T]he meaningful, action-oriented component of conceptualization . . . reflects how bodies of our sort can interact with objects" (sect. 1.3, para. 2). Certain artificial systems conceptualize in this way. Edelman's Darwin III (1989) categorizes objects by tracing their outlines with its hand, by feeling their texture, and by seeing their visual patterns. Drescher's schema mechanism (1988; 1991) categorizes in terms of the possible results of actions (see also Franklin 1995, Ch. 12).

"[T]he spatial-functional patterns based on projectable properties from the environment are combined or meshed with the patterns from memory [patterns representing goals]" (sect. 3.1, para. 1). A Maes net (1990) provides a mechanism for just this kind of meshing. Equipped with a sensory-data-to-percept preprocessor, Kanerva's (1988) sparse distributed memory could furnish another such mechanism.

"We cannot direct our perceptual systems to ignore differences . . . between two chairs" (sect. 3.2, para. 2). True. But note that we need not treat these two chairs as individuals with, say, name, history, and so forth. One can be the-chair-I'm-sitting-in and the other the-empty-chair-to-my-right. Computationally, these two approaches are quite different (see Agre & Chapman 1987).

"[I]n the service of prediction, we have developed the ability to . . . suppress the overriding contribution of the current environment to conceptualization" (sect. 3.4, para. 1). Johnson and Scanlon (1987) found the need to build this same ability to "think" offline into their Pacrat. In her spreading activation behavior nets, Maes (1990), uses no-action-below-threshold to achieve offline "thinking."

"Memory's automatic contribution to conceptualization: When we are walking the path home, we do not need to consciously recall which way to turn at each intersection" (sect. 5.1, para. 1). Is this Brook's (1991) "the world's its own best model?" Continual sampling of the environment is taking place. Yet, knowing which branch to take is a not a nonprojectable property of the environment. It's not a property of the environment at all. It's a consequence of the goal of reaching home. But is it the result of some internal model? In the case of the branch being at hand, I think not. Planning a route in advance would require a model. Maybe the idea of meshing conceptualizations provides the beginnings of a mechanism for choice at the branch, while running a trajectory with environmental input suppressed is the beginnings of a mechanism for planning.

"When the jogger puts on the sweatshirt, there is a mesh between the jogger and the sweatshirt: wherever the jogger goes, the sweatshirt goes too" (sect. 6.3, para. 4). The frame problem (Brown 1987; Franklin 1995, p. 116) that has so plagued Artificial Intelligence doesn't arise in humans. Meshing seem to provide an explanation.

Assumptions. "[T]o a particular person, the meaning of an object, event, or sentence is what that person can do with the object, event, or sentence" (sect. 1.3, para. 1). The very notion of meaning seems to refer back to the discredited attempt to map arbitrary symbols to the world. I suggest that internal "patterns of possible bodily interactions" have a causal relationship to a corresponding "object, event, or sentence," rather than one of meaning. To a thermostat, the particular shape of its bimetalic strip has a causal relationship to its world. An outside observer might ascribe a meaning, say 70°, to that shape, but this ascription has no relevance to the thermostat (thought of as a particularly simple agent sensing its particularly simple world and acting on it). To the thermostat, the shape of the strip is simply its perceptual mechanism in the service of action selection: so, too, "patterns of possible bodily interactions."

"Embodied representations" (sect. 1.3, para. 2): Thinking of "patterns of possible bodily interactions" as "representing" something doesn't buy us anything. Symbols represent things. These "patterns of possible bodily interactions" causally interact with things. The association of the patterns with the things is a representation only to an outside observer.

"[S]patial layout is a projectable property, whereas ownership is a nonprojectable property that must come from experience" (sect. 2.1, para. 2). Though the distinction signaled by the terms "projectable" and "nonprojectable" seems a useful one, the terminology chosen seems less than felicitous. "Projectable" would connote the environment actively projecting the property toward the sensing agent. Not so. It's the sensing that's active, and perception that creates the property in the first place (Franklin 1995, pp. 413–14; Oyama 1985). The agent projects both projectable and nonprojectable properties onto the environment. The distinction is one of degree of constraint; projectable properties are more constrained by the environment (see comments on sect. 5.1).

Questions. "To support action, the perception of projectable properties is in terms of patterns of possible actions" (sect. 2.2, para. 1). If so, the job of the perceptual apparatus is to turn incoming sensory data into appropriate patterns of possible action. What could the mechanism be? Skarda and Freeman have shown that recognition of an odor by a rabbit depends on which basin of attraction a pattern of activity on the olfactory bulb falls into [See Skarda & Freeman "How Brains Make Chaos in Order to Make Sense of the World" *BBS* 10(2) 1987.] I suspect that all of our recognitions of objects, events, and sentences happen by such a mechanism. But recognition is the identification of the appropriate concept. This leaves me wondering about the mechanism that takes us from sensory patterns to "patterns of possible bodily interactions."

"[S]tripes . . . are encoded as patterns of action" (sect. 3.1, para. 3). Patterns of actions rather than patterns of vision? Are the actions eye movements tracing out the stripes as in Edelman's Darwin III? And, how do we abstract a purely sensory concept, say red, in terms of "patterns of possible bodily interactions?"

And what of mental imagery? Is the perceptual apparatus used inversely to transform action patterns into something closer to degraded sensations? I can conjure up an image of Michelangelo's David with no hint of action present, though my underlying conceptualization of the David may well be in terms of possible actions.

If humans conceptualize in terms of patterns of possible actions, so must our higher primate cousins. African grey parrots have been shown to conceptualize (Pepperberg 1983). How far afield in the animal kingdom does this mode of conceptualization extend? What other modes, if any, are there?

The role of memory in planning and pretense

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Abstract: Corresponding to Glenberg's distinction between the automatic and effortful modes of memory, I propose a distinction between cued and detached mental representations. A *cued* representation stands for something that is present in the external situation of the representing organism, while a *detached* representation stands for objects or events that are not present in the current situation. This distinction is important for understanding the role of memory in different cognitive functions like planning and pretense.

Glenberg distinguishes between two modes of memory: automatic and effortful. In the automatic mode, memory functions as a source of patterns of action that mesh with the perception of projectable patterns obtained from the environment. The effortful mode involves suppressing the patterns from the environment and letting conceptualization be guided solely by trajectories formed from previous experiences.

In my writing on the subject (Gärdenfors 1995; 1996), I have distinguished between two kinds of mental representations: *cued* and *detached.* A *cued* representation stands for something that is present in the current external situation of the representing organism. In general, the represented object need not be present in the actual situation, but it must have been triggered by something in a recent situation. When a particular object is categorized as food, for example, the animal will act differently compared to when the same object had been categorized as a potential mate.

In contrast, *detached* representations may stand for objects or events that are neither present in the current situation nor triggered by some recent situation. A chimpanzee who walks away from a termite hill to break a twig in order to peel its leaves off to make a stick that can be used to catch termites has a detached representation of a stick and its use. In Glenberg's terminology, the detached representations are all trajectories the animal can *actively* conceptualize.

I want to argue that the distinction between cued and detached representations fits very well with Glenberg's two modes of memory and that it is useful for understanding many aspects of the role of memory in higher cognitive functions. Here I will just address planning and pretense (for an analysis of other functions, see Gärdenfors 1996).

As Glenberg notes in section 3.4, *prediction* requires the (dangerous) suppression of inputs from the environment. The ability to envision various actions and their consequences is a necessary requirement for an animal to be capable of *planning.* Following Gulz (1991, p. 46), I will use the following criterion: An animal is planning its actions if it has a representation of a goal and its current situation and is capable of generating a representation of partially ordered sets of actions for reaching the goal. The representations of the goal and the actions must be detached, that is, the input from the environment must be suppressed.

There are several clear cases of planning among primates and some less clear cases in other species. However, all evidence for planning in nonhuman animals concerns planning for *present* needs. Apes and other animals plan because they are hungry or thirsty, tired, or frightened. Humans seem to be the only animal that can plan for *future* needs. Gulz (1991, p. 55) calls planning for present needs *immediate planning;* planning for the future is called *anticipatory planning.* Humans can predict that they will be hungry tomorrow and so they save some food; we realize that the winter will be cold, so we start building a shelter in the summer.

The crucial distinction is that for an organism to be capable of anticipatory planning it must have a *detached representation of its future needs.* In contrast, immediate planning only requires a cued representation of the current need. There is nothing in the available evidence concerning animal planning, notwithstanding all its methodological problems, that suggests that any species other than *Homo sapiens* has detached representations of its desires. In Glenberg's terminology, this requires that humans be able to suppress the feelings and desires of the current situation and evoke memories of other desires during anticipatory planning.

The point here is that evoking memories of desires and emotions presumes a rudimentary "theory of mind" (see, e.g., Gopnik 1993; Leslie 1987; and Premack & Woodruff 1978). An organism must somehow realize that the memory of an emotion was *its own* emotional experience. Such a memory is also a prime example of the embodied conceptualization on which Glenberg focuses in his theory of memory. This line of argument thus underpins his claim in section 5.2.3 that "a major factor in the development of a concept of self is just the ability to suppress environmental information."

A distinction similar to that between cued and detached representations has been made by Leslie (1987), who argues that "decoupled" representations are necessary for an organism to engage in *pretense*. Leslie suggests (1987, p. 415) that when a child pretends that a banana is a telephone, the pretend representation must be "quarantined" from some of the sensory information. The perception of the banana must be complemented with information about telephones evoked from the child's memory. Leslie claims (1987, p. 416) that the emergence of pretense "is an early symptom of the human mind's ability to characterize and manipulate its own attitudes to information. In short, pretense is an early manifestation of what has been called a *theory of mind*."

The upshot is that planning and pretense, as well as other higher cognitive functions, presume Glenberg's effortful mode of memory, that is, the capacity to suppress patterns from the environment and to let conceptualization be guided solely by previous experiences encoded as trajectories. As a consequence, this capacity is a *sine que non* for the development of a "theory of mind."

Where is the body in the mental model for a story?

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Abstract: Researchers in the field of discourse processing have investigated how mental models are constructed when adults comprehend stories. They have explored the process of encoding various classes of inferences "on-line" when these mental microworlds are constructed during comprehension. This commentary addresses the extent to which these inferences and mental microworlds are "embodied."

The field of discourse processing has investigated how meaning representations are constructed in the adult understanding of connected discourse, such as when a person reads a novel or listens to a lunchroom conversation. The early models were quite disembodied, as portrayed in Glenberg's description of the standard, symbolic, proposition-based theory of meaning. However, the standard theory has been abandoned by most researchers in discourse processing. This abandonment can be attributed to theories that insisted on more grounded representations, as in situational semantics (Barwise & Perry 1982), procedural semantics (Miller & Johnson-Laird 1976), and studies of deixis (i.e., references to contextual indexes of speech acts, such as locations, times, and who is speaking to whom; see Duchan et al. 1995). Today's discourse processing theories offer richer specifications of the referential content of discourse segments, the situation model, and the communicative context of the discourse (Britton & Graesser 1996; Gernsbacher 1994). Although some of these theories have embodied meaning representations, the processing mechanisms do not incorporate Glenberg's distinctive claims about meshing, trajectories, projections, and suppression.

This commentary raises the question of whether the meaning representations that humans construct during discourse comprehension are embodied ones. Story comprehension is worth examining because stories have received the most attention by discourse researchers, and they are microcosms of events and experiences in the real world. That is, both stories and everyday experiences include people performing actions in pursuit of goals, events that present obstacles to these goals, conflicts between people, emotional reactions, and spatial scenarios. When a novel is comprehended by an adult, the reader constructs a fictitious microworld of such content. To what extent is the content of the microworld an embodied representation?

If the mental microworld were completely embodied, the reader would encode many details about the characters, objects, spatial layout, actions, and events – much as in a high-resolution videotape. However, stories are read rather quickly, at the rate of approximately 150 to 400 words per minute, so a fuzzy videotape would be more feasible. In either case, adults would encode many elaborations about perceptual features and actions. When comprehending the action "the cook tripped the butler" in a mystery novel, the reader would generate inferences about *how* the action was performed, such as the instrument of tripping (foot), the room of the tripping, the location of the tripping within the room, the part of the butler's body that was initially contacted, and the trajectory and intensity of the fall. The reader would also generate inferences that explain *why* the action was performed, for example, to get revenge or to prevent the butler from meeting a guest.

Available evidence indicates that mental microworlds are embodied in some respects. Zwaan et al. (1995) had college students read literary short stories in order to assess whether readers monitor various dimensions of the microworld, such as characters, temporality, spatiality, causality, and intentionality (i.e., characters' goals and plans). Reading times for sentences increased when a new character entered the microworld, when there was a large gap or transformation in the time line (i.e., flash back or flash forward), when there was a change in spatial setting, when an incoming action was not causally related to the prior context, and when a character generated a new goal or plan. In contrast, coherence breaks at the propositional, textbase level had virtually no impact on reading times. Zwaan et al.'s results are compatible with Glenberg's theory of embodied language comprehension.

Some negative evidence, however, suggests that mental microworlds are not completely embodied. Graesser et al. (1994) proposed a constructionist theory that identifies the inferences that readers encode on-line when they comprehend narrative. According to this theory and available empirical evidence, readers construct inferences that explain *why* actions/events occur and *why* the writer would bother mentioning something in the text, but not *how* the actions/events occur. For example, when reading "the cook tripped the butler," the notion of "revenge" would get encoded but not the notion of "foot." Thus, story comprehension is explanation-driven, but not driven by a need to specify frivolous details about how actions/events occur and about static properties of characters and objects. Such details are encoded only to the extent that they help explain the plot and the rationale for the writer explicitly mentioning something.

The problem of embedded microworlds also suggests that there are limits on the embodiment of narrative actions. If the narrator asserts that the cook tripped the butler, the action receives a direct focus in the discourse and may very well be embodied. However, it is doubtful whether the same action would be embodied in an embedded microworld: "The wife was embarrassed when she heard her husband fumble nervously through the story about the cook tripping the butler." In this case, the meaning representation of the cook's tripping the butler would probably be a meatless skeleton or a symbolic token rather than an embodied representation. The question would also arise as to which body is relevant. Would it be the body of the wife, the husband, the cook, or the butler? Contemporary theories of narrative comprehension have emphasized the importance of tracking the existence and points of view of multiple agents in the story world, including the narrator and the narratee (Duchan et al. 1995). Glenberg's theory does not identify (1) the agent that most constrains the embodied meaning representation and (2) the conditions in which embodiment is suppressed.

In closing, most researchers in discourse processing would resonate with Glenberg's claims about embodied meaning representations. However, there are conditions in which the representations are either not embodied or are substantially depleted of flesh and bone. Glenberg needs to identify these conditions in order make his theory a serious competitor in the field of discourse processing.

Embodied representations are part of a grouping of representations

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Abstract: Glenberg argues for embodied representations relevant to action. In contrast, we propose a grouping of representations, not necessarily all being directly embodied. Without assuming the existence of representations that are not directly embodied, one cannot account for the use of knowledge abstracted from direct experience.

Glenberg's innovative proposal is grounded in the assumption that memory is designed to serve particular goals; this involves the computational level, in the sense of Marr (1982). We will address this aspect of Glenberg's approach before we turn to the more specific, algorithm-level assertions.

The computational level. In psychological theories of memory and cognition, mental representations are usually implicitly expected to represent the world as veridically and completely possible. Empirical evidence of discrepancies between what is mentally represented and what is actually the case are referred to as "distortions," "illusions," or "fallacies" if they cannot be attributed to "capacity limitations." When eventually biological requirements are taken into consideration, it often turns out that the discrepancy can be seen as resulting from an advantageous processing principle. Research on visual attention provides an example. Attentional phenomena have traditionally been viewed as arising from a basic capacity limitation, but today it is widely proposed that they may be better understood as a consequence of coordinative processes that protect ongoing action choices from interruption by irrelevant information (e.g., Van der Heijden 1991).

Glenberg takes the opposite approach. His proposal *proceeds* from considerations about the purpose of cognitive processing and thereby specifies principles of information selection right from the beginning: mental representations contain information relevant to action or action prediction. Representations can only be expected to be veridical or complete to the extent necessary or advantageous for these purposes. This approach is extremely important for research on memory and language where guidelines for making hypotheses about information selection are lacking. Many studies have attempted to determine what information gets encoded during text comprehension, yet there is still no principled and comprehensive account of the data: readers/listeners form neither "veridical" representations of the propositional text base nor fully specified representations of real-life-like situations. For example, it cannot really be explained why readers/listeners put special weight on the protagonist's goals (Graesser et al. 1994; Kaup et al. 1996) or how the experimental task or instruction influences which information is mentally represented (e.g., Albrecht et al. 1995).

To conclude: the presupposition that mental representations are ideally veridical and complete has to be abandoned. A discussion of the principles of information selection is urgently needed. One hopes that Glenberg's target article will stimulate such a discussion.

The algorithmic level. Glenberg's central concept, embodied representations, seems to be rich representations containing various kinds of information (motor programs as well as kinestetic, visual, auditory, haptic, and other perceptual information, emotions, goals, etc.) whereby relevance to action or action prediction constitutes the selection criterion. This idea is problematic, if an embodied representation is meant to be supported by just a single mental subsystem. Instead, a grouping of representations, each supported by a different mental subsystem that is responsible for providing a specific kind of information (cf. Barwise & Etchemendy's [1995] "heterogenous reasoning"), is better compatible with numerous findings from the neurosciences and psychological research with the dual-task paradigm. It is well-established that interference effects depend on the specific combination of task-irrelevant environmental stimuli and the particular kind of information needed for the task at hand. This basic finding is difficult to reconcile with the notion of a single integrated representation, nor can it be accounted for by Glenberg's notion of suppression, in which the environment is globally set against internal representations.

Indirectly embodied knowledge. Glenberg's proposal is not very clear with respect to a serious problem for any embodiment theory, namely, the meaning of things "when there is no apparent possibility for bodily interaction" (sect. 1.3, para. 6). We agree with Glenberg that Talmy's "force-concept" (sect. 6.4) can be considered an example of knowledge abstracted from experience: starting with the bodily experience of gravitation and mechanical force, it seems possible to expand the concept into other areas, such as electromagnetic force. However, instead of assuming that the representation of force stays exclusively on the level of embodied representations, we prefer the view that knowledge can be "indirectly embodied." More precisely, humans are able to abstract from the details of an experience to a greater or lesser extent. We accordingly propose replacing the dichotomy of "embodied representations vs. abstract concepts," with a spectrum in which knowledge of different types of abstraction coexists. "Indirectly embodied concepts" are those that lack the specific aspects of bodily interaction for the experiences from which they originate. Such "abstracted representations" are essential for commonsense reasoning (see Habel & Eschenbach 1995). For instance, abstracting from certain aspects of direct experience with sound and heat, indirectly embodied concepts such as "radiation" or "transmission" may be formed. Such abstracted concepts of "distant (material) influence" are useful for commonsense reasoning. For example, the layman's difficulty with thinking about radioactivity is caused by the inability to perceive it, but this can be partially overcome by using abstract conceptualizations.

