Situated simulation in the human conceptual system

Lawrence W. Barsalou
Emory University, Atlanta, GA, USA

Four theories of the human conceptual system—semantic memory, exemplar models, feed-forward connectionist nets, and situated simulation theory—are characterised and contrasted on five dimensions: (1) architecture (modular vs. non-modular), (2) representation (amodal vs. modal), (3) abstraction (decontextualised vs. situated), (4) stability (stable vs. dynamical), and (5) organisation (taxonomic vs. action–environment interface). Empirical evidence is then reviewed for the situated simulation theory, and the following conclusions are reached. Because the conceptual system shares mechanisms with perception and action, it is non-modular. As a result, conceptual representations are multi-modal simulations distributed across modality-specific systems. A given simulation for a concept is situated, preparing an agent for situated action with a particular instance, in a particular setting. Because a concept delivers diverse simulations that prepare agents for action in many different situations, it is dynamical. Because the conceptual system’s primary purpose is to support situated action, it becomes organised around the action–environment interface.

After briefly reviewing current theories of the conceptual system, this article explores the proposal that situated simulations lie at the heart of it. The emphasis will be on empirical evidence for this view. For theoretical development, see Barsalou (1999), Barsalou (in press), and Simmons and Barsalou (2003b).

Generally speaking, a conceptual system contains knowledge about the world. A fundamental property of this knowledge is its categorical nature. A conceptual system is not a collection of holistic images of the sort that a
Whenever selective attention focuses consistently on some component (or components) of experience, knowledge of a category develops (cf. Schyns, Goldstone, & Thibaut, 1998). Each time a component is attended to, the information extracted becomes integrated with past information about the same component in memory. When attention focuses on a blue patch of colour, for example, the information extracted is stored with previous memories of blue, thereby producing categorical knowledge for this component. Over time, myriad components accumulate memories in a similar manner, including objects, events, locations, times, introspective states, relations, roles, properties, and so forth.

Certainly the learning that produces categorical knowledge occurs within a biologically constrained architecture and thus is biased towards learning some categories more easily than others. Furthermore some preliminary category representations are likely to be in place before learning begins. The relative contributions of learning and biology do not receive further discussion here, although their interaction is central to the development of conceptual systems.

Categorical knowledge for components of experience plays fundamental roles in the cognitive system, providing representational support for all cognitive processes. Consider online processing. As people interact with the environment and attempt to achieve goals, the conceptual system contributes in three ways. First, it supports perception, predicting the entities and events likely to be perceived in a scene, thereby speeding their processing (e.g., Biederman, 1981; Palmer, 1975). The conceptual system also helps construct perceptions through figure-ground segregation, anticipation, filling in, and other sorts of perceptual inferences (e.g., Peterson & Gibson, 1994; Reed & Vinson, 1996; Samuel, 1997; Shiffrar & Freyd, 1990, 1993). Second, the conceptual system supports categorisation. As entities and events are perceived, the conceptual system assigns them to categories. Third, once something has been assigned to a category, category knowledge provides rich inferences constituting expertise about the world. Rather than starting from scratch when interacting with something, agents benefit from knowledge of previous category members.

Besides being central to online processing of the environment, the conceptual system is central to offline processing in memory, language, and thought. In each of these tasks, processing a non-present situation is often of primary importance, with perception of the current environment being suppressed to facilitate processing the imagined situation (Glenberg, Schroeder, & Robertson, 1998). In memory, a past situation is reconstructed. In language, a past or future situation is represented, or even an impossible one. In thought, a past, future, or counter-factual situation is analysed to support decision making, problem solving, planning, and causal reasoning. In all three types of offline processing, the conceptual system plays central roles. In memory, the conceptual system provides elaboration at encoding, organisational structure in storage, and reconstructive inference at retrieval. In language, the conceptual system contributes to the meanings of words, phrases, sentences, and texts, and to the inferences that go beyond them. In thought, the conceptual system provides representations of the objects and events that occupy reasoning.