Another example: since numbers can be seen as abstract concepts, we must consider whether, and by what links, knowledge about numbers and numerical properties is embodied. Even if connection between numbers and sets of concrete entities can be seen as the embodied origin of some numbers, namely, the small ones, it is useful to use an abstract number concept for problem solving. Numbers, that is, abstract entities, are the basis for the solution of related but clearly distinguished problems with respect to quantities (e.g., "buying three Cokes, each for $1.00" and "watching three beautiful sunsets while drinking one martini each time"). Furthermore, it is not plausible to see direct embodiment as the way to ground large-number concepts. Rather, they are only indirectly correlated – via small numbers – with our embodied environment (cf. the "numerosity" concept of Gallistel & Gelman, 1992). [See also Davis & Pérusse: "Numerical Competence in Animals" *BBS* 11(4) 1988.]

To summarize: it is important to combine the level of embodied representations with representations of a more abstract character in a heterogeneous system.

Has Glenberg forgotten his nurse?

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Abstract: Glenberg's conception of "meaning from and for action" is too narrow. For example, it provides no satisfactory account of the "logic of Elfland," a metaphor used by Chesterton to refer to meaning acquired by being told something.

> All that we call spirit and art and ecstasy only means that for one awful instant we remember that we forget.
>
> G. K. Chesterton (in Gardner 1994, p. 101)

Bolzano, Brentano, and Husserl all had a problem with Kant. They would not believe that logic and psychology have something to do with one another. They would not believe that the laws of logic are identical with cognitive processes. For example, Husserl taught that logic has nothing to do with "cognitive acts." Putnam (1981), Lakoff (1987), and Glenberg have a problem akin to the aforementioned authors. They do not believe that thought is abstract (disembodied), atomistic, and logical (Lakoff 1987, p. xiii). Lakoff teaches "experientialism," the doctrine that reason is made possible by the body. Glenberg buys Lakoff's doctrine, together with Rosch's (1973) prototype theory (ignoring classic objections to prototype theories of categorization; see Johnson-Laird 1987). He sets out to promote the experientialist doctrine by proposing that memory is for, and meaning is from, action.

We shall not argue with Glenberg about the old idea that meaning can come from doing or using things. What we want to discuss is his forgetting of the logic of Elfland. "I knew the magic beanstalk before I had tasted beans; I was sure of the man in the moon before I was certain of the moon." By using these metaphors, Chesterton (1994), the inventor of "Father Brown" and critic of Darwinism, admirably expressed what Popper (1935) wrote a whole book about: the primacy of deduction over induction. As far as Glenberg's ideas about semantics or language comprehension are concerned, Chesterton's lesson is this: there are things the meaning of which we do not get by doing or using them. There are laws we learn before we can speak and shall retain when we cannot write. (In Chesterton's time and context, these "laws" were mainly taught by nurses via fairy tales.) These laws, thus imparted, can give us meaning. Examples include the lesson of "Beauty and the Beast," which states that "a thing must be loved before it is lovable"; or the less poetic lesson that "if Jack is the son of a miller, a miller is the father of Jack."

Thus, as long as Glenberg's neo-Gibsonian, anti-Tarskian theory does not provide an account of getting meaning from being told something (cf. Johnson-Laird 1987), it remains incomplete. Glenberg's reply to the third objection to his ideas, which is closely related to our argument, may leave many readers bewildered. He counters the point that some things are meaningful even when there is no apparent possibility for bodily interaction with the insight that meaning depends on context! When dealing with mental models, he says that being told "That plate is hot" modifies the embodied representation of the plate in order to modify interactions with the plate. Perhaps if he gave the reader some general notion of how and under what conditions such modifications take place, one would have a starting point for tackling the delicate problem of the logic of Elfland.

Glenberg's account is also strangely isolated from other previous and similar ones. Thus, one wonders how much his theory sketch adds to Piaget's (1968) genetic epistemological theory of the development of meaning in infants. How do embodied conceptualizations relate to Piaget's "schème" (the generalizable aspect of coordinating acts that can be applied to analogous situations)? When Glenberg says that abstract words are understood by analogy to concrete ones, does he mean something like Piaget's transition from the sensorimotor stage of thinking to the preoperational and operational stages? In this regard, we wonder how Glenberg acquired the meaning of the term "abstractness," since he picks the notion of "force" as a prototypical abstract concept. We can see how this concept can be embodied. But would concepts like "atom," "schizophrenia," or "Greek philosophy" not be somewhat more exciting challenges to his theoretical claims?

In terms of Chesterton, one may be tempted to ask: Has Glenberg forgotten his nurse, or whoever it was who told him fairy tales?

The myriad functions and metaphors of memory

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Abstract: Glenberg provides a new and exciting view that is especially useful for capturing some functional aspects of memory. However, memory and its functions are too multifarious to be handled by any one conceptualization. We suggest that Glenberg's proposal be restricted to its own "focus of convenience." In addition, its value will ultimately depend on its success in generating detailed and testable theories.

Glenberg proposes a new approach to memory that is predicated on certain assumptions about the function of memory. He states that his proposal "is not a fully testable theory" (sect. 1.3, para. 7), but evaluates it in light of empirical findings in a post-hoc manner. Overall, 23 different phenomena of memory, language, and thought are addressed (as summarized in sect. 7.1), ranging from the symbol grounding problem to the effects of expertise.

We believe that Glenberg's proposal is best viewed as a metatheoretical rather than a theoretical contribution. What he is offering is more a metaphor (or set of metaphors) for thinking about memory than an articulated and testable theory. As metaphors, the concepts of "embodiment," "mesh," "trajectory," and so forth allow certain aspects of memory to be construed in terms of the physical analogs of these concepts. They can help guide our thinking about memory and perhaps inspire the development of a new genre of memory theories. However, as currently formulated, the concepts and auxiliary assumptions are too underspecified to constitute such a theory in themselves.

Metaphors play an essential role in science (Koriat & Goldsmith 1996a). They are cognitive tools that help in abstracting the critical aspects of the phenomena, in defining the questions of interest, and in guiding the research approach. Moreover, they provide a general conceptual framework that serves that development of specific theories and models. Unlike the theories that they breed, however, metaphors are neither right nor wrong: They can be judged only in terms of their usefulness. This applies to Glenberg's proposal as well. Three main conclusions follow from this viewpoint.

First, a major benefit of Glenberg's conceptualization is that it brings to the fore certain neglected aspects of memory. As he points out (sect. 7.4), traditional memory research has generally focused on the study of item memorization. Behind this preoccupation lies the storehouse metaphor of memory, which has shaped much of the history of memory research (Koriat & Goldsmith 1996a; Roediger 1980). In recent years, however, many important memory phenomena that have attracted experimental attention – such as procedural memory, implicit or indirect memory, and priming effects – do not yield readily to conceptualization in terms of the storage and retrieval of discrete memory traces. To accommodate these and other phenomena, several alternative conceptualizations have been put forward, including Bransford et al.'s (1977) "stage-setting" metaphor, the "proceduralistic" or "skill" view of memory (e.g., Crowder 1993; Kolers & Roediger 1984), and the "tool versus object" distinction offered by Jacoby and Kelley (1987).

Such efforts notwithstanding, we are still lacking convenient metaphors to guide our thinking about the effects of past experience on perception and action. Glenberg's view focuses attention on precisely this aspect of memory and offers a rich vocabulary for construing the working of memory within the functional context of an organism's active interaction with the environment (cf. Bruce 1985; Neisser 1988). Hence, one could find the view useful even if it had no predictive power beyond other existing formulations.

Second, however, metaphors fulfill a critical function by serving as stepping stones toward testable theories. Here we see Glenberg's proposal as mainly a promissory note. Our feeling is that there is a jump from a metatheoretical, metaphorical level of analysis to the empirical level (as but one example, consider the argument regarding the need for cyclical activity in rehearsal, put forward in sect. 4.3, para. 4). Although a metaphor both guides and constrains the types of theories that can be developed, different theories – and hence predictions – can be derived from the same metaphor. Ultimately, then, the value of the proposal will depend on its success in breeding detailed theories from which testable predictions can be derived.

A third observation also stems from our view of the function of conceptual metaphors. As a cognitive tool, each metaphor has its own "focus of convenience" (Kelly 1955), that is, a domain of phenomena or processes for which it is best suited. The focus of convenience of Glenberg's proposal seems to be the implicit and procedural aspects of memory that support a major portion of our daily interaction with the environment. These phenomena are salient in many of the examples used to introduce the basic core of the proposal (sect. 2).

Glenberg, however, makes a great effort to stretch his conceptualization to other areas that seem to be well beyond its natural focus of convenience. Although his desire to provide a comprehensive and integrative conceptual framework is understandable, we feel that by going too far afield he does a disservice to his proposal. Some of the extensions of his framework seem to be rather forced and unconvincing. For example, the idea that explicit, episodic remembering is effortful because it requires suppression of "clamped" impinging stimuli (sect. 5.2) adds little to existing explanations and fails to address many of the essential aspects of such remembering that seem to be captured better by other metaphors.

In our opinion, one should not attempt to achieve too much with any single metaphor. Glenberg began his proposal by asking "what is memory for?" and his answer led him to a particular view of memory with a particular focus of convenience (see also Alterman 1996; Karn & Zelinsky 1996). Others, focusing on different functions and aspects of memory, have been led to rather different views. For example, emphasizing the role of memory in providing a faithful account of past events, we proposed a "correspondence" metaphor (Koriat & Goldsmith 1996a) that is useful in such domains as autobiographical memory, eyewitness testimony, and metamemory (Koriat & Goldsmith 1994; 1996b). Neisser (1996) stressing the social functions of memory in everyday life (e.g., impression management), proposed to view memory as a form of "doing" (see also Winograd 1996). Anderson (1996), stressing the contribution of memory to the formation of value judgments (e.g., attitude formation), opted for a "value metaphor," in which memory involves the "on-line construction of values and integration thereof."

How should one treat such differences of opinion regarding the essential nature of memory? Clearly, each view entails its own unique framework for memory research and theorizing. Nevertheless, they can all live together peacefully and contribute to the study of memory in their respective domains. As we have argued previously (Koriat & Goldsmith 1996c), memory is not monolithic, and any attempt to characterize it in terms of a single conception or function will certainly not do justice to its inherent heterogeneity. Thus, in line with our call for "metaphorical pluralism," we applaud Glenberg's proposal as a stimulating new addition to our arsenal of conceptual tools for understanding memory. However, no approach can claim to have a monopoly on the myriad facets and functions of memory.

What working memory is for

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Abstract: Glenberg focuses on conceptualizations that change from moment to moment, yet he dismisses the concept of working memory (sect. 4.3), which offers an account of temporary storage and on-line cognition. This commentary questions whether Glenberg's account adequately caters for observations of consistent data patterns in temporary storage of verbal and visuospatial information in healthy adults and in brain-damaged patients with deficits in temporary retention.

If I close my eyes and then try to pick up the pen on the desk in front of me, it is immediately apparent that we humans have temporary representations of our immediate environment. These representations survive the offset of visual perception and support our interactions with the environment that we have recently perceived. Memory then offers a means to support this interaction, but are the temporary representations products of how memory works or do they arise from emergent properties of the cognitive apparatus for temporary retention (Logie 1995; Richardson et al. 1996)?

Consider another observation. There are individuals who, following brain damage, are unable to retain simple verbal sequences, and who fail to show a range of phenomena linked with temporary retention of words by healthy brains (e.g., Vallar & Baddeley 1984; for a review, see Della Sala & Logie 1993). Yet these same individuals can hold normal conversations and seem to have little difficulty in finding their way around in the world. A different kind of brain damage can result in individuals who have no difficulty retaining verbal sequences or describing a scene while viewing it, yet cannot adequately access information from parts of the scene once it has been removed (Beschin et al., in press; Guariglia et al. 1993).

The current representations of scenes or words in each of the above scenarios might be likened to Glenberg's notion of meshing or conceptualization. But in his analysis there is little to account for those aspects of memory that, in the absence of the external physical stimulus, might allow the conceptualizations to be maintained moment to moment, or to be updated and manipulated. Various theories of cognition have attributed these kinds of cognitive functions to what is often referred to as working memory. There appears to be no place for this breed of theory in Glenberg's view, yet he argues that on-line conceptualization is the reason that we have memory. His arguments fail to consider the reports of patients with specific deficits of temporary storage. However, the contrasting data patterns from amnesics and from patients with short-term retention deficits offer strong evidence for functional dissociations between modules of working memory and a cumulative collation of knowledge and experiences.

The demonstration of long-term as well as short-term recency effects (sect. 4.3, para. 1) does little to erode the case for a separate working memory. The time scales over which these different forms of recency appear are dramatically different, and I have yet to see evidence of suffix effects or effects of delayed recall in a study of long-term recency. Moreover, the demonstration of semantic coding in temporary storage tasks simply indicates that short-term storage is not limited to the traditional view of a short-term verbal memory. The finding is entirely consistent with working memory as a bailiwick of specialized cognitive functions that support temporary storage and on-line manipulation of representations. Other counterarguments can be offered for the remaining examples given in this section of Glenberg's target article.

The notion of working memory offers a framework within which to account for on-line semantic processing (e.g., Just & Carpenter 1992), for temporary storage of visual and spatial properties of the environment (Logie 1995), and for temporary storage of verbal material. In particular, the concept of the phonological loop has been singularly successful in providing a coherent account of a range of phenomena, including neuropsychological data, using relatively few assumptions (Baddeley 1996).

The argument that the modules of working memory simply comprise a range of acquired skills (sect. 4.3, para. 2) begs more questions than it answers. We know at least as much (if not more) about temporary memory as we do about skill acquisition. For example, why should there be such consistent data patterns in temporary storage performance across individuals if performance relies on acquired skills rather than some universal aspect of a cognitive architecture? Moreover, could a theory based on acquired skills offer a coherent account both of normal temporary storage and of deficits found in patients such as "PV" (Vallar & Baddeley 1984) or "NL" (Beschin et al., in press)? An alternative role for skill acquisition might be in learning to use components of the cognitive apparatus or in learning to use them more effectively. For example, most human beings have the apparatus for generating speech, and aspects of this apparatus can be used covertly for subvocal rehearsal. The model of the phonological loop then offers an account of the nature of this apparatus and how it is used to provide temporary verbal storage. A related argument has been made for temporary retention of movement sequences and visual properties of scenes or objects (Logie 1995).

The distinction between working and long-term memory has an extended pedigree, going back at least as far as Locke (1690) who referred to the distinction between "contemplation" and the "storehouse of ideas." Of course, historical precedent does not necessarily justify the distinction, but unlike the blind men (sect. 7.4, para. 2), we already have a global view of the elephant (i.e., memory). What we are interested in is how its various parts help it make a path through the jungle.

Memory must also mesh affect

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Abstract: To model potential interactions, memory must not only mesh prior patterns of action, as Glenberg proposes, but also their internal consequences. This is necessary both to discriminate sensorimotor information by its relevance and to explain how goals about the world develop. In the absence of internal feedback, Glenberg is forced to reintroduce a grounding problem into his otherwise sound model by presupposing interactive goals.

Glenberg's target article provides an excellent description of how cognitive categories might develop through bodily interactions: memory meshes patterns of action with previously meshed patterns of action by virtue of their (analog) shape. I believe Glenberg's basic thesis, that memory contributes to survival by modeling potential interactions, has much to offer. While dictionaries tend to identify memory with conscious recall, Glenberg provides a framework for modeling not only recollections but virtually any kind of empirical sensorimotor adaptation. It is well worth examining how far Glenberg's framework can take us in simulating intelligent behavior and where it may need augmentation.

We first need to define what is meant by "patterns of action." Glenberg bases them on "projectable properties of the environment" (sect. 2.1). His use of the term *properties* is unfortunate because it implies that we should conceptualize memory in terms of properties that exist independently of any particular organism (with its unique body, sense organs, and life history). The same is true when Glenberg writes of the need to remain "reality-oriented" and to see "the environment for what it is" (sect. 3.2, para. 1). Although one may certainly assume the existence of an observer-independent reality, it does not follow that it is possible or useful to develop cognitive constructs in terms of it. I find no basis to claim that an organism has anything outside itself and its sensory projections to guide its interactions: It cannot infer the likely consequences of interactions except through spatiotemporal correlations in its sensory projections and internal variables.

An organism's sensory projections provide multidimensional analog input from sense organs. However, in order to model potential interactions, its cognitive system must be able to determine which changes in its sensory projections were self-induced. (This is necessary, for example, to determine whether to attribute a movement on the retinal image to the organism or to a perceived object.) Thus, memory must also mesh feedback concerning the organism's multidimensional motor signals.

Glenberg offers no specific proposal to incorporate internal feedback into his "spatial-functional" notion of mesh and expresses ambivalence concerning whether this would be possible (sect. 7.2). Given the conclusions of his analysis (namely, that memory is for modeling potential interactions), internal feedback and motivation must be included, first, because internal feedback is necessary to discriminate survival-relevant differences in an organism's sensory projections. One way we learn to distinguish sensory projections is by correlating them with their physiological and affective consequences. For example, we learn to discriminate berries not only by the interactions they afford (e.g., picking, chewing) but how they taste and how we feel after eating them. We are also naturally predisposed to certain affective reactions (e.g., fear of snakes).

Suppose memory were to mesh sensory projections and motor signals to the exclusion of their internal consequences. Then spatial features that were more relevant to discriminating objects by their physiological effects would be obscured by those that were less relevant but more pronounced. According to Glenberg, what makes "one path the path to your house, is its relevance to you, that is, how you have interacted with it in the past" (sect. 2.1, para. 2). But the path's "relevance to you" cannot be equated with "how you have interacted with it" *unless* your affective reactions to it and the affective consequences of your interactions with it have been meshed with your prior interactions.

The second reason memory must incorporate internal feedback and motivation is because we cannot settle the symbol grounding problem (Harnad 1990) until we have explained how goals arise. Glenberg writes that "[o]bjects fall into the same (basic) category because they can be used to accomplish the same interactive goal" (sect. 1.3, para. 3). Presumably, an organism (gradually) sensitizes itself to the category through achieving the goal. This presupposes that it *already* has a goal that can be expressed in terms of patterns of actions based on projectable properties of the environment. This is no less solipsistic than presupposing that it already has a symbol that corresponds to the category (e.g., Fodor's 1975 nativism). Truly adaptable behavior requires some interactive goals to develop within the lifetime of the organism, because specific interactive goals cannot evolve in anticipation of needs that have yet to arise. Hence, it would seem reasonable to posit internal variables (which indicate general health maintenance and reproductive needs) that guide empirical adaptation (i.e., memory) toward the development of interactive goals.

One characteristic of radical behaviorism (and simple reinforcement learning) is that it excludes interactive goals as theoretical constructs. Instead, it is assumed that patterns of response develop on the basis of stimulus and reward without reference to goals about the world. It would seem that, within Glenberg's framework, potential goals are solely a function of an organism's body and environment. An alternative is that an organism develops goals with reference to its conceptualization (or perceptual world) under the influence of internal feedback (Cowley & MacDorman 1995; MacDorman 1996).

Is memory caught in the mesh?

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Abstract: Can memory be cast as a system that meshes events to actions? This commentary considers the concepts of mesh versus association, arguing that thus far the distinction is inadequate. However, the goal of shifting to an action-based view of memory has merit, most notably in emphasizing memory as a skill and in focusing on processes as opposed to structures.

By attempting to tie memory to action, Glenberg is allying himself with his colleagues who study attention (e.g., Allport 1989) and who increasingly emphasized this connection. Although I would not accuse him of false modesty in saying that "this sketch is not a fully testable theory" (sect. 1.3, para. 7), I do applaud the effort and agree that it is necessary for a full understanding of cognition. In what follows, I consider the success of this particular enterprise with regard to memory only, leaving its relevance to language for others to evaluate.

No "sketch" is well defined and absolutely free of speculation; indeed, its purpose is to stimulate the development of a more full-fledged theory. Nonetheless, I found the frequent reliance on undefended intuition troubling. What is a "commonsense test of what it means to have meaning" (sect. 1.2, para. 2)? And why is it "hard to imagine how cognition could be based on the mappings of arbitrary symbols" (sect. 1.2, para. 7)? Likewise, I found the casting aside of existing accounts to be rather cavalier, as when at the outset it is simply asserted that most theories reveal "little that is important about memory" (sect. 1.1, para. 2). Which theories are meant to be included in this sorry collection? Or take the case where propositional theories are discarded because "a simple list of well-formed propositions" (sect. 1.2, para. 8) could not possibly do the necessary job. Would anyone expect this to be a "simple" task? And then there is the case of feature-based systems, where "it is difficult to understand how people can ever learn anything truly new" (sect. 3.3, para. 4). Why would this criticism not also be true for a system based on actions (or their components)?

More in the way of concrete comparisons to and criticisms of existing views would have been welcome. Even explanations that would appear to serve as springboards for Glenberg's views – such as instance theories (e.g., Logan 1988) or transfer-appropriate skill views (e.g., Kolers & Roediger 1984) – are only mentioned and not integrated into the present sketch. I would take this a step farther: when the behaviorists tried to account for all of cognition in terms of behavior, appeals were made to such ideas as subvocal speech to explain language (Skinner 1957). How big a step is Glenberg's account from this position, and in what direction?

The central concept of Glenberg's approach is that of "mesh." Meshing integrates a stimulus/episode/event with an action. Initially, I was tempted to view meshing as a convolution of stimulus and action, like the memory storage scheme in TODAM2 (Murdock 1993). But then what would it mean to say that a mesh is not an association, as Glenberg repeatedly emphasizes? If what is meant is that associations link two episodes or stimuli, whereas meshes integrate an episode with an action, then I think this relies on too narrow a definition of association. Even Aristotle wrote that "acts of recollection, as they occur in experience, are due to the fact that one movement [that is, thought] has by nature another that succeeds it in regular order" (in Herrnstein & Boring, 1966, p. 328). How could we ever tell a thought-movement mesh from an analogous association? Perhaps Glenberg's intention is to avoid the excess baggage associated with the concept of association; if so, it would be valuable to specify more clearly *how* a mesh is not an association, given that this is his core idea.

Having thus far been critical, I hasten to add that there is much to commend in Glenberg's account. I agree that memory is best viewed as a set of skills serving perception and action, which explains why there are no all-purpose, effortless mnemonics. Skills – whether in memory or in tennis – require practice. I also concur that priming due to past experience(s) does not enhance present perception; rather, it increases the fluency of interpretation and the coming to mind of relevant prior episodes (see Masson & MacLeod 1996). Similarly, conscious recollection produces its characteristic "feel" via an attribution applied to fluent reprocessing (cf. Jacoby & Brooks 1984). I even agree that comprehension may be a general skill (Palmer et al. 1985).

If Glenberg's view of memory based on event–action meshing is to prosper, many questions must be addressed at a number of levels. I will end by raising a few of these (without providing any hint of an answer). How can we distinguish events from actions, or is this even a reasonable question? How is a mesh *not* an association? What role do instances play in remembering? Why, if we do not experience categories, are object pictures categorized faster than they are named (Smith & Magee 1980)? What must be done to connectionist modeling to make it work for an "embodied system"? If suppressing the environment is crucial to successful remembering, might field dependence (Witkin & Goodenough 1981) be a good predictor of individual differences in memory? Should connecting of events to actions, as opposed to other events, lead to better memory for those events (see Cohen, 1989, for supporting evidence)? And above all, is mesh strong enough to support memory?

Semantic memory

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Abstract: Glenberg tries to explain how and why memories have semantic content. The theory succeeds in specifying the relations between two major classes of memory phenomena – explicit and implicit memory – but it may fail in its assignment of relative importance to these phenomena and in its account of meaning. The theory is syntactic and extensional, instead of semantic and intensional.

Disguised as a monk from the Monastery of Memory, Glenberg infiltrates the Citadel of Semantics, bastion of philosophers and linguists. Glenberg wants memories to be meaningful, to be about things in the world, and he wants to understand how memories refer. But prevailing theories of memory do not provide solutions to these problems. Glenberg's answer is that meaning is bodily movement, that memory is a vassal to perception and action, and that memory is for meshing the "embodied conceptualization of projectible properties of the environment . . . with embodied experiences that provide nonprojectible properties (sect. 2.2, para. 5)." Glenberg is after a theory of meaningful memories, a genuine theory of semantic memory.

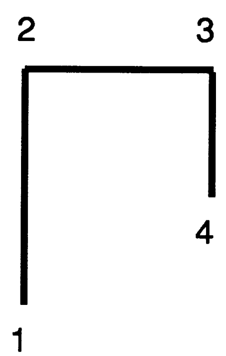

Figure 1 (McNamara). Four-point path.

I will confess that even after several readings of the target article, I don't understand exactly what Glenberg has in mind. It occurred to me, for example, that with a bit of care I could substitute proposition-speak (e.g., proposition, argument overlap, elaboration, etc.) for Glenberg-speak (e.g., conceptualization, mesh, embodiment, etc.) and the paper would be transformed into an endorsement of propositional theories. This leads me to conclude that I'm missing something big. Hence, my comments will be brief and probably idiosyncratic.

Let me start by identifying what I think are two intriguing ideas, one I think is right and one about which I am skeptical. The right idea is that there is an extremely important but largely unexplored relation between perception, action, and memory (e.g., Rieser 1989). Glenberg describes some of the relevant research, but an example is more compelling. Consider the four-point path in Figure 1. Study this diagram for a few seconds, and then answer the following questions without looking at the figure:

1. Without rotating your body, point to 1 as if standing at 3 facing 4.

2. After rotating your body 180°, point to 4 as if standing at 2 facing 1.

The first judgment is hard; the second one is easy. Why? The answer is clear – bodily movement accomplishes mental computation – but the mechanisms are poorly understood (but see Pellizzer & Georgopoulos 1993).

The other idea is that the role of implicit memory is to integrate representations provided by perceptual systems with representations of previous experience, and that our experience of explicit memory arises from the suppression of the environment and the attendant rise of the influence of representations of past experience. To my knowledge, this conceptualization of the relation between implicit and explicit memory is new. My enthusiasm is dampened, however, by the claim that the most important function of memory is the implicit, automatic function of integrating immediate and past perceptions. Here's my problem: People for whom this system is intact but the other system is scrambled (anterograde amnesics) are totally helpless. They can't learn anything new (with the exception of Tower of Hanoi, mirror tracing, and other equally exciting skills) and must be under 24-hour care. Amnesics cannot find the path home, let alone follow it. Contrast the plight of an amnesic patient to that of patient M.S., who has severely impaired visual implicit memory but intact explicit memory: He owns a computer software company (Gabrieli et al. 1995). I acknowledge that this comparison is unfair because M.S. has apparently lost only one of what may be a large number of implicit memory systems. Even so, the comparison forces me to wonder about the relative importance of each memory system. I don't think there is any doubt about who – H. M. or M. S. – we would rather be. The automatic, implicit memory system is surely important for something, but it is fundamentally aplysia memory: it is the system that's been around for hundreds of millions of years, not the system that is responsible for the rich complexity of human cognition.

Although Glenberg pines for a theory of semantic memory, he formulates his proposal in the language of syntax: The *structure* of a mental representation is lawfully related to the object represented; a concept is created by the *mesh* between perception and memory; and ideas can be associated because the *structures* of their mental representations *fit* together. Why are these ideas expressed in the language of form when the goal is a language of content? My hypothesis is that people have no other way of conceiving of, or at least talking about, meaning. Indeed, theories of meaning seem to be of two types, syntactic or extensional. Either they specify the form of and the formal operations on semantic presentations (e.g., Katz 1972) or they focus on the causal relations between agents and objects (e.g., Gibson 1979). Both of these problems are important ones to solve (e.g., Harnad 1990), but even together they are not sufficient as a theory of meaning. The first type of theory isn't semantic at all, and the second probably isn't the right kind of semantic theory (e.g., Fodor 1980). What is missing in all theories of which I am aware, including Glenberg's, is *intension:* The stuff that allows us to communicate about tables, cephid variables, and unicorns; the stuff that explains why it is possible for someone to believe that O. J. Simpson lives in California and not believe that the murderer of Nicole Brown Simpson lives in California, even though the two may be one and the same person. As I understand them, embodiment, mesh, and symbol grounding are not intensional concepts.

Glenberg's proposal is a species of naturalistic psychology. The concepts of embodiment, mesh, and so on are not theoretically grounded until we have some idea about what bodies get embodied in and what it is that representations get meshed with. Glenberg's psychology of memory would seem to require a theory of the structure of the world; after all, projectible properties will be described in the vocabulary of physics, not psychology. There is nothing wrong in principle with naturalistic theories, but they may have severe practical limitations, such as being the last of all scientific theories to be completed (e.g., Fodor 1980). I appreciate Glenberg's desiderata of a theory of memory, but I'm inclined to think that memory researchers may be better off abandoning the citadel, returning to the monastery, and getting back to work.

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Is memory like understanding?

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Abstract: There are three major weaknesses with Glenberg's theory. The first is that his theory makes assumptions about internal representations that cannot be adequately tested. The second is that he tries to accommodate data from three disparate domains: mental models, linguistics, and memory. The third is that he makes light of advances in cognitive neuroscience.

Glenberg attempts to integrate memory, linguistic, and mental-model research into a coherent model of the practical uses of memory. He claims that cognitive properties are "embodied" and cannot be treated as meaningless symbols that can be manipulated. Glenberg develops the idea that representations are analogically related to properties in the world, stating that the body and its interaction with the environment play a crucial role in cognition.

Glenberg's theory has three shortcomings. The first is that it makes assumptions about the nature of internal representations. In the past, debates on this issue have been somewhat fruitless because it is impossible to determine their format definitively. The second is that his theory largely ignores neuropsychological research and recent advances in cognitive neuroscience. The third is that there may be important differences between language comprehension and mental-models research on the one hand, and memory research on the other, that make an abstract approach to its study less useful than an approach that focuses more directly on the brain and behavior. Each of these points will be addressed in turn.

Glenberg begins his paper by renouncing the idea that cognitive representations can be reduced to meaningless symbols. He argues instead that internal representations are analogically structured (or embodied). Although he develops his idea well, and his model is less abstract than those that treat representations as meaningless symbols, he still relies on assumptions about how we mentally represent memories. This type of argument is reminiscent of the imagery debate in the 1970s that lasted about a decade and was never adequately resolved. Although important information was acquired about other topics of interest in imagery (e.g., whether or not it was epiphenomenal and whether or not it was functionally equivalent to perception), no answer was established about the nature of its representation. Anderson (1979) raised the important point that one cannot decide the format of images because for every theory that proposes one type of representation there can be another theory postulating another representation that makes the same predictions. This is because one can always alter the process operating on the representation to fit the results. Anderson's point is also relevant to Glenberg's claim because Glenberg also argues about the format of internal representations.

The nature of internal representations is less commonly debated among memory theorists than among those who study reasoning and linguistics. Neuroimaging techniques and data from neuropsychological patients have helped advance our knowledge about the brain systems underlying memory, and these data have been the basis of many memory debates. However, this sort of integrative approach combining efforts in neuroscience, biology, and psychology is not a focus of research in the fields of reasoning and comprehension – perhaps because both of these cognitive skills initially require the cooperation of lower forms of cognition, such as memory, perception, and attention. Our knowledge is still incomplete about the underlying brain areas responsible for carrying out these lower cognitive processes, and this information is necessary before we can begin to study reasoning and comprehension at the brain systems level. It is accordingly more useful to discuss these two processes at a more abstract level, like the one proposed by Glenberg. However, because we have some information about the brain regions responsible for memory, but not for reasoning and comprehension, a single model may not account for all three cognitive processes.

The discussion of "what memory is for" focuses more heavily on the commonalities between memory and the two higher cognitive processes than on the brain systems model of memory. Although this approach has many strengths, any discussion of memory needs to incorporate these findings. Glenberg dismisses much of this groundwork. For example, he claims that it is unnecessary to posit a distinction between short- and long-term memory because properties of both types of "systems" affect each other (e.g., recency effects can be long term; errors in short-term memory can be semantic in nature). However, Baddeley (1990) pointed out that these results do not necessarily present a problem for the view that there is more than one memory store, and it is possible for tasks to reflect the operation of more than one store.

Many would agree that the most crucial data in support of multiple memory systems come from neuropsychological patients. Not only are there patients who have impaired long-term memory with intact short-term memory (and vice versa), but there is also a growing literature using brain imaging techniques indicating that specific areas of the brain are designed to process specific types of information. While Glenberg's theory does not deny this, it certainly neither speaks to this issue nor treats it as having any importance. Glenberg states (sect. 4.1, para. 1) that he means explicitly to equate episodic and semantic memory. He states that theorists in recent years have acknowledged that although memories differ in the underlying processes used to retrieve and store memories, this does not necessarily imply that separate systems exist to support such memories. While this statement is in principle true, even major proponents of the processing view of memory acknowledge its difficulty with accounting for neuropsychological data (Roediger 1990). In light of the recent findings using both neuropsychological patients and neuroimaging techniques, the brain system view should not be dismissed.

In sum, although it is important to consider the underlying format of memory representations and to compare memory to other cognitive processes, such endeavors should be undertaken cautiously. Glenberg's model invites active discussion among theorists in these three subfields, but important differences in the level of complexity and current knowledge between subfields should be acknowledged. And finally, recent advances in memory research that have revealed an important interface between cognition and neuroscience should be considered and incorporated into in any theory of memory.

Functional memory: A developmental perspective

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Abstract: The functional theory of memory set out in Glenberg's target article accords with recent proposals in the developmental literature with respect to event memory, conceptualization, and language acquisition from an embodied, experiential view. The theory, however, needs to be supplemented with a recognition of the sociocultural contribution to these cognitive processes and emerging structures.

In answering the question "What is memory for?" Glenberg states that "embodiment in terms of action patterns is just what is needed to facilitate interaction with the environment and prediction" (sect. 6.2). This fits very well with a developmental perspective. For example, Nelson (1993) similarly suggested that the basic function of memory is to support action in the present and to predict future states. Specifically: "Any system of learning and memory conserves information about environmental conditions. It enables the organism to undertake action to meet goals under specific variable conditions . . . . The basic . . . functional memory system directs action in the present and predicts future outcomes" (p. 372). This functional view of memory allows for individual differences – and specifically for differences in perspective and memory between adult and child – while preserving a general process account (as does Glenberg's theory).

Other parts of Glenberg's functional theory of memory, conceptualization and language comprehension, also fit well in a developmental perspective. For example, the "functional core concept" outlined by Nelson (1974) could easily be restated in Glenberg's terms: "to a particular person, [child] the meaning of an object, event, or sentence is what that person can do with the object, event, or sentence" (sect. 1.3, para. 1). Furthermore, the statement "objects fall into the same (basic) category because they can be used to accomplish the same interactive goal" (sect. 1.3, para. 3) maps neatly onto the idea of "slot-filler categories" as the origin of the abstraction of functionally based superordinate categories such as food, furniture, and animals (Nelson 1988; Lucariello et al. 1992). These ideas are all consistent with Lakoff's construction of "embodied cognition" as well as with an experiential developmental psychology and an "experiential semantics" (Nelson 1996).

Glenberg's theory of memory might well have evolved from the script theories of action, event memory, conceptualization, and language comprehension (Schank & Abelson 1977), although he does not refer to this source. The important functions of updating and predicting were articulated in terms of scripts almost 20 years ago, and subsequent research based in this framework also produced evidence of poor memory for repeated typical episodes and good memory for unusual or atypical episodes of a recognizable scripted event, findings Glenberg refers to from other more recent paradigms. There is much else in the script literature that is compatible with Glenberg's theory and that may provide additional support, as well as extend it in new directions and raise new issues. For example, any encounter by an individual is thought to instantiate a script appropriate to that situation; how does the individual's memory representation automatically recognize or match an available script to a newly encountered situation? To my knowledge, this problem remains unsolved and appears to be as problematic for Glenberg as for Schank and Abelson (1977).

Although there are many more specific points worthy of comment, given space constraints I can consider only two of them. One is the case of infantile amnesia. I have addressed this in terms of prior event knowledge – a kind of automatic memory – supplemented by a personal, social function of conscious recollection in narrative form. Such recollection is fostered by exchange of memory talk between adults and children, as much developmental research now attests, leading to the establishment of an autobiographical memory system (personal memory) beginning between three and four years (Nelson 1993). I agree that the establishment of this memory function is related to the establishment of a distinctive sense of self and other. Glenberg's relating of recollection and prediction in terms of the effortful suppression of projectible properties is most interesting in light of recent work suggesting that the establishment of a continuing self with a history (personal memory) and a personal future takes place at about the same age (about 4 years), and that these developments are related to the kinds of talk that children and adults engage in on these topics. It may be further noted, however, that autobiographical memory involves two kinds of temporal order: order within an episode or narrative and order between the events represented. Achieving the latter order no doubt requires considerable management and effort. But the order within events – how things go from first to last within a script, for example – appears to be automatic in an embodied memory system for infants and young children as well as for adults (Bauer 1996; Nelson 1986).

Finally, the claim that the onset of autobiographical memory (and the offset of infantile amnesia) is related to the discussion of past episodes with other people reflects a more general assumption that understanding human cognition, in its development as well as in its developed forms, requires seeing it as part of a world of sociocultural activity as well as in its embodied state. Language becomes a surrogate for direct experience only through the intersubjectivity and interactivity of the child and her caregivers. The issue that Glenberg deliberately sidestepped – that of the matching of language forms to the individual conceptualizations derived from embodied representations – can only be addressed within a social communicative framework. As such, it is the key to many of the issues that he addresses, and specifically to those involved in language comprehension. The symbol grounding problem (Harnad 1990) cannot be solved entirely through embodied cognition but requires the recognition that words are socially shared symbols that somehow overcome the difficulties posed by the existence of individual experiential worlds (see Nelson, 1996, for further discussion).

Against suppression and clamping: A commentary on Glenberg

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Abstract: The ability of Glenberg's model to explain the development of complex symbolic abilities is questioned. Specifically, it is proposed that the concepts of clamping and suppression fall short of providing an explanation for higher symbolic processes such as autobiographical memory and language comprehension. A related concept, "holding in mind" (Olson 1993), is proposed as an alternative.

This commentary will examine two components of Glenberg's theory; clamping (sect. 3.3) and suppression (sect. 3.4). Glenberg ties clamping and suppression to the emergence of recollective experience in children (sects. 5.2.1–6.1). Clamping and suppression fall short of providing the basis for the symbolic abilities that are crucial to the waning of early childhood forms of memory and the comprehension of language. Further development and modification will be necessary for Glenberg's model to explain the role of a dynamic memory process in linguistic creatures.

Recollective experience in children may be better interpreted from the perspective of the general ability to "hold in mind" two differing representations (Olson 1993; Russell 1996). It is neither the ability to cancel out or suppress the contribution of the environment to conceptualization, nor the ability to clamp or suppress the conceptualization based on the environment that bootstraps autobiographical memories and a sense of self, as Glenberg maintains. Rather, it is the basic ability to "hold in mind" a representation that is not the direct result of what is "held in view" (Olson 1993; Russell 1996).

"Holding in mind" is very similar to clamping. Both allow the child to construct a representation of the world that exists independently of the child's current experience of the world (Russell 1996). Clamping occludes or immobilizes environmental input (suppression is the flip side of the same coin). Although "holding in mind" does dampen the overriding input of the environment, unlike clamping, it allows for a dynamic interplay between concept and reality. The child is able to think about one thing while experiencing something different (Russell 1996). The development of the ability to hold in mind changes the child's relationship not only to the world but also to representations of the world. Glenberg glosses over these important points in his treatment of childhood amnesia.

Childhood amnesia may be described as the inability to recollect any autobiographical memories of the first three years. Glenberg conflates this definition of childhood amnesia with the general inability to form memories with episodic "traces," autobiographical or not. He argues that apart from the ability to suppress environmental inputs, childhood amnesia is resolved because children develop the ability to control what they are thinking about, which Glenberg links to the acquisition of language. Simply having the ability to control what you are thinking, however, does not explain how the child develops a concept of self that allows for autobiographical memory. Children must also be able to manage representations about sources; that is, information about the world as well as their current attitude toward that information – it is "I who sees this" (Perner 1991).

This fundamental representation of the self as the source of perceptions and knowledge about the environment, which is separate from the perception and formation of knowledge structures about the environment, provides a basic, self-referential duality. It is this duality – "that which is represented" versus "that which is doing the representing" – that forms the basis for a concept of self. Once this is achieved, the child is able to conceptualize knowledge as a representational state of the mind, something that is "owned" by the self. (Perner 1991). In Glenberg's words, the child is beginning to think in "adult ways."

It is unclear how Glenberg's model could provide for such a development through the constructs of clamping and suppression. The general ability to compare two representations of the same thing, one "held in mind," the other "in view," is a prerequisite for higher-order operations such as formulating a proposition or reflecting on one's own thoughts. This does not mean that there is a sudden point below which children are unable to recall events from the past. Rather, as this basic skill of holding in mind develops and takes into account more extensive and subtle distinctions between the two representations being held, richer representations can be formulated, some of which permit episodic memory. The development of "holding in mind" revolutionizes both what is stored and the way children access information about the environment, thus changing their relationship to their memories. The child's mode of representing events changes in accord with changes in the ability to relate what is "held in mind" to what is "held in view." Memories made before this change in representational ability do not have the same sort of information as memories made at a later stage of representational ability.

Clamping and suppression also fall short of explaining language comprehension (sect. 5.2.3). Glenberg assumes that language comprehension involves decoding the spoken or written message in a literal fashion; the meaning of an utterance is realized as potential action in the environment (sect. 6) and abstract language is understood in concrete terms (6.4). Good comprehenders are considered to be good at suppressing the environment. One wonders how these "good comprehenders" would do at comprehending figurative language. Glenberg's proposal gives short shrift to language phenomena and avoids the crucial distinction between "what-is-said" and "what-is-meant." Clearly, "holding in mind" allows for the comparison of representations of the utterer's speech, gestures, or other metalinguistic information. "Holding in mind" allows a dynamic interplay among many representations of diverse information. Clamping may account for the occlusion of information but it seems less adequate to account for the carrying forward of information that may be usefully related to current perceptual experiences. This is where "holding in mind" might be relevant. It is unclear how clamping and suppression could deal with metalinguistic concerns and allow for different levels of meaning.

In conclusion, Glenberg succeeds in providing a theory that views memory in relation to the richness of human cognitive processes such as navigation. His thesis fails to explain highly complex symbolic processes such as the development of self and the comprehension of language.

What is modeling for?

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Abstract: What would Glenberg's attractive ideas look like when computationally fleshed out? I suggest that the most helpful next step in formalizing them is neither a connectionist nor a symbolic implementation (either is possible), but rather an implementation-general analysis of the task in terms of the informational content required.

In an engaging and thought-provoking target article, Glenberg starts by asking what memory is for; in answering this question, he also suggests what memory might *be.* The proposed purpose of memory is clear: It supports perception and action in the world. The general idea behind the posited mechanism is also clear, but the details are less so. This is a perfectly reasonable state of affairs for the time being, as Glenberg's intention was presumably to convey the outlines of a simulation-based approach to conceptualization and memory and to indicate a number of radical reinterpretations that this approach suggests. He has succeeded in this, in my estimation. The central concept, of internal simulation aligning with occasionally suppressible perception, is an appealing one. Still, once the basic idea has been absorbed, a question concerning the concretization of this general notion presents itself: What sorts of representations might underlie such simulated embodied conceptualizations, and what operations might manipulate them? In a word, what do these ideas look like when fleshed out computationally?

Glenberg points out that some of the ideas he has adopted can be traced to connectionism; a natural question then is whether the approach as a whole is appropriately modeled through connectionism. I would first like to discuss briefly two pieces of connectionist research that may be of relevance for the formalization of these ideas, and would then like to suggest that the aspects of these systems that make them appropriate are not intimately bound up with their connectionist character. A symbolic system could easily exhibit the same properties. So to peek at our punch-line in advance: There are certainly tools available that can aid in the formalization of mesh, bodily constraints, and trajectories, but those tools can reside on either side of the great connectionist/symbolic divide. I believe that the relevant issue for these purposes is not so much the implementational substrate of the mechanism, but rather the informational content of the data structures involved.

Bartlett Mel's work on robot control (Mel 1988; 1989) exhibits a feature that is quite similar to a central aspect of Glenberg's program. Mel's work concerns a connectionist system that learns to guide a robot arm to reach objects. The critical point is that once the model has been trained, it can activate a mental image of the arm in its environment and can use this mental simulation to evaluate contemplated arm movements without actually moving the arm in the external world. Once the mental simulation is done and a course of action has been decided upon on, the model can act. This internal simulation corresponds fairly closely to Glenberg's notion of temporarily suppressing interaction with the outside world so that simulation can play a dominant role.

Another possibly relevant piece of research is my own connectionist work in modeling the acquisition of spatial semantics (Regier 1996). This model learns to map simple two-dimensional percepts of objects moving relative to one another onto spatial terms in a number of languages. The aspect of the work that is germane to Glenberg's proposal is its incorporation of perceptual structure that constrains its operation, such that not everything is learnable. This then is an example of constraint that Glenberg would probably view as "bodily" in nature, embedded in a connectionist model.

Thus, these two pieces of connectionist research highlight two very general implemented principles of the Glenbergian project: mental simulation and perceptual constraints. But there is nothing particularly connectionist about either of these two principles. Their implementation in connectionist fashion may be reassuring in that it indicates that such implementation is well within the state of the art, but both mental simulation and perceptual constraints could easily be accommodated within a symbolic system. In fact, the idea of a perceptual symbol system (Barsalou & Prinz 1996) exemplifies a fundamentally symbolic approach to cognition that has perceptually constrained mental simulation at its heart. Despite the inspiration Glenberg draws from connectionism, and despite the existence of connectionist systems that embody some of the principles he espouses, it is those principles themselves, rather than their implementation in this or that system, that ultimately form the core of the effort.

What, then, is modeling for? If after all the trouble of implementation we are left with the conclusion that it is the general principles we began with that count, why bother? The answer is that the process of modeling can lead to a clarification of these general principles. Prior to jumping to implementation, a careful examination at the computational and algorithmic levels (Marr 1982) would determine the content of the data structures required and the nature of the operations running over them. And this, rather than the implementation itself, could help in making Glenberg's attractive but still largely intuitively grasped theoretical notions more concrete. That would definitely be worthwhile.

What memory is for action: The gap between percepts and concepts

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Abstract: The originality of Glenberg's theoretical account lies in the claim that memory works in the service of physical interaction with the three-dimensional world. Little consideration is given, however, to the role of memory in action. We present and discuss data on spatial memory for action. These empirical data constitute the first step of reasoning about the link between memory and action, and allow several aspects of Glenberg's theory to be tested.

The theoretical first section of Glenberg's target article proposes that there is a close link between conceptualization and action, yet relatively little experimental data from the literature about movement science are considered. Considering Glenberg's paper as a whole, one feels that between the idea that concepts are embodied in action and their role in language comprehension a step is missing. As pointed out by Glenberg (sect. 7.4), common "laboratory paradigms for studying memory may well be missing the mark. Many of these paradigms use random lists of words as the object of memory." This is particularly true if "memory is embodied and designed for negotiating a three-dimensional environment" (sect. 7.4, para. 1) and if "the world is conceptualized (in part) as patterns of possible bodily interactions, that is, how we can move our hands and fingers, our legs and bodies, our eyes and ears, to deal with the world that presents itself" (sect. 1.3, para. 1). The first step for testing Glenberg's theory should thus be to investigate what memory is for action. The aim of this commentary is to make use of examples of interaction between perception and memory in the guidance of simple actions that may be useful in bridging theoretical considerations about action and discussions about semantic memory or language. We will thus show how different levels of object representation may interact during the production of simple motor responses to spatial stimuli.

A problem with Glenberg's theory of meshed patterns of action is that it suggests that there may be a single way in which memory and perception interact to guide a given action in a given context. Once the unified mesh has been built from the projectable and nonprojectable properties of the spatial layout, this "unified" representation is used to guide action. In addition, this view benefits from an automatic contribution of memory. A lot of data, however, indicate that motor and symbolic representations of a given stimulus can be dissociated (Goodale & Milner 1992; 1995; Jeannerod & Rossetti 1993). Patients with visual agnosia or blindsight provide an interesting example, being able to reach and grasp a simple visual object without identifying it (Goodale et al. 1991; Perenin & Rossetti 1996); they are counterevidence to the idea that the "meaning of an object or a situation is a particular pattern of possible action" (sect. 2.2, para. 3). In addition, such patients are unable to produce a similar action when the target object has to be memorized (see Milner & Goodale 1995; Rossetti 1997). They seem able to integrate the metric properties of an object with action on it, but they remain unable to memorize this percept to delay the action or to combine the percept with memorized representations that could allow conscious recognition of the object. In contrast, optic ataxia patients cannot act on objects they can describe and recognize normally (Perenin & Vighetto 1988). These cases do not agree with the statement that "the meaningful, action-oriented component of conceptualization is not abstract and amodal" (sect. 1.3, para. 2). In the same way, prefrontal lesions in the monkey produce a dissociation between visually guided and memory guided saccade or reaching to the same target (Funahashi et al. 1993; Procyk et al. 1996). In addition, the neuroanatomy of the visual areas and their projections suggests that there is an early segregation between a dorsal stream specialized for vision for action and a ventral stream specialized for visual object recognition (see Goodale & Milner 1992; Jeannerod & Rossetti 1993; Milner & Goodale 1993). These data may be regarded as elementary examples of segregation between percepts and concepts. Action implies space perception and representation, but does it always require conceptualization? The above examples show that action can be accurate even when no conceptualization is available to the patient. There must be a "morphological" level of sensory integration that lies between the physical and the symbolic levels (see Petitot 1990). This level would code metric but not symbolic properties of spatial layouts.

In criticizing the distinction between short-term and long-term memory, Glenberg argues that different "skills," rather than different "modules," are involved in producing separate sets of data (sect. 4.3). The motor control literature shows that this is not always the case. According to Glenberg, there would be no a priori reason to believe that a given action would be based on different representations, depending upon the length of a short delay after stimulus presentation. Several such examples are, however, available in the literature (Bridgeman 1991; Gentilucci et al. 1996; Goodale & Stevens 1992; Goodale et al. 1994; Rossetti & Regier 1995; Rossetti et al. 1996; White et al. 1994; see review in Rossetti, in press). One of the most striking examples made use of the Müller-Lyer illusion of length (Gentilucci et al. 1996). Although the perceptual effect of this illusion is very vivid, it affects pointings from one end of the line to the other only very minimally (see also Aglioti et al. 1995). The effect of the illusion on movement length increases, however, when the layout has to be memorized during a longer delay. Another example is illustrated here in Figure 1. Pointing movements produced either zero seconds or a

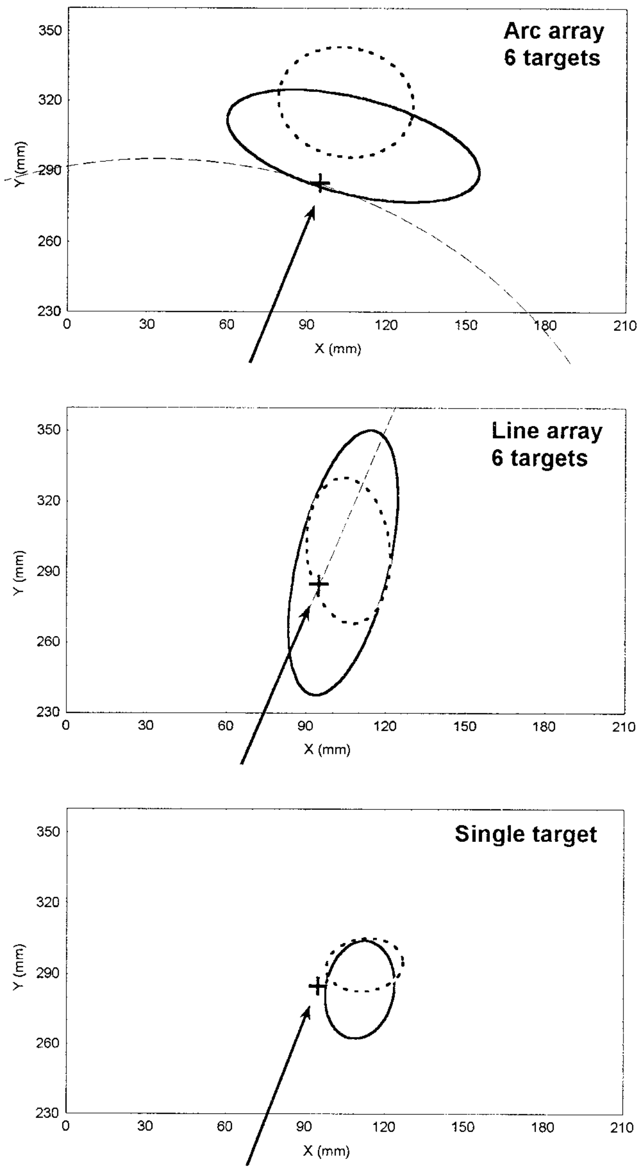

Figure 1 (Rossetti & Procyk). Confidence ellipses (95%) of pointings toward the same absolute target position in space under three different conditions. Target positions were encoded by a brief (300 msec) passive positioning of the left index finger on a sagittal panel, and pointing was done with the right hand either 0 sec (dotted ellipses) or 8 sec (bold ellipses) after target presentation, on the other side of the panel. In the *single target condition*, Ss had to point to a target that was 30 cm from the starting point (arm resting on the table) and 11° anterior to the vertical axis crossing the starting position. In the two other conditions, Ss had to point toward six possible target locations, including the location used in the single target session. In the *arc condition*, targets were positioned on an arc centered on the starting position (ø 30 cm), as shown by the broken line. In the *line condition*, targets were positioned on a line crossing the starting point (11°), as shown by the broken line. The ellipse orientation observed after the 8 sec delay in the arc and line conditions differed significantly. In both cases, ellipse orientation was aligned with the target array, that is, with the spatial layout used in each particular condition. These specific orientations of the pointing scatter were observed neither when the delay was 0 sec nor when the spatial layout was reduced to a single target. Arrows indicate movement direction (individual results from a representative subject).

few seconds after target presentation should lead to similar performance, although longer delay should cause greater variability. Qualitative differences obtained in such a condition provide a strong argument for two possible modes of sensory processing: The spatial layout morphology is integrated in the action only for the longer memory delay (Rossetti & Régnier 1995, Rossetti et al. 1996). This confirms that "action-oriented meaning can vary greatly with context" (sect. 1.3, para. 6) and, more specifically, that "Patterns of action derived from the projectable properties of the environment are combined . . . with patterns of interaction based on memory" (sect. 2.2, para. 2). If our results confirm that "Patterns of action based on the environment (projectable properties of the environment) are automatically, that is, without intention, meshed with patterns based on previous experience" (sect. 2, para. 1), they nevertheless indicate that this may be so only after a given delay.

If "embodied mental models reflect a structured space (that is, . . . structured by possible actions)" (sect. 6.3, para. 5), then it is difficult to explain why the mental model of a target position to be reached should vary according to whether or not the position has to be memorized. A possible way to reconcile Glenberg's theory with empirical data about the role of memory in action is to consider that the "meshing" of percepts and concepts takes time. In our experimental conditions (Fig. 1), it is not true that "spatial layout is a projectable property" (sect. 2.1, para. 2), because all targets are never available simultaneously. It may be that our shorter delay did not provide enough time for "embodied memories" to interact with "the current environment" (sect. 5.1). A possible way to stress the elaboration of a conceptualized representation of a spatial layout is to require the subject to produce a verbal estimate of the current position to be pointed to. Under this condition, the effect of the spatial layout already clearly appears for the 0 sec delay (methods similar to those in Figure 1). Thus, the delay and the forced verbalization produced similar qualitative effects on the pointing, showing that the very same action can depend or fail to depend on contextualized representation. This result also suggests that "automatic" and "effortful" (sect. 5) components of memory contributing to conceptualization may be responsible for similar effects on action.

Delayed-response tasks do not involve "changing conceptualization (changing because the stimulation changes in response to action)" (sect. 4.3, para. 3). They disagree with Glenberg's theory, however, in that they show changes in the representation underlying the action. To be compatible with these experimental data, Glenberg must integrate the idea that the meshing of percept with concept requires some time to be accomplished, that is, that there may be a time gap between percept and concept.

Suppression, attention, and effort: A proposed enhancement for a promising theory

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Abstract: Although Glenberg's theory benefits from the incorporation of a suppression concept, a more differentiated view of suppression would be even more effective. We propose such a concept (based on the attention framework first developed by William James in the late nineteenth century), showing how it accounts for phenomena that Glenberg describes and also for phenomena that he ignores.

Memory, Glenberg writes, is for imbuing the "obvious" properties of an environment with personal significance, such that an objective world acquires subjective import. The mental meshing of one's present context with the remembrance of previous embodied experiences provides the meaningful conceptualizations needed to guide effective perception and action. While this functional approach impressively draws together a wide range of empirical findings, one wonders how an embodied mind in its natural habitat happens to clamp certain projectable properties and not others. How does it select from memory those experiences that bear most usefully upon the current situation? Without the capacity to attend selectively to some external phenomena or memories and to ignore others, a person's thought and behavior are confused, disorganized, and largely ineffective, as the experience of frontal lobe patients, schizophrenics, and others attests.

	External	Internal
Easy	Viewing scenic nature or social drama	Daydreaming
Effortful	Maintaining vigilance in the face of boredom	Problem solving

Figure 1 (Schwartz et al.). Two dimensions of attentional functioning.

Glenberg addresses one aspect of the problem of selection when he notes that the capacity for prediction sets up a conflict between the internal and external contributions to conceptualization; he suggests that cognitive suppression developed as a solution to this problem. We agree that suppression serves this function, but we think it does much more besides. In what follows we show how considering the role of memory and suppression within a broader attentional framework enables us to incorporate psychological phenomena that do not mesh easily into Glenberg's conceptualization.

Following Kaplan (Kaplan 1995; Kaplan & Kaplan 1989) and Cimprich (1992), we derive our attentional framework from the taxonomy William James proposed in his *Principles of Psychology* (1890/1981). James noted that attention can be directed either "outward" toward the phenomenal world ("sensorial" in his terminology) or directed "inward" toward memories, abstract ideas, and so forth. We refer to this as the internal–external dimension of attentional functioning. James also noted that attention can be summoned (and held) involuntarily or directed willfully. We refer to this as the easy–effortful dimension of functioning, because willfully directing one's attention seems always to involve some degree of effort. Treating these two dimensions as orthogonal yields the matrix shown in Figure 1.

The top left cell encompasses those instances when the mind attends effortlessly to external phenomena that intrinsically hold one's interest and dominate awareness, such as mountain vistas, wild animals, dramatic (or dramatized) human social interaction, and so on. Of the four cells in the matrix, the easy–external form of attention seems most closely related to Glenberg's notion of clamping projectable properties of the environment, inasmuch as the focus is directed outward and the conceptualization does not involve effort. We should not, however, equate absence of effort with absence of suppression, for some forms of suppression can feel quite effortless. A reader absorbed in a mystery novel, for example, or a hunter stalking his prey, or a person engaged in courting or mating behavior all exhibit reduced sensitivity and/or responsiveness to stimuli that might otherwise attract their notice. In such instances, we suggest, the psychological content and/or process (mystery, hunting, mating) resonates so strongly with evolved human inclinations that it engages mechanisms of suppression (and thus captures attention) without, or even in spite of, one's conscious intention.

The bottom right cell, by contrast, corresponds most closely to Glenberg's notion of effortful reflection in the service of prediction or recollection. Here suppression of the external contribution to conceptualization frees thought from the here and now to facilitate goal-directed mental transformations such as solving problems. Glenberg speculates that suppression of the external contribution to awareness is experienced as effortful and aversive because ignoring the environment is dangerous. We agree that purposeful reflection often does feel effortful and that ignoring the environment can indeed be dangerous. However, we find Glenberg's causal linkage not altogether compelling because, as we point out below, reflection is not always effortful and there are effortful forms of suppression that actually serve to enhance rather than to diminish the external contribution to conceptualization.

The top right cell of the matrix, for example, encompasses those instances, such as daydreaming and reverie, when the internal contributions to conceptualization so dominate awareness that a person can seem almost oblivious to external circumstances. (We assume, however, that even in such circumstances a person continues to monitor the external state of affairs preattentively.) Clearly at such times the projectable properties of the environment are in some sense suppressed, but this suppression involves no feeling of effort. Does the absence of effort suggest that neglecting the environment while daydreaming is somehow less dangerous than ignoring it when engaged in purposeful thought?

Moreover, just as one might at times find it necessary to suppress awareness of the environment in order to liberate thought from the here and now, so might one effortfully suppress reflection in order better to attend to what's going on in the environment. When "what's going on" happens to be a particularly boring lecture or journal article, or an uneventful vigil for a sentry keeping watch, the amount of effort involved may reach truly heroic proportions. The feeling of effort in such instances, however, cannot signal the danger of ignoring the environment, because the effort is associated with attending to the environment.

Why, then, does suppression, whether of the internal or external contribution to conceptualization, often feel effortful? We suggest that suppression is effortful because, like swimming upstream, it involves willfully opposing the inertial flow of undirected thought, and overcoming (neurophysiological) inertia, of whatever kind, requires (physiological) work. For example, consider trying to inhibit a response that you have already initiated, as in the stop-signal paradigm (Logan & Cowan 1984). This type of motor suppression generally feels effortful, though it seems unrelated either to prediction or to recollection. We suggest, rather, that all effortful mental activity consists in deliberately intervening in or suppressing one's ongoing thought or behavior for the sake of some internally represented goal. Consequently, in the absence of any represented goal or problem to solve, thought is largely exogenous (driven by external cues), habitual (following default associative structure), and effortless.

These differences notwithstanding, we applaud Glenberg for having proposed an ambitious and synthetic theory of cognitive functioning. By placing the mind in the body and the body in the world, he offers an engaging perspective on the hows and whys of human memory. While we question a number of his specific assertions, we enthusiastically endorse the spirit of his proposal. To those of us for whom symbolic cognitive models consisting of disembodied formalisms and propositional logic seem as dry as the desert sands, Glenberg's functional approach stands as a refreshing oasis in the conceptual landscape.

Conceptualizing a sunset $\neq$ using a sunset as a discriminative stimulus

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Abstract: Glenberg offers two different accounts of embodied conceptualization. The first fails in cases where no direct bodily interaction is possible. The second fails in cases where the object in question cannot serve as a discriminative stimulus; moreover, it yields inappropriate content even in cases where it can be applied. Glenberg's disregard for the conceptual agenda set by the social world is also disquieting.

There's a lot to like about Glenberg's proposal. Some concepts do seem to have "functional-spatial" content: functional fixedness is a robust phenomenon; home is where you hang your hat; and, at least for three-year-olds, a hole is to dig (Krauss 1952). Who knows? Maybe there are organisms whose *Umwelt* is, indeed, entirely furnished by things-of-action. Moreover, it seems that thinking sometimes recruits mechanisms that subserve perception and motor activity, for example, imaging improves motor performance (Finke 1986) and loss of meaning associated with word repetition can be staved off by engaging in semantically appropriate gestures (Werner & Kaplan 1963). All in all, it seems plausible that (1) bodily interactions with the physical world constitute the content of some concepts, and (2) cognition sometimes recruits perceptual/motoric vehicles.

What then, is not to like? Well, for one thing, Glenberg's proposal that "embodied representations" have the content they do "by virtue of being lawfully and analogically related to properties of the world . . . [as] transduced by perceptual-action systems" (sect. 1.3, para. 2) arrives with not so much as a hint that theories of content that lean on nomological liaisons or similarity relations have their own nontrivial problems. When push comes to shove, Glenberg turns, unannounced, to a different theory. Better, probably, to leave heavy duty semantics to people who do it full time, most of whom would flinch at hearing standard philosophical doctrine on sentence meaning presented as "[it is] whatever allows one to determine if [the sentence] applies to particular situations" (sect. 1.2, para. 5); verificationism is as unpopular as classical description theory these days.

It is also the case that even good evidence that *some* concepts have functional-spatial content (or that *some* cognitive activities are supported or accompanied by motor activation) does not make it equally plausible that this is true of *all* conceptualization. Glenberg admits that "experiences of music, taste, and emotions . . . have aspects that do not fit well into a spatial-functional straitjacket," but thinks that "the same sort of analysis" may turn out to be applicable (sect. 7.2, para. 1). His idea of what constitutes success is worth a closer look. How, for example, could an individual conceptualize a sunset? Glenberg's answer is that "a beautiful sunset is a context that combines with objects and memories to suggest actions consistent with warmth, relaxation, and a good beer" (sect. 1.3, para. 6). That is, a sunset can signal an individual, *S*, that various activities – making a fire, going to the "fridge," etc. – will (under the circumstances) have as their consequences warmth, relaxation, and a good beer. Put a bit more formally, Glenberg's solution is that a sunset can be conceptualized because it can serve as a discriminative stimulus. How so? Well, as any operant theorist knows, discriminative stimuli acquire reinforcing properties along with their ability to "control" some bit of behavior. Were Glenberg's story to be that *S*'s conceptualization of *X* is a matter of *S* having response tendencies with respect to *X*, then, if *X* comes to serve as a discriminative stimulus for *S*, *X* has ipso facto been conceptualized by *S*. This seems to be what he has in mind: "Our understanding [conceptualization] of pleasurable experiences is in part action-toward those experiences, whereas our understanding [conceptualization] of aversive experiences is in part action-away" (sect. 7.2, para. 2). This alternative characterization is unsatisfactory on at least two counts. First, identifying meanings with responses (or dispositions to respond) notoriously fails to yield appropriate contents (Alston 1964). The first snowfall of the season may also "suggest actions consistent with warmth, relaxation, and a good beer," but one's conceptualization of the first snowfall is not the same as one's conceptualization of a beautiful sunset. Second, this account still does not allow conceptualization of items that are neither available for direct physical interaction nor serviceable as discriminative stimuli.

Informal examples are not the only hard cases. An important account of object recognition construes it as a parsing of visual displays into standard 3-D forms (*geons*) related to each other in a limited number of ways (Biederman 1987; 1988). How objects can be or have been handled plays no explanatory role. Even in developmental psychology, the homeland of sensorimotor intelligence, it has become increasingly clear that infants' and young children's equivalence classes both antedate and crosscut similarities based on overt manipulation (Mandler 1990). Shared impalpability, for example, does not incline 4-year-olds to lump together smoke, shadows, and beeps, on the one hand, with thought contents, on the other (Wellman 1990).

Finally, the world in which Glenberg's embodied cognizers are situated is curiously impoverished. One would never suspect that everyday mind reading, coordination of action, detection of cheating, identification of kinship, or negotiation of discourse (to name only a few) set pressing conceptual agendas (Tooby & Cosmides 1992). "Social cognition" is characterized with startling brevity as requiring nothing more distinctive than the ability to see people "not just as objects that we can affect, but as beings who can affect us in turn" (sect. 7.2, para. 5). Nor would one suspect from Glenberg's account that representation of properties such as being a smile, a face, a speech sound, or the sound [ba] are no more indebted to individual experience than are properties "specified by information available in the light" (sect. 2.1, para. 2): Even explicitly Gibsonian approaches to social cognition are ignored (McArthur & Baron 1983; Zebrowitz 1990).

Glenberg recommends a pragmatic approach to meaning and memory. A pragmatism worthy of the name, however, must be scrupulous in characterizing the nature of the task (Marr 1982).

Productivity and propositional construal as the meshing of embodied representations

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Abstract: Contrary to prevailing views, *productivity* and *propositional construal* are *not* problematic for perceptual views of representation. Glenberg's embodied representations contribute to our understanding of how these two important processes might be implemented perceptually.

For at least the last three decades, the dominant view in cognitive psychology has been that human knowledge is represented by systems of amodal propositional symbols. In his target article, Glenberg argues that human knowledge is represented instead by analogical, perceptually based, "embodied" representations. Glenberg argues that psychologists' theories of memory have focused on propositional symbols because these symbols reflect the stimuli used in classic memory paradigms, namely, lists of words. Glenberg argues that this focus on propositional symbols has caused theorists to ignore the more important and more prevalent "embodied" representations that he discusses in his paper. While we agree with Glenberg that researchers' tools and paradigms influence their theories (Gigerenzer 1991), we believe that other factors, such as philosophical arguments, have also contributed to the widespread acceptance of propositional representations in psychology, together with the rejection of embodied theories. In this commentary, we outline and discuss two traditional philosophical arguments against embodied theories, and we discuss how Glenberg's embodied theory could handle these kinds of arguments.

Embodied theories of representation are not new. Many early philosophers, such as the British empiricists, argued that people's thoughts and memories are represented by images derived from perceptual experience. These theories and others like them, however, have been dismissed in modern philosophical circles because of strong objections made by twentieth century philosophers and psychologists. Two important problems for traditional embodied views are their inability to represent *productivity* and *propositional construal* (Barsalou, in preparation; Barsalou & Prinz, in press). Although it is not explicitly stated in his paper, we believe that Glenberg's idea of "mesh" has two different technical senses that address these two philosophical concerns.

The first philosophical problem concerns how an embodied theory can represent productivity. Humans produce an indefinitely large number of expressions or thoughts from a finite number of components. A theory of representation must be able to explain how primitive representations combine to form larger representational structures. Psychologists and philosophers have embraced propositional symbols because they can be combined easily by the syntactical rules of logical languages, such as predicate calculus. It is more difficult, however, to imagine how analogical or embodied symbols could be combined to produce new representational structures. What would be the syntax of these embodied representations?

Barsalou (in preparation) and Barsalou and Prinz (in press) illustrate how a perceptual theory of knowledge could produce productivity. Glenberg's construct of "mesh" adds to our understanding of this important process (see Prinz & Barsalou, in press, for a similar proposal). Following Glenberg's "deflated ball" example (sect. 3.1.3), combining embodied representations involves meshing patterns of action for *deflated* and *ball* in a manner that satisfies constraints on how their referents occur in the world. These constraints are spatial and functional rather than associative or probabilistic. Thus, the syntax for how new thoughts can be produced by combining existing ones is dictated by the constraints on how objects can be manipulated or acted upon in the world.

This is an important claim about productivity because it provides a means of grounding symbols in meaningful content (Harnad 1990). Although propositional symbols can be easily combined through rules of syntax, these combinations can result in odd or meaningless combinations because the symbols that are being manipulated are abstract. For example, under a propositional syntax, finding a meaningful interpretation for *tilted ball* should be as easy as finding a meaningful interpretation for *tilted candle*, because the same syntactic rule can be used for both combinations. But clearly *tilted candle* is easier to interpret than *tilted ball*. Because a ball cannot be tilted in the real world, an embodied theory predicts that *tilted ball* is more difficult to interpret than *tilted candle*. As this example shows, Glenberg's embodied theory of meshing representations suggests testable constraints for how concepts are combined productively. According to his theory, the constraints on the syntax for combining concepts are provided by the constraints on how objects can be manipulated in the world.

In our laboratory, we have found evidence that people use the constraints for how objects behave in world as a syntax for combining concepts. In studies of conceptual combination, Wu (1995) compared feature production for noun phrases in which the same modifier (e.g., *half*) either revealed the insides of an object (e.g., *half watermelon*) or left the insides of the object occluded (e.g., *half smile*). Wu found that subjects produced more internal features (e.g., *red*, *seeds*) for noun phrases that revealed the insides of the objects than for noun phrases that left the insides occluded. These results suggest that subjects mentally simulate how the two concepts combine in the world and use this simulation to produce features. These results are in line with Glenberg's argument that constraints in the world dictate the productive combinations that underlie mesh.

A second philosophical problem for embodied theories has been that perceived situations can be construed in many different ways, but an image of a situation only records the situation rather than construing it in one particular manner. For example, imagine that you are rearranging your dining room furniture and have the thought that "the lamp is above the table." This is clearly different from the thought "the table is below the lamp." In the first case the lamp is the focus of thought, whereas in the second case the table is the focus. An analogical representation, such as a picture of the situation, however, cannot distinguish these two possible construals. A theory of embodied representations must be able to represent a particular construal to be a legitimate theory of how memories and thoughts are represented (Pylyshyn 1973).

We believe that a second sense of "mesh" can handle this philosophical problem. This sense of mesh corresponds to Glenberg's "path home" example (sect. 3.1.1). In this sense, patterns of action from memory are brought to bear on "clamped properties of the environment" to conceptualize a situation. Thus a path, which is a pattern of the environment, can become *a path home* when it is meshed with memories of following that path home on previous occasions. The path home is a conceptualization and also a propositional construal of the perceived setting.

To further specify how this meshing takes place, we believe that Glenberg needs to posit embodied representations that are types, which can be filled with tokens from the environment. These types are perceptually based, frame-like structures whose function is to construct perceptual simulations of entities and events in their absence (Barsalou, in preparation; Barsalou & Prinz, in press). In our example, a lamp above a table, the embodied representation for *above* (*x,y*) is a schematic image having a top and a bottom region in which attention is focused on the top region (Langacker 1986; Talmy 1983). Objects from the environment (e.g., *lamp, table*) can then productively instantiate these particular slots to form a simulation of what the situation might look like in the world. The embodied representation for *below* (*x,y*), on the other hand, also has a top and a bottom region, but attention is focused on the bottom region. Thus, particular propositional construals can be created by meshing types from memory with tokens from the perceived environment. To return to Glenberg's example, "the path home" is a schematic image of a path that focuses on an endpoint, home. The clamped properties of the environment (e.g., *a particular path*) are meshed with this schematic image to construct one particular construal of the scene.

Contrary to many prevailing views, productivity and propositional construal are *not* intractable for perceptual views of representation. We believe that Glenberg's two senses of "meshing" embodied representations contribute to our understanding of how these two important processes might be implemented perceptually. On the one hand, mesh addresses productivity by assuming that combining embodied representations involves meshing two or more patterns of action from memory so that they satisfy the constraints on how objects are manipulated in the world. On the other hand, mesh addresses propositional construal by assuming that patterns of action from memory can be brought to bear on perception of the environment to construe situations.

The "mesh" approach to human memory: How much of cognitive psychology has to be thrown away?

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Abstract: While sharing the author's interest in the development of an action-based framework for memory research, I think the present version is neither new nor particularly productive. More differentiation is needed to describe memory functioning in a variety of domains and on the many levels of activity regulation. Above all, Glenberg's proposals seem to contradict empirical data.

The target article evokes a strong déjà-vu impression. Dissatisfaction with the Ebbinghaus tradition is as old as the tradition itself. More than 100 years ago Wundt opposed this type of experimentation and theoretical synthesis. Later on, Janet, Bartlett, Lewin, the cultural-historical school of Vygotsky, Piaget, and the Gibsonians elaborated on the theme. In cognitive psychology, a constructive critical contribution was provided by the levels-of-processing approach of Craik and Lockhart (1972) and by such (reformed) classicists as Neisser (1976) and Norman (1993).

There is nothing wrong with the fact that Glenberg is in such good company. The problem is with empirical testing. When he is specific, I am not sure that existing results support his views. Here are several points. First, if the embodied representations (like Piaget's earlier sensorimotor schemes) play such a crucial role in memory and in conceptualization, why does the cognitive development of children with severe (inborn) abnormalities of motor functions not demonstrate any striking deviation from its normal course (Gouin-Decarie 1969)? Second, if implicit memory is primarily in service of the integration of projectable properties of objects and bodily actions, it is surprising that perceptual priming (as opposed to explicit recognition) does not depend on the prima facie "projectable" property of objects, that is, their size (Cooper et al. 1992). Third, the presumed suppression of outer activities in the conceptually driven processing mode contradicts reports that such a shift of attention to internal information processing can lead to more overt behavior, for example, to a disinhibition of optokinetic nystagmus (cf. Gippenreiter & Romanov 1972). Fourth, in view of recent evidence on the dissociation of visual processing pathways connected with motor actions and leading to phenomenal perception (Bridgeman et al. 1991; Milner & Goodale 1995), I would expect a similar dissociation in memory performance where Glenberg, in contrast, sees integration.

While some ad hoc explanations may be possible, an obvious problem arises with the use of the terms "projectable," "stimulus-driven," and so on. The cognitive approach was born in Koehler's criticism of perceptual theories based on projectable properties and Chomsky's analysis of words like "stimulus" and "response." Should we indeed start from scratch?

The views recommended by Glenberg are too undifferentiated, being based on the common dichotomy between data-driven and conceptually driven mechanisms. There are more than two levels in the control of human activity (see Velichkovsky 1990). Thus, several different levels can be at work in the domain of sensorimotor mechanisms (Bernstein 1996). Not all these mechanisms are data-driven in the straightforward sense, and suppression of some of them could well lead to activation of others.

Hardly more elaborated are Glenberg's ideas of processing "above" sensorimotor coordinations. For him this is a relatively homogeneous domain where memory takes over the control of conceptualizations despite the disturbing influence of the environment. Though this may often occur, we are able to reexamine our past and we are also able to change our learned attitudes. In other words, it is an oversimplification to think that the function of memory is either to "mesh" with environmental contingencies or to override their influence. In human cognitive activity, memory has to be permanently articulated and "overridden," in service of both creative imagination and the reality principle. This selective "suppression of memory" is perhaps one of the main functions of prefrontal cortex (Deacon 1996). Examples of this "suppression" include self-referential cognition, linguistic pragmatics, the understanding of poetry and intellectual strategies such as reductio ad absurdum, which are all connected with some form of "as-if" mental experimentation. The distinction between these groups of higher-order mechanisms is well supported by the neuropsychological dissociation of self-referential experience and semantic memory (one of the cornerstones of memory systems theory – see Schacter & Tulving 1994) and by other recent theories of functional organization in cognition (Challis et al. 1996).

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Towards a dynamic connectionist model of memory

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Abstract: Glenberg's account falls short in several respects. Besides requiring clearer explication of basic concepts, his account fails to recognize the autonomous nature of perception. His account of what is remembered, and its description, is too static. His strictures against connectionist modeling might be overcome by combining the notions of psychological space and principled learning in an embodied and situated network.

Glenberg's view of memory combines notions arising out of connectionist modeling with some basic insights from cognitive linguistics. It can be evaluated, not only by its cogency, consistency, and completeness as an account of memory, but also by its coherence with current thinking in these related fields. Some such integrative conceptualization is necessary if we are to understand how the various "systems" (e.g., visual, auditory, linguistic, and motor) can "talk" to each other, and cooperate smoothly and instantaneously. We agree that there is a need to develop cognitive models in situated and embodied agents and to accommodate flexible and emergent cognitive structures. We also agree that, despite its general failure so far to develop embodied and situated models, connectionism represents "the surest route to formalizing these ideas" (sect. 3.5, para. 6). However, we think that Glenberg's attempted integration falls short of a successful achievement in a number of important respects, enumerated below. In addition, we wish to qualify Glenberg's criticism that, in the connectionist modeling of conceptual structures, "most theorists fail to specify what the features are, and . . . how those features might be learned or changed as the consequence of development" (sect. 3.5, para. 3). By reviewing some recent connectionist models, we hope to extend the discussion of connectionism and to suggest an approach towards the development of models, which, by virtue of being embodied and situated in an environment, might learn psychologically principled internal representations.

Glenberg's assertion that the perception of meaningful structure in "projectable" properties depends upon a contextually suggested combination with remembered action patterns seems inadequate as an approach to perception and is no clearer than association as an account of conceptualization and potential representation in memory. Many phenomena suggest that the visual system can detect the symmetries produced by multiple transformations (Garner 1974; Leyton 1992; Palmer 1991). Meanwhile, Barnsley and others (e.g., Barnsley & Anson 1993) have shown that visual images can be encoded by the parameters of a collage of probabilistically iterated transformations. It is at least possible that what we perceive as structure or organization is the "resonance" of neural units, which automatically carry out such transformations, thereby generating an output that matches the current sensory input. Although such transformations may have had their evolutionary origin in the image changes consequent upon particular physical movements, the visual system has evolved to respond to such a rich variety of structure in an image that it seems implausible to suppose that the perception of every organization must still be directly grounded in some actual or potential pattern of action.

The author is not explicit enough about what it is that is remembered. According to Glenberg, "memory is embodied by encoding *meshed* . . . sets of patterns of action" (sect. 2, para. 1). This characterization seems too static and literal – too like a videotape – for his purposes. By comparison, in the view of perception sketched above, the memory of an image may correspond to the parameters of the collage of transformations by whose iteration the image might be regenerated. By extension, memory for nonprojectable, action-oriented properties might be economically coded in a similar way. In both cases, what is stored would be the parameters controlling some dynamic process.

With respect to the failures of connectionism in modeling conceptual structures, we agree that Glenberg's strictures hold for models that represent stimuli at an input layer, using a set of preabstracted psychological features, for which the act of abstraction by the modeler bears the bulk of the model's explanatory burden (Brooks 1991; Komatsu 1992). However, there are at least two types of connectionist model that are able to learn and modify their internal representations. First, there are supervised models, sometimes referred to as "connectionist semantic networks," which employ architectural "bottlenecks" to reveal underlying representational structures in a set of input/output pairings (e.g., Rumelhart & Todd 1993). Second, under the title of "semantic map," the established self-organizing map has been applied to learning internal conceptual representations (Kohonen 1990). The fact that both approaches rely on some uncomfortably arbitrary interpretation of the inputs (and outputs, in the supervised case) reinforces Glenberg's call for the embodiment and situation of cognitive models. However, this does not detract from the extent to which the specification of the learning rules constitutes a complete and formal description of the process by which the internal representations in such models are acquired and altered.

At the same time, such internal representations do not themselves constitute *principled* models of human conceptual structures. For example, although the structure of the learned internal representations is highly dependent on the architecture of a connectionist semantic network, the precise forms of the various architectures used in practice do not appear to be sufficiently constrained by an analysis of desired representational outcomes. Arguments for the appropriateness of a learned internal representation are typically based either on intuition (e.g., a semantic map is observed to use neighboring units to represent words with subjectively similar meanings) or on some form of post-hoc analysis (e.g., a hierarchical clustering analysis of a bottleneck layer in a semantic network reveals an appropriate taxonomy of the natural kinds being represented). Therefore, we consider that connectionist semantic maps and networks overcome Glenberg's criticism regarding the specification of learning principles, but fail with respect to the specification of representational principles.

In contrast, there are connectionist models that use psychologically principled internal representation but fail to specify the way such representations are learned and modified. We refer particularly to models such as alcove (Kruschke 1992) and others (e.g., Shanks & Gluck 1994), which assume that stimuli are represented in a "psychological space" (Shepard 1987a). Whether or not the psychological space construct proves to be an entirely adequate model of human conceptual structure, the important point is that these connectionist models explicitly and consistently adopt a set of representational principles that have a strong basis in psychological theory.

A connectionist model able to learn and modify principled conceptual representations would seem to require a combination of both types of model we have just described. One envisages constructing something like a connectionist semantic network so as to ensure that its internal representations constitute a psychological space. The information required to form these representations (akin to the indices of psychological similarity that drive multidimensional scaling algorithms) would need to be implicit in the input/output pairings presented to the model. In line with the thrust of the target article, the way to generate these implicit representational constraints is to consider the model as an embodied and situated agent, existing in an environment from which it receives sensory information (the inputs), and which is influenced by its actions (the outputs). This conclusion resonates with arguments by Shepard (1987a; 1987b), who has emphasized the adaptive function of the psychological space approach to human conceptual structure and has argued that such representational structures must evolve subject to constraints implicit in an organism's interaction with its environment.

In our view, the argument of the target article is subject to shortcomings rather than fundamental flaws. To overcome them will inevitably involve, among other things, achieving a detailed account of the interface between perception and cognition, as well as that between language (including sign language), gesture, and action. With respect to connectionist modeling, the representational dictates of psychological spaces would seem to provide a promising starting point in the pursuit of a connectionist "mesh" between mental representations, the agent, and the physical environment. Despite its limitations, therefore, we feel that this account is a challenging first step toward a more useful and realistic view of memory as a dynamic process.

Author's Response

What memory is for: Creating meaning in the service of action

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Abstract: I address the commentators' calls for clarification of theoretical terms, discussion of similarities to other proposals, and extension of the ideas. In doing so, I keep the focus on the purpose of memory: enabling the organism to make sense of its environment so that it can take action appropriate to constraints resulting from the physical, personal, social, and cultural situations.

R1. Clarifications

R1.1. Embodiment and mesh. I will discuss only the target article, rather than the general idea of embodiment. The basic assumption is that the cognitive system's main function is to control bodily action; to ensure that actions fit the physical, biological, personal, social, and cultural constraints of specific situations. How is this done? These types of constraints are in terms of bodily action. Combining constraints is tantamount to creating a consistent, coherent (that is, doable) action. For example, to quench your thirst at the dinner table, you reach for a glass in a manner that reflects the physical shape of the glass, the biological need, and your personal history with the glass (that is, you reach for your glass, not your companion's); moreover, you do so in a manner that does not breach social and cultural conventions. The meaning of the glass to you, at that particular moment, is in terms of the actions available. The meaning of the glass changes when different constraints on action are combined. For example, in a noisy room, the glass may become a mechanism for capturing attention (by tapping it with a spoon), rather than a mechanism for quenching thirst. The coherent combination of actions is what I refer to as "mesh." Note that mesh is nothing like taking the average of many actions. Nor is mesh simply concatenating actions. Instead, mesh requires the integration (e.g., coarticulation) of actions to fit the constraints of the specific situation. In this way, cognition is situated and individuated. On this account, cognition requires analogical mechanisms, that is, mechanisms sensitive to the literal shapes of objects and the capabilities of the body. Thus cognition is embodied. These ideas contrast to nonanalogical accounts of cognition that use arbitrary amodal symbols to represent objects, actions, and events.

We understand language (that is, it takes on meaning) in the same way we understand a physical situation – in terms of possibilities for action. An important function of language is to change the conceptualization of a situation, that is, to change the actions possible. Thus, when your glass is empty, your companion may say, "Here, take mine," thereby eliminating the normal social constraint on drinking from someone else's glass, or if he is particularly desirous of his own wine, when noting your glance at his glass he may say, "Don't touch it," thereby strengthening the social constraint. When we read narrative text, we understand the text in terms of actions available to the protagonist as the situation described by the text develops. When we can't mesh the actions described with our understanding of the situation, the text appears incoherent. Similarly, if your glance was not toward your partner's wine glass but beyond it to the salt shaker (i.e., if you were conceptualizing the situation in terms of the socially permissible action of reaching for the salt shaker), your partner's "Don't touch it" would appear bizarre, or incoherent with the situation, prompting you to say, "Huh?"

Is this equivalent to "proposition-speak" (**McNamara**)? The psychologist's propositions are built out of abstract, inherently meaningless, amodal elements that are manipulated by rules allowing operations such as concatenation and substitution. The elements discussed in the target article are not abstract, not inherently meaningless, and not amodal; they are not manipulated by rules (although see the discussion of numbers in sect. R3 on Extensions). Instead, elements fit together on the basis of their analogical shapes.

On the embodied account, meaning is not reducible to bodily movement (**McNamara**), nor is it equivalent to "response tendencies" and "discriminative stimul[i]" (**Slater**). As described above, conceptualization of a situation is in terms of the responses available, and availability results from a mesh of many constraints. As Slater notes, a particular bodily movement can have different meanings in different situations (reaching for the glass, reaching for the soap, etc.). But contrary to what Slater presumes, meaning is not reducible to bodily movements. Meaning derives from actions available in particular situations, and those actions (as well as the situations) are defined by action-based goals and how those combine with the affordances of the situation. (I am using the Gibsonian term "affordance" to refer to possible actions as determined jointly by characteristics of the physical situation and abilities of the body. I extend the meaning of the term in the discussion of affect in the section Extensions.)

Crowder & Wenk suggest that mesh is a matter of having fine-grained (but arbitrary) symbols, and that "current exemplar models of memory can simulate mesh with an ongoing retrieval process that continuously retrieves multiple representations acting in concert." Indeed, many of the exemplar models are impressive, but mesh has little to do with grain and even less to do with the sorts of retrieval processes that many of the exemplar theories propose (see discussion of exemplar theories in the sect. R2 on Connections). The issue is not grain, but how the symbols (embodied or arbitrary) come to mean, and consequently the operations permissible. A fine-grained encoding of a situation by arbitrary symbols remains, at best, a description of the situation that needs to be interpreted to effect action. The requirement for interpretation introduces what appear to be insurmountable problems, as reviewed in the target article. Perhaps more important, the operations on those arbitrary symbols appear to be of the wrong sort. For example, some exemplar models (e.g., Hintzman 1986) simulate retrieval from memory by creating a weighted average on each dimension encoded in the retrieval cue. The weight is determined by similarity of memory traces to the cue. How would such a model combine actions consistent with quenching thirst, personal history, and social constraints? The resulting retrieved memory would be an uninterpretable mishmash. Also, models such as Hintzman's can only work by specifying, for once and for all, the dimensions of encoding. Thus, to make a glass an appropriate response in different situations, all memories of glasses must specify not only that it may contain water but that it rings when tapped, it holds flowers, it breaks and becomes a jagged weapon, it can hold down a table cloth, it makes a fine present, and it amplifies sounds when held to the wall (at least in old movies).

For similar reasons, mesh cannot be reduced to convolution (see Murdock 1993, todam2) as **MacLeod** suggests. todam2 creates mishmashes of meaning. The convolution mechanism combines representations (vectors) using mathematical operations similar to taking a dot product. The mathematics have no regard for what the elements in a particular vector may represent. As such, todam2 will equally well associate (convolve) the representations of "glass" and "water" and the representations of "glass" and "light-year," whereas humans would find it much easier to find a connection between the former two than between the latter two.

Graesser suggests that a completely embodied representation would be "much like a high resolution videotape" (see also **Vickers** & **Lee**'s point 2), and that that is not consistent with observations of people's understanding of texts. To get the representation at an appropriate "resolution," **de Vega** suggests a type of suspended embodiment, and **Habel et al.** propose that some representations are indirectly embodied. I will address these proposals in the section R2 but for now I will clarify why an embodied representation is unlike a videotape. Our actions in the world are based on affordances fleshed out by mesh with nonprojectable properties, not an examination of all properties of the environment. Furthermore, memory is updated by tracking the changes in the possibilities for action; which actions are now possible and which not. Details of the physical environment, except as affecting the particular experiencer's actions in a particular situation, are irrelevant.

The same is true for understanding a situation described in a narrative. As we read, we develop an action-based understanding of the situation described by the text. Unlike a videotape, this is a conceptualization in which certain actions are possible and others not. The sentences that describe possible actions (that mesh with the conceptualization), are perceived as coherent. In traditional terminology, coherent sentences seem to be primed, that is, preactivated, preprocessed, preinferred, and so on. But, as discussed in the target article (sect. 6.2), there is no need to postulate any sort of automatic preprocessing. Instead, sentences that are easily processed are those that describe ideas that mesh with the current conceptualization. Sentences that describe actions that do not mesh with the developing conceptualization are perceived as incoherent, unless the author takes pains to indicate that the sentences are not meant to mesh, but are meant to set up an alternative conceptualization (or mental space, to use terminology from Fauconnier 1985). These alternatives are signaled by locutions such as "he thought about," "meanwhile," "in 1886," or by using the indefinite this (Gernsbacher & Shroyer 1989) as in "there was this guy."

This sort of approach seems to be exactly what is needed for **Jacobs & Ziegler**'s "logic of Elfland," that is, how we can learn by being told, rather than through direct experience. Understanding what we are told is not forming an abstract description of the sentences (i.e., the psychologist's propositions). Instead, like being told that one can drink from one's companion's glass of wine, language changes the way we understand the world in terms of actions available. Consider Jacobs & Ziegler's example of the lesson from "Beauty and the Beast" that "a thing must be loved before it is lovable." The lesson seems so divorced from ordinary action, so abstract, how can it be understood in an embodied system? I suspect that it is not accidental that lessons such as this are conveyed through fairy tales. The fairy tale provides a concrete illustration of narrative actions that allow us to appreciate the meaning of words such as "love." In understanding the fairy tale, that is, in forming an action-based conceptualization, the child learns which interactions correspond to terms such as "loving" and "being loved," and which actions make one lovable. Telling a child (or adult) the lesson without the illustration does no good: the words alone are empty, without meaning, and soon forgotten. The way the child learns from the fairy tale is the way that we learn in any abstract domain (e.g., mathematics). Initial learning depends on examples, figures, illustrations, and analogies. In all of these cases, we need to conceptualize the lesson in terms of the concrete and actionable.

R1.2. Short-term memory. Whereas **Crowder** & **Wenk** judge my rejection of a separation between long-term and short-term memory "as perfectly justified by the evidence but not any sort of radical change," **Logie, Musen,** and **Rossetti & Procyk** object. The latter three commentaries cite neuropsychological evidence consistent with the separation. As the commentators note, I have made little use of neuropsychological evidence in developing my arguments. This reflects my uncertainty as to how to interpret two of the primary types of neuropsychological evidence, localization of function and dissociations. I will briefly describe some of the reasons for my uncertainty. Sarter et al. (1996) note many problems associated with the interpretation of brain imaging. Some of these problems are: (a) complex cognitive functions may not be isomorphic with neural systems; (b) increasing local activity of excitatory or inhibitory interneurons may yield similar signals but have divergent functions; (c) often a problematic form of the subtractive method is used in data analysis; (d) neural circuits may be diffuse and have different functions depending on the level or pattern of activation, (e) the logical relation between data and conclusion is not ideal – we wish to assert that a cognitive function arises from a physiological process, but we manipulate cognition and observe changes in physiology, rather than vice versa. As Sarter et al. note, some purchase on the problem can be had by combining the imagining studies (in which cognition is manipulated and physiology observed) with studies of patients with lesions (in which physiology is disrupted and changes in cognition observed). Nonetheless, interpretation of these studies is also far from simple. For example, Farah (1994) begins with three well-documented dissociations (e.g., selective impairment in knowledge of living things). For each dissociation, she discusses difficulties in attributing the dissociation to impairment in a specific, localized module. At the same time, she demonstrates how an alternative set of assumptions about the operation of the brain (assumptions congenial to network models) provide a different, but no less compelling, interpretation.

Farah's conclusion that dissociations do not necessarily imply functionally separate systems is strongly echoed in the memory literature. One example is the current debate regarding dissociations between explicit and implicit memory tasks. It is now accepted that dissociations can be interpreted as revealing separate systems (e.g., Schacter et al. 1990) or not (e.g., Roediger et al. 1994). Similarly, we are recognizing the difficulty in figuring out which dissociations count as critical data. One illustration of these difficulties is provided by Logie et al. (1996). They note that Baddeley's model of working memory is supported by a pattern of data including (a) a word-length effect (shorter memory span for long words compared to short words) following both auditory and visual presentation of the to-be-remembered words, (b) a phonological similarity effect (shorter spans for similar sounding words) following both auditory and visual presentation, and (c) in patients with presumed impairments to the working memory system, the absence of all but the auditory phonological similarity effect. In stark contrast to the seemingly clear picture of dissociation of effects and impairments, Logie et al. present the following data: (a) in a sample of 251 nonimpaired subjects, 108 failed to show one or more of the standard effects; (b) when subjects were retested, the appearance or absence of an effect was unreliable; (c) the appearance of an effect was strongly related to the type of strategy reported by the subject; and (d) strategy use was variable: about 25% of the subjects reported changing strategy within a test session.

Logie et al. (1996) choose to interpret these data within the working memory framework. For example, in this framework the occurrence of a word-length effect may require the use of a subvocal rehearsal strategy that engages the relevant working-memory structures. However, once we recognize that different effects can reflect strategic choices, to what extent is it necessary to postulate a functionally separate working memory? Might not the strategy, acting within a general memory system, produce the effects? Might not dissociations with neurological impairment reflect the inability to execute a particular strategy rather than the impairment of a particular information-processing module? Consider the following analogy between skilled use of memory and a physical skill, such as playing tennis. The tennis player may use different strokes (strategies) depending on the situation. The different strokes may be differentially effective, may show different developmental patterns, and may be differentially influenced by various injuries (e.g., to the elbow, the wrist, or the knee). Nonetheless, few would claim that there is a backhand system that is functionally separate from the forehand system, and that both are different from the serving system.

Before extending the analogy, consider the following possibility: suppose that memory skills and strategies are developed to deal with common situations such as planning, taking action, and constructing a conceptualization from language. As these situations are common to the human condition, so are many of our memory skills. Psychologists, however, assume that these skills and strategies reflect the operation of separate modules and design procedures to break down the everyday skills and strategies into components using procedures such as memory span (recall in order an arbitrary list of words). Note that a memory span task only makes sense if there is something like a limited capacity short-term store specialized for keeping track of arbitrary lists of information. If there is no working memory, and instead there are skills designed for real language in real contexts, the memory span task may reveal little. At this point, an advocate of the theory of working memory might well ask, "If there is no working memory system, how could a memory span task ever result in consistent data and consistent dissociations?"

Consider a laboratory investigation of tennis playing in which we extract the player from the complex situation (a tennis game with a real opponent) and try to probe what we believe to be modules underlying the skill. We might begin by putting the tennis player in a special room with a table-tennis paddle whose size makes it much more convenient to study than a full-sized racquet. The player's task is to avoid being hit by balls ranging in size from squash balls to medicine balls. Almost surely performance in this task would correlate moderately with performance on the tennis court (as reading span correlates with comprehension skill). Furthermore, we could easily produce dissociations. For example, in a no-impediment condition, the tennis player can dodge slow-moving medicine balls, but he is less successful in using the table-tennis paddle to defend against fast-moving squash balls. In the impediment condition we force the tennis player to stand in one small area. Such an impediment is analogous to a neurological insult or the imposition of an external constraint in a memory span experiment such as forcing the subject to vocalize "the the the . . ." throughout presentation of the stimuli (a procedure known as articulatory suppression). Confinement to one small area results in selective deterioration of performance: the tennis player can no longer dodge the medicine ball, but his defense against squash balls is unaffected. We would also find that people with physical disabilities (e.g., a broken leg) would behave much as the tennis player in the impediment condition. The point is that this bizarre investigation would produce stable and complex data and dissociations without revealing much about tennis skill. If our assumption that memory is designed to deal with arbitrary lists of stimuli is as wrong as the assumption that tennis skill depends on being able to dodge arbitrary missiles, then what we learn from the consistent data produced by the memory span procedure may have the worth of what we learn from table-tennis dodgeball.

Logie notes that we do not know very much about the development of skills (tennis or otherwise). Nonetheless, taking a skill-based view of short-term performance suggests several avenues for testing and reinterpreting existing data. First, the causal arrow can be reversed. For example, the correlation between reading span (a type of memory span) and success at handling ambiguous sentences (Carpenter et al. 1994) is taken as support for the claim that people vary in working memory capacity and that that capacity affects language processing. In contrast, consider, as do St. John and Gernsbacher (1995), that it is the skill in language tasks (c.f. tennis) that determines skill on the measurement task (c.f., table-tennis dodgeball). Second, the skill-based view makes the prediction that training in a language skill (e.g., practice in center-embedded clauses or relative clauses) should be reflected in enhanced performance in a reading span experiment using those types of materials.

Rossetti & Procyk also discuss differences between short-term and long-term performance, but from a different perspective. In their task, subjects learned to point to a single target, one of six targets in a linear array, or one of six targets arrayed in an arc. In all conditions, on any given trial a single target was presented (by passive movement of the hand opposite to that which makes the response). With an eight-second delay between target presentation and responding, the distribution of errors mimicked the layout of the six targets, either linear or arc-shaped. The differences in the distribution of errors was not evident when there was no delay between target presentation and responding. Does the difference in error distributions across delay imply a special short-term process? Rossetti & Procyk offer an alternative answer: there is a measurable delay in the time it takes to mesh memory trajectories (based on linear or arc-shaped training) with projectable features defining the location of the single target presented. A related interpretation is that shortly after target presentation, responding is strongly constrained by clamped projectable properties; when the projectable properties are absent (in the delayed condition), trajectories play a more significant role in controlling movement.

R1.3. Associations. Both **Crowder & Wenk** and **MacLeod** ask how completely I eschew associations as an explanatory construct. My reply: completely. Certainly events appear to follow one another, actions follow one another, and memories follow one another. If that is all that we mean by an association, then I have no argument, because "association" is used as a descriptive term synonymous with "conditional probability greater than simple probability." Psychologists and neuroscientists have come to use the term as a theoretical construct, however. An association has become the mechanism for producing the memories that follow from one another. Association is used an explanatory term because we have conceptualized knowledge as consisting of amodal, meaningless symbols that have few ways of relating to one another. That is, the only way to connect one such symbol to another is through an association (or a propositional equivalent). If we consider analogical representations, however, then other mechanisms of relating become possible. For example, mesh relates ideas by virtue of the coordination of patterns of action that underlie meaning. Whether or not there is any merit to action-based conceptualization, it is clear that associations are not a powerful explanatory mechanism. In using associative theories, any two ideas (representations) ought to be equally associable, or constraints on associability are external to the representations. But ideas are not equally associable, and it seems that no list of external constraints can be complete. One solution is to do away with associations by letting the symbols be analogical and intrinsically meaningful.

Crowder & Wenk suggest that perhaps associations are applicable at the neural level of analysis, if not at the cognitive level. No doubt there are conditional probabilities at the neural level, but should we take them as explanatory principles? As mechanisms become microscopic, a case can be made that analogical shape becomes even more important. As an example, consider the analysis of genetic expression. At the Mendelian level, one does talk in terms of probabilities. At the chromosomal level, one talks in terms of information units, and genes, but even here analogical properties, such as the physical distribution of genes on chromosomes, become important. When one examines the operation of the genes, their analogical shapes take on the utmost importance. For example, it is because of the particular three dimensional folding of the proteins encoding genes, and how those foldings constrain interaction with the constituents of the chemical environment, that the genes express themselves at the time and place that they do (Stein et al. 1996). That is, the proteins must literally mesh with components of their environment to get the job done.

R1.4. Implicit memory phenomena. **Benjamin & Bjork** suggest that a problem for embodiment is "that mere exposure to a stimulus can alter subsequent performance on certain perceptual or cognitive tasks . . . [and S]uch stimulus-driven processing, typically independent of a subject's tasks or goals at the time, suggests functions and operations of memory that do not fit neatly in the embodiment framework." In contrast to this statement, Benjamin & Bjork go on to discuss how implicit memory effects are dependent on the subject's tasks and goals. For example, asking a subject to read a word out of context (e.g., "peach") will enhance the subjects' ability to identify the word from a fragmented version of the letters. However, asking a subject to (orally) generate the word from a hint ("a fruit with a fuzzy skin") will not much affect (visual) fragment completion but will enhance performance when more "conceptual" information is required, such as rapidly naming a dozen fruits. In the target article, I suggest that these sorts of goals affect whether verbal stimuli are, as in the read condition, conceptualized in terms of the projectable properties, or, as in the generate condition, conceptualized in terms of the (action-based) meaning of the referents. The different conceptualizations (and resulting trajectories) will only affect performance on later tasks that can mesh with those trajectories. As **Crowder & Wenk** note, this proposal is not different from Tulving's encoding specificity principle.

McNamara argues that implicit memory does not deserve the prominence it is given in the target article, because implicit memory "is fundamentally aplysia memory: it is the system that's been around for hundreds of millions of years, not the system that is responsible for the rich complexity of human cognition." This argument fails for three reasons. First, it implies that a system is to be denigrated because it has worked so well. Thus, we might also question the importance of the immune system, the circulatory system, and the visual system, all of which have been around a long time. Second, it is by no means clear that explicit, conscious retrieval processes contribute much to human cognition. When solving everyday tasks such as making breakfast or finding our way to the office, it seems that we use explicit memory only when things go wrong: "Where did I put the coffee mug?" Otherwise, most tasks (putting the key in the ignition, pressing the accelerator, shifting into reverse) are done relatively automatically. Similarly in following language we do not consciously attempt retrieval: the words flow and we understand. It is only when a word or phrase does not effortlessly mesh with the developing conceptualization that we might ask ourselves, "What does that word mean? Where have I heard it before?" the sorts of questions asked on an explicit memory task. Finally, Schunn and Dunbar (1996) report that implicit memory priming contributes to complex scientific reasoning.

R1.5. Flexibility. An emphasis on grounded meaning "seems to underestimate the flexibility and functions of human memory," suggest **Benjamin & Bjork. MacLeod** questions how people could learn anything truly new in a system based on action. **De Vega** notes that the target article does not present anything close to a worked-out account of figurative language, and this point is also made by **Ramsay & Homer** ("Glenberg assumes that language comprehension involves decoding the spoken or written message in a literal fashion") and **Vickers & Lee** ("This characterization seems too static and literal"). These criticisms reflect the most egregious failure on my part to make my ideas clear, because I had intended the embodied framework to be much more flexible than standard models of memory and comprehension.

Let's start with **MacLeod**'s question: How can we learn anything new? Consider an infant learning the concept "table." At first a table may be simply a location where her feeding takes place. Then, it may be a stable object that can be used to pull herself up to a standing position. A table may become a source for making noise by banging on it, and finally a table can become a surface that can support her food while eating and her paper while drawing. The point is that the table offers different affordances as the child's actions become more differentiated: what the child can do with the table, what it means to her, changes as she develops. We don't have to decide for the child on a few canonical features or dimensions that represent table for now and evermore. Instead, the meaning of the concept changes with experience, and will continue to change over the course of the child's life, and as the culture (e.g., how artists use and portray tables) changes the interactions we have with tables. What is true for children is true of the adults: objects and events come to mean different things to us as our skills in dealing with those objects change. The meaning of computers has changed dramatically with the advent of electronic communication; the meaning of "love" changes with our experiences of being loved. In none of these cases can meaning be distilled, formalized, and reified; it is always changing. Of course there are well-defined and well-behaved concepts in formal, artificial systems, but we do not live in such a system.

An embodied system that incorporates the idea of mesh is flexible in the way that memory is used in dealing with the world. If meaning were encoded by a list of features (the 0s and 1s that **Benjamin & Bjork** champion), the table, computer, or love experiences would be doomed to the same inflexible characterization. In an embodied system, we can mesh the affordances of a table with memories of eating. We can also mesh our embodied understanding of tables with the embodied goal of getting our body elevated so that we can swat a bug. Given some embodied understanding of "love," we can even mesh actions consistent with loving and affordances of tables. This flexibility in our construal of "table" is what obviates the need to decide on a fixed set of features, dimensions, default values, frames, scripts, tracks, MOPs, etc.

It is the flexibility of mesh that helps us to understand flexibility in language use. Goldberg's (1995) example "She sneezed the foam off the beer" illustrates part of the phenomena. Given that "to sneeze" is an intransitive verb, this sentence is not just ungrammatical, it ought to be next to impossible to understand. Nonetheless, most of us will have little difficulty with the sentence because we can mesh the actions of sneezing with foam flying off the top of a glass of beer. Similarly we can comprehend Shanon's (1987) "The newsboy porched the newspaper" by meshing an action-based conceptualization of newsboys with affordances of newspapers (at least those folded appropriately) and constraints on action appropriate to our culture (at least that of the 1950s). In the 2050s, when newsboys, porches, and physical newspapers may be things of the past, it will probably be near impossible to understand such a sentence outside of a carefully constructed context.

Keysar and Bly (1995) have demonstrated that people are quite flexible in their ability to interpret metaphor. Thus some students may be told that "The goose hangs high" means that someone is to experience very good luck, and other students may be told that "The goose hangs high" means that someone is doomed. Both sets of students will find the interpretation given them first convincing and the alternative interpretation strange. One account of this finding is that much metaphorical language is arbitrary and not, as Lakoff suggests, motivated. There is, however, an embodied account equally consistent with the data (and similar to the account in Keysar & Bly 1995). We can mesh with the projectable properties of high-hanging goose nonprojectable properties, such as the animal's history. If we imagine the high-hanging goose to be the result of a successful hunt, then it is emblematic of success and good luck. However, if we imagine the family goose strung up by vigilantes during the night, it becomes almost as frightful as a burning cross. Once a coherent interpretation (meshed conceptualization) has been reached, memory is updated, and that update (trajectory) will bias future interpretation. Our conceptualization of the family goose hanging with a broken neck will now be hard to mesh with "good luck."

R1.6. Projectable properties. The "use of the term *properties* is unfortunate because it implies that we should conceptualize memory in terms of properties that exist independently of any particular organism. . ," writes **MacDorman.** In a similar vein, **Franklin** writes that it is "perception that creates the property in the first place. . . The agent projects both projectable and nonprojectable properties onto the environment. The distinction is one of degree of constraint; projectable properties are more constrained by the environment." I agree with both commentators. I lifted the distinction between projectable and nonprojectable from Epstein (1993), and in taking it out of his context, did it a disservice. Perhaps a better term for the sort of theorizing in the target article is Gibson's affordance. I chose not to use that term, however, because I did not want to bring along with it Gibson's aversion to nonprojectable features being added to flesh out a conceptualization. The two terms, projectable property and affordance, are related. Affordances, the actions available in a particular situation, depend jointly on the projectable (physical) characteristics of the environment and the human body. As MacDorman writes, "one may certainly assume the existence of an observer-independent reality," but what we make of that reality depends on the particular organism "with its unique body, sense organs, and life history." If I had been clearer on this point, I suspect that **McNamara** would not have mistakenly suggested that "Glenberg's psychology of memory would seem to require a theory of the structure of the world; after all, projectable properties will be described in the vocabulary of physics, not psychology," **Velichkovsky** would not have confused projectable properties with retinal image size, and **Anderson** would not have suggested that I attempted "to base memory on visual perception."

A clearer exposition of projectable properties may well have also answered **Velichkovsky**'s question as to why children with "severe abnormalities of motor functions" do not demonstrate "striking deviations" in cognitive abilities. As argued in the target article, joint evolution of the cognitive/perceptual system and the body has ensured that the cognitive/perceptual system is sensitive to projectable properties of the world that are relevant to bodies of our type. Thus, we can expect some ability to detect affordances relevant to interaction, whether or not an individual is physically capable of the interaction.

R1.7. Role of theory and assumption. By writing the target article I hoped to accomplish several goals. One is to point out how assumptions about the nature of representation and meaning have defined the problems and methodologies of cognitive psychology and blinded us to other ways of doing business. Second, I wanted to develop an approach to memory and language comprehension that would smoothly integrate with investigations of other components of human experience. Third, as **Habel et al.** note, my framework provides guidelines for generation of hypotheses and a rationalization for the findings at hand. For example, proposing that conceptualization of text, like conceptualization of the environment, is action-based helps us to understand why readers appear to track protagonist's goals and why narrative is easier to follow than exposition. Narratives are descriptions of actions, interactions, and changes in the environment (or the protagonist's interpretation of the environment) of the sort the cognitive system is designed to deal with.

Nonetheless, **Koriat & Goldsmith** and **Musen** question the reach of the framework. Koriat & Goldsmith suggest that there are many valid metaphors for the workings of memory, and each metaphor has its own "focus of convenience." In contrast, I believe that a powerful theoretical description of memory will have implications for language, development, planning, and so on. Also, it is almost certain that by combining constraints from other domains, we will converge on a correct description more quickly than by attempting to model behavior in domains separated solely for convenience.

Musen agrees with **Koriat & Goldsmith**'s criticism regarding the reach of the framework, and she also finds that assumptions about internal representation are a "major weakness" of the target article. Indeed, most of those assumptions are not currently testable, but that is not an argument against making them explicit. Research is always based on assumptions, explicit or not. Thus, our assumptions about associations support the use of paired-associate learning, and our assumptions that symbols are abstract independent elements support work using lists of arbitrary verbal stimuli to study learning (e.g., Musen & Squire 1991). It can only help to make these assumptions explicit and to examine alternatives.

Notwithstanding the benefits of a broad reach, **Koriat & Goldsmith, Musen, Regier,** and others point to an important deficiency. Mine is at best a framework. Any real worth remains to be demonstrated through the development of testable hypotheses.

R2. Connections

The commentators describe (sometimes in approving tones, sometimes disparaging) connections with other literatures and approaches. Rather than listing all of them, I will single out a few that seem to need some comment.

R2.1. Exemplar models. As noted before, **Crowder & Wenk** compare my approach to that of exemplar models of memory in which each experience (even separate experiences of the same nominal event) is registered as a separate "trace." The comparison was based on the ability of exemplar models to retrieve blended information from memory specific to the current context, resulting in a streaming of cognition. There are several ways in which the comparison is not apt. First, exemplar models (as currently instantiated) model memory traces as a string of arbitrary symbols, in no way (or at least in most ways) is not analogous to the event being represented. Second, because the string of symbols is arbitrary, the blending of information during retrieval does not depend on the nature of the objects represented, only the syntax of the representation. Third, trajectories in the target article do not correspond to memories of exemplars. A trajectory is the change in conceptualization (the pattern of possible actions) produced by taking an action, an independent change in the environment, or mesh with other trajectories. Trajectories are a bias or pathway of change. Crucially, the trajectories are not arbitrary because they are constrained by our ideas of possible action. That is, not all actions are immediately possible from a given starting position. This characterization of trajectories approximates **Vickers & Lee**'s call for memories that "correspond to the parameters of the collage of transformations by whose iteration the image might be regenerated."

Vickers & Lee go on to note that current connectionist models incorporate components similar to the ones I call for. Namely, some connectionist models abstract interesting regularities and relations from the input. As they note, however, the input is often composed of arbitrary symbols. Other models use representations that are "psychologically principled," and Vickers & Lee refer to Kruschke's (1992) alcove, a connectionist version of an exemplar model of categorization. Because alcove uses arbitrary coding of dimensions (and the relevant dimensions must be specified for the model) it differs from my proposal in the ways noted above for the memory models. Nonetheless, alcove has a number of attractive features that may correspond to aspects of my approach. For example, an important component of alcove is learning to attend to dimensions that are important for a particular task. Attentional learning in alcove is close to **Solomon & Barsalou**'s notion of "propositional construal" in an embodied approach to cognition.

R2.2 Script Theory. The target article, **Nelson** suggests, "might well have evolved from the script theories of action." Whereas there is some similarity of motivation (e.g., to account for human memory and comprehension of real world events), the mechanisms are disparate. Script theory (e.g., Schank & Abelson 1977) is based on psychologist's propositions, and hence relies on arbitrary symbols and extrinsic constraints on relations. Initial versions of script theory were exceptionally brittle; situations had to match the script (or one of its associated "tracks") very closely in order for the script to apply. Connectionist versions of schema theory (Rumelhart et al. 1986) overcome some of the brittleness, but not the arbitrary coding. Thus, they must rely on extrinsic constraints or frequency of co-occurrence as the major features controlling thought.

In the context of script theory, **Nelson** raises the question, "how does the individual's memory representation automatically recognize or match an available script to a newly encountered situation?" I do not postulate that thought depends on instantiating an appropriate script. Nonetheless, the general version of the question is legitimate: How does one select past experience to apply to the current situation? We rarely (if ever) are thrown into a situation unrelated to what we were just doing and thinking. Situations flow and transform sensibly by following real physical and cultural constraints (which is what makes trajectories useful). For example, although we may describe a day's activities as going to work and then going to lunch, the events are not discrete. The work activities gradually stop (as my colleague enters my office) and transform themselves (as we walk down the hall to the elevator) into lunch activities. Thus, in applying past experiences to the current situation, it is extremely rare that one must select from among all possibilities, and most of the time there is little selection at all: conceptualization of the current situation blends into the next by virtue of analogical fit.

R2.3. Piaget. The connection to Piaget, in particular the similarity between action-based conceptualization and the Piagetian notion of a sensory-motor schema have been noted by **Carlson, Jacobs & Ziegler, Velichkovsky,** and others. In fact, the connection is even closer. The Piagetian symbol is not the abstract amodal symbol of many cognitive theories. Instead, it is arises from action and imitation, and is analogical in the sense that, in some ways, the symbol resembles what it stands for. The visual image is a prototypical Piagetian symbol. For Piaget, action is integral to learning, even in learning the concept of number. In that case, the physical actions that check one-to-one correspondence are thought to underlie the abstract concept of number. In addition, a number of Piagetian claims and interpretations are consonant with the interaction between clamping and suppression I postulated. For example, the preoperational child's thought can be characterized as centering on the states of the environment, rather than transformations, whereas the child in the stage of concrete operations seems to appreciate the transformations as well as the states. Such a situation might arise if the preoperational child is strongly clamped to the current environment. As the child learns to suppress the clamping, trajectories based on previous experiences and imagined changes can supplement the conceptualization. Similarly, the young child's thought is characterized as egocentric: reflecting the relation of objects to the child without concern for other perspectives. Again, this description corresponds closely to the notion of thought clamped by projectable properties.

There are several differences between Piagetian theory and my own. First, I wish to explore the application of an action-based, analogical account of cognition to adults and to the problems of understanding language. Second, I am pushing a single principle underlying cognitive development: the interactions between bodily growth, experiences with the environment (including the social environment), and development in the ability to suppress the clamped environment.

R3. Extensions

R3.1. Perceptual symbols and numbers. A basic assertion in the target article is that we comprehend situations and language in terms of patterns of action: what something means to us is what we can do with it. For the most part, I left unexamined the possibility of other aspects of representation, and whether particular forms of representation (e.g., a visual image) are consistent with meaning as patterns of action. Many of the commentaries suggest the need for abstract symbols (**Benjamin & Bjork, Carlson, Habel et al.**), goals (**Carlson, de Vega, Franklin, Gärdenfors, MacDorman**), partially-embodied representations (**de Vega, Graesser, Habel et al.**), and perceptual symbols, or analogical representations of characteristics of perceived information (**Franklin, Solomon & Barsalou, Vickers & Lee**). As Vickers & Lee put it for visual perception, "the visual system has evolved to respond to such a rich variety of structure in an image that it seems implausible to suppose that the perception of every organization must still be directly grounded in some actual or potential pattern of action." How can we accommodate an action-based account of meaning with the convincing arguments that we know much about the environment (e.g., colors) in addition to patterns of action?

An attractive possibility is suggested by **Solomon & Barsalou** (see also Barsalou 1993). They propose that perceptual experience creates perceptual symbols. These symbols do not simply describe the environment, but like Piagetian symbols, they are analogically related to the environment. Importantly, perceptual symbols are not exact copies of physical stimulation. Instead, the symbols are sensitive to what we are attending and to how we construe the situation (how the projectable properties mesh with nonprojectable properties). Thus, perceptual symbols capture the projectable properties that are relevant for the actions we are contemplating, and in that sense perceptual symbols capture relevant affordances.

Perceptual symbols can be made to do a lot of work (Barsalou 1993). Here I will use them in an unusual way to account for one domain of human performance that many commentators assume require abstract, amodal symbols: operations on numbers. As **Habel et al.** note, it is relatively easy to imagine that our understanding of small numbers is based on direct action, such as one-to-one correspondence, but what are we to do with numbers like "943?" Most of the time, we treat such numbers simply as "a lot." Nonetheless, we can make fine discriminations, such as between 943 and 944, and this ability does not seem consistent with treating all of these numbers as simply “a lot.” Part of our ability is surely the use of one-to-one correspondence to note small differences and ordinal relations, such as between 943 and 944, but we are still left with how we deal with larger differences. My proposal is that through laborious, time-consuming repetition we have learned how to make arbitrary transformations, of the following sort: The three perceptual symbols “9” (i.e., a representation of the shape of the numeral 9, not the concept of nine), “+,” and “4” may be replaced with the perceptual symbol “13.”

Several points follow. First, computational skill is the arbitrary manipulation (substitution) of perceptual symbols. I am characterizing the substitutions as arbitrary because the operations have nothing to do with natural constraints based on projectable properties; the numerals “9” and “4” cannot be literally meshed to produce the numeral “13.” Learning these substitutions is brute force memorization, that is, brute force creation of trajectories, and that is why so many people find learning and doing mathematics to be boring, laborious, and close to meaningless. In fact, if meaning derives from patterns of possible action, then the perceptual symbols of numerals are close to meaningless: operations on them do not respect projectable, action-based properties. Nonetheless, the perceptual symbols used in number manipulation need not be special amodal cognitive symbols that differ in kind from those used in other domains.

Second, on this analysis, computational skill (and other formal systems that depend on learning brute force trajectories) cannot be taken as the paradigm case of human thinking. Most thinking, most meaning-making, most planning, and most action arises from following embodied constraints on mesh, not rule-bound, arbitrary symbol manipulation. Those of us who teach undergraduate mathematics courses know that proficiency in mathematical manipulation cannot be a valid index of general intelligence. There are too many intelligent and competent people who blanch at the sight of numbers.

Third, some people have tremendous ability in mathematics, and that ability is certainly more than skill in brute force symbol substitution. How does the mathematician think? The mathematician has learned to go beyond numbers as perceptual symbols (i.e., visual images of the numerals). Instead, the mathematician has learned to form embodied representations of quantities and their transformations, much like a child learning about division by imaging a pie being cut up. What the mathematician does with numbers is similar to what speakers of a language do with words: we go beyond the immediate (numeral or word) to an embodied representation whose transformations follow natural constraints. This hypothesis explains why the teaching of mathematics (and other abstract ideas) is so greatly facilitated by the use of concrete examples: the examples give us an easily embodied interpretation of the numbers.

R3.2. Suspended embodiment? The need for some sort of representation that is not fully embodied is suggested by **De Vega, Graesser,** and **Habel et al.** De Vega notes that understanding “Mary flew from Madrid to New York” does not seem to require a detailed unpacking of all the actions (e.g., checking her bags, walking through the metal detector, etc.). Similarly, Graesser suggests that when reading “the cook tripped the butler” we think about revenge, not the detailed unpacking of “trip” as actions of extending a foot and so on. If understanding is embodied as action, what has happened to all of the actions?

As a prelude to answering this question, keep in mind that we can unpack understanding to finer and finer levels of action. If someone asks me what it means to “fly to New York” I can start describing airplanes, airports, and so forth. My ability to unpack will peter out much sooner than an airline pilot’s description, and that is why he knows more about flying than do I. Nonetheless, the ability to unpack “fly to New York” does not imply that all of that knowledge is precompiled: much of it can be assembled on the fly by meshing trajectories. There is no prespecified schema that is brought up upon hearing “fly” or “trip.” Instead, when comprehending language, the interpretation of “fly” or “trip” is forced to mesh with the interpretation of the situation described so far. In the absence of devices that signal change of topic (e.g., Gernsbacher & Shroyer 1989), it is our embodied interpretation of the situation that forces (or at least makes probable) an interpretation of the subsequent language at the appropriate level: the level that meshes with the current conceptualization. Thus, if the text describes how the cook gauged the speed of the butler’s walk, raised her leg, and braced for an impact, then mention of “foot” would easily mesh with the understanding of “trip” whereas as mention of “revenge” would not. However, if the text describes the cook as considering all of the butler’s past insults, then reading “revenge” will be facilitated relative to reading “foot.” In neither case is there priming in the sense of pre-activation or explicit expectation (see target article, sect. 6.2.).

What then is automatically inferred? What parts of the text are always tracked? Which actions always included? None. Understanding current language depends on the situation set up by the previous language; we understand to the extent that current language generates ideas that mesh. Thus, if the butler were in Madrid and the cook in New York, asserting that the cook tripped the butler would be hard to comprehend, because it does not respect embodied understanding of these situations. Running across such a sentence would force us to consciously unpack our conceptualization, give up, assume a change of topic, or question the speaker, “What do you mean?” On this account, much of language comprehension skill depends on speaking/writing skill. That is, an effective speaker uses words that create conceptualizations that mesh for the listener. The speaker can do this because of the commonality of human experience; he knows the sorts of action-based conceptualizations the listener is creating (because they are like his), and he uses words that describe embodied transformations of those conceptualizations. If the speaker is not skillful in considering how his conceptualization may differ from the listener’s (e.g., if the speaker is a child), then communication fails.

R3.3. Suppression, effort, attention, and propositional construal. My undifferentiated notion of suppression is commented on by **Carlson, Ramsay & Homer, Schwartz et al.,** and **Velichkovsky.** By considering suppression (of the clamping of projectable features) to be a continuous variable rather than all-or-none, many of the issues raised by the commentaries can be resolved. Thus, in conceptualizing a situation in terms of which actions are possible, our thinking can range from being predominantly controlled by the projectable properties of the environment (as seems to be the case with young children and perhaps, as Schwartz et al. suggest, frontal lobe patients) to predominantly controlled by the mesh with nonprojectable properties (i.e., a very thirsty person who refrains from drinking from his companion's glass because of strong social constraints). This range of possibilities highlights the need for coordination between projectable and nonprojectable properties, rather than suppression of projectable properties. Indeed, it seems that coordination must be the case for language comprehension to work: to varying degrees we must attend to both the projectable properties of the language signal and the meaning of the signal.

I argued that suppression of projectable properties of the environment was effortful. **Schwartz et al.** note that suppression is unlikely to be the only determinant of cognitive effort. When aspects of the environment are suppressed in the service of an engaging task such as reading a mystery, "the psychological content and/or process (mystery, hunting, mating) resonates so strongly with evolved human inclinations that it engages mechanisms of suppression (and thus captures attention) without, or even in spite of, one's conscious intention" that is, little effort is involved. Schwartz et al. also "suggest that suppression is effortful because, like swimming upstream, it involves willfully opposing the inertial flow of undirected thought, and overcoming (neurophysiological) inertia, of whatever kind, requires (physiological) work."

These ideas can be accommodated by my framework. Translate "resonates . . . with evolved human inclinations" into transformations that follow embodied constraints; and translate "willfully opposing the inertial flow" as brute force manipulation of perceptual symbols, as in mathematical computation. Thus, daydreaming seems much less effortful than problem solving because daydreaming follows embodied constraints on transformation, whereas brute force problem solving does not. Nonetheless, in both cases we need to exert some effort to suppress the clamping of the environment, or physically break the clamping by closing our eyes or looking at a blank wall.

Coordination between suppression and clamping seems close to capturing the distinction **Ramsay & Homer** make between "holding in mind" and holding "in view." Holding in view is conceptualization based predominantly on clamped projectable properties (compare to **Gärdenfors** "direct" representation); holding in mind is conceptualization based on (relative) suppression of those properties and coordination with nonprojectable properties (compare to Gärdenfors's "detached" representation). As I noted, the effort of suppression (or coordination) is a signal that the conceptualization is in part imaginative, and hence, to use Ramsay & Homer's word, "owned" by the agent. Alternating between relative suppression (holding in mind) and relative clamping (holding in view), provides a way of considering the differences in meaning of the conceptualizations. I have not, however, considered how such an alternation would take place.

The coordination between suppression and clamping is also consistent with **Solomon & Barsalou**'s discussion of propositional construal. That is, the meaning of objects and events depends on how we construe them, but what does it mean to construe? As Solomon & Barsalou note, meshing projectable properties of the object with action-based goals provides one solution. When trying to move the furniture to make a pleasing arrangement, we attempt to center the table *below* the lamp. But, when trying to install the lamp, we attempt to center the lamp *above* the table. That is, how we construe the situation depends on the actions we are planning. Similarly, the roadway can become the path home, the path to the grocery store, or a place to throw a frisbee. The actions in which we are engaged or contemplating, when meshed with the environment, determine how we construe that environment.

Propositional construal is just what **McNamara** finds missing from the target article: intension. That is, conceptualizing a situation in terms of actions available, particularly when those actions are constrained by mesh with nonprojectable properties, is exactly what is required to make that situation about something. The situation means to us and is about the actions available to accomplish some goal such as centering the table or throwing a frisbee. McNamara also notes that mine is a "language of form [of objects] when the goal is a language of content." But surely the forms of objects contribute to the actions supported by the objects, and hence the meaning of those objects to us.

R3.4. Affect. But what determines the particular propositional construal, the particular goal that we are acting on? As noted by **Anderson, Carlson, de Vega, Franklin, Gärdenfors,** and **MacDorman,** some notion of affect or value needs to be included to guide and organize action. There are three questions to consider: How is value determined? How does value affect conceptualization and direct action? And, related, how is behavior guided by long-term goals? Here is a new proposal: changes in the affective/physiological state of the body changes affordances.

Consider a terrifying situation. Low-level mechanisms detect that the situation is terrifying by noting large looming objects, exceptionally loud noises, threatening postures, and so on. After detection, our bodily state rapidly changes through a wash of chemical and neuronal signals. The heart races, the skin sweats: in a word, we are in a state of high arousal. Given this arousal, some actions are unavailable. We cannot engage in cool reflection, we cannot walk slowly and calmly, we cannot stand still, we may be unable to speak. That is, the major paring of options has been made by the body: fight or flight.

Consider a more prosaic example. You are working hard at your computer, well past the lunch hour. As your bodily state of hunger increases, you start to feel more and more uncomfortable. As your hunger grows, the possible actions afforded by the environment change because your body is changing. Soon, the keyboard no longer affords typing and the chair no longer affords sitting: to a body such as yours, the only actions possible are related to food-seeking.

Given these sorts of changes in bodily state and how they can change conceptualization, it is easy to understand how someone can be blinded by passion (no actions appear possible except those directed toward the loved one) or incapacitated by grief (no actions appear). Perhaps instances of clinical depression submit to a similar analysis. The depressed body registers few affordances so that few actions seem possible. Thus the depressed person spends an inordinate amount of time sleeping, and when awake, he or she feels that nothing can be done. Changing the bodily state through drug treatment relieves not just the feeling of depression but the inactivity also. That is, to a different body, actions now appear possible. How then can a talking therapy have any effect? Cognitive therapies induce a mesh of projectable features and actions suggested by the therapist. That is, like the dinner companion who allows me to drink from his glass, the therapist's words induce the patient to conceptualize the current state as one in which actions are possible. As another analogy, consider a tired novice (the patient) hiking in the woods with a guide (the therapist). When the novice is faced with fording a river, he sees no possibility for action, and he stops. The guide points out that the arrangement of stones in the river afford dry-stepping and encourages action. All is well, unless the novice is very tired (very depressed). In this case, the novice's body tells him that even the stones pointed out by the guide do not afford stepping for his body. Only a change in the body's state will change the situation.

So far, the analysis has suggested how changes in affective state can control conceptualization and immediate behavior. Remaining questions concern long-term goals, long-term planning, and taking current action designed to accomplish those long-term goals, what **Gärdenfors** calls "anticipatory planning." If there is plenty of food around, and if action is controlled by conceptualization of the current situation, why do we bother to plant (or shop) for tomorrow? My proposal uses the same sort of mechanism outlined above, but with a feedback loop (see Damasio 1994 for documentation and discussion of the neural mechanisms underlying such a loop). The argument has three parts. First, the current state of plenty (or deprivation) can, with the effort of suppression, be meshed with trajectories based on memory. That is, we can daydream about changes in the current situation. Second, this new conceptualization will produce characteristic changes in the body (see sects. 2.3.1. and 2.3.2. in the target article; Ch. 6–10 in Damasio 1994; or simply consider how your own daydreaming can change your level of arousal). Third, the changed bodily state changes conceptualization of patterns of action. Just as real hunger leads to real actions directed toward food-seeking (because it appears that there is nothing else to do), imagined hunger, through its effects on the current body, leads to real actions directed toward food-seeking. These actions can be characterized as planning for tomorrow.

There are several ways in which this account is different from the simple assertion that thinking about the future motivates action (although this, in fact, is what I am trying to explain), and different from accounts such as **Anderson**'s cognitive algebra for computing value. First, the account provides a theoretical mechanism to translate thought into motivation: thought literally changes bodily state. Second, the account provides a mechanism for how motivation can direct behavior: changes in bodily state change affordances. Third, the account does not require the precomputation of value (or as **Gärdenfors** would name it: a detached representation of a desire) for future outcomes. Fourth, although the values of different pieces of information are taken into account and in some sense averaged, there is no manipulation of values or symbols by rules equivalent to those of algebra. Instead of computing values like a digital computer following rules, the body computes value more akin to an analog computer, using the integration, or mesh, of possibilities.

R3.5. Social interaction. Both **Nelson** and **Slater** object to my relative neglect of the social world. As Slater describes it, the human conceptual agenda is strongly influenced by "everyday mind reading, coordination of action, detection of cheating, identification of kinship or negotiation of discourse." Nelson asserts that "The symbol grounding problem cannot be solved entirely through embodied cognition but requires the recognition that words are socially shared symbols that somehow overcome the difficulties posed by the existence of individual experiential worlds." I agree fully. Navigating the social environment is as critical as following paths and fording streams, and reading faces is as important as reading texts. Furthermore, arguments in the target article for basing cognition on action in the physical environment (e.g., importance of action to survival, joint evolution of brain and body, mesh of projectable and nonprojectable properties) pertain with equal force to taking action in the social world. I apologize for the neglect, and I hope for success in extending the framework in these directions.

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Letters "a" and "r" appearing before authors' inintials refer to target article and response respectively.

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