Finally the conceptual system plays a third central role in cognition. Besides supporting online and offline processing, it supports the productive construction of novel concepts (e.g., Hampton, 1997; Rips, 1995; Wisniewski, 1997). The conceptual system is not limited to representing entities and events that an agent has experienced in the world. Because the conceptual system establishes categorical knowledge about components of experience, it can combine these components in novel ways to represent things never encountered. Thus an agent can combine categorical knowledge for striped and waterfall to represent the novel category, STRIPED WATERFALL. Because of this ability, the conceptual system can categorise novel entities during online processing (e.g., a striped waterfall), and it can represent these novel entities offline in language and thought. This powerful process allows humans to imagine non-present situations, thereby increasing their fitness in the evolutionary landscape (cf. Donald, 1991, 1993).

THEORIES OF THE CONCEPTUAL SYSTEM

Theorists have proposed many accounts of the conceptual system. This section first sketches three types of theory that have dominated research for the last 30 years: semantic memory, exemplar models, and feedforward connectionist nets. In reviewing these theories, only their most standard forms are presented. For each theory, a wide variety of models exists, and an even wider variety is possible. Presenting the standard forms of these theories serves simply to illustrate the diversity of the theories possible. When relevant, important variants to standard forms are noted. Following these first three approaches, a fourth and relatively novel approach is presented: situated simulation theory.
To characterise and contrast these four approaches, they will be positioned on five dimensions that structure the space of possible theories. Certainly other dimensions are potentially relevant, but these particular five capture important differences between the four types of theory considered here. These dimensions are also useful in organising the literature review that follows. As Table 1 illustrates, these five dimensions are architecture, representation, abstraction, stability, and organisation. Their definitions will become clear as the four theoretical approaches are presented.

**Semantic memory**

Semantic memory is the classic theory of the conceptual system, arising from a proposed distinction between semantic and episodic memory (Tulving, 1972). Semantic memory models still dominate much theoretical thinking about the human conceptual system. Specific examples include the network models of Collins and Quillian (1969), Collins and Loftus (1975), and Glass and Holyoak (1975). As Hollan (1975) notes, prototype and other feature set models (e.g., Reed, 1972; Rosch & Mervis, 1975) are roughly equivalent to their network counterparts, together forming a more general class of semantic memory models. For an extensive review of semantic memory models, see Smith (1978).

As Table 1 illustrates for architecture, semantic memory is widely viewed as modular, that is, as an autonomous system, separate from the episodic memory system and also from sensory-motor systems. Semantic memory does not share representation and processing mechanisms with these other modules, but is instead a relatively independent module with distinct characteristics.

**Table 1**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Semantic memory</th>
<th>Exemplar models</th>
<th>Feed-forward</th>
<th>Situated simulation</th>
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<tr>
<td>Architecture</td>
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<td>Representation</td>
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<td>Abstraction</td>
<td>Decontextualised</td>
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<td>Organisation</td>
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<td>Action-Environment</td>
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*Note.* The most standard form of each theory is characterised in this table. As the text illustrates, many variants exist for each theory. For organisation, "taxonomic" in parentheses indicates that taxonomic structure is implicit in these theories, not explicit.

One of these distinct characteristics is its representational format. As Table 1 illustrates, representations in semantic memory are widely viewed as amodal. Most basically, they are not the same as representations in sensory-motor systems. Instead they are redescriptions of sensory-motor representations into some new representation language that does not have sensory-motor qualities. Rather than being modality-specific, these representations are amodal, namely, arbitrary symbols that stand for sensory-motor representations and for the environmental entities they represent.

Representations in semantic memory are further viewed as relatively decontextualised, as the dimension for abstraction in Table 1 illustrates. In the typical theory, the representation of a category is a prototype or definition that distills relatively invariant properties from exemplars. Lost in the distillation are idiosyncratic properties of exemplars and background situations. Thus the representation of *chair* might be a decontextualised prototype that includes *seat*, *back*, and *legs*, with idiosyncratic properties and background situations filtered out. Although functional properties may be extracted and stored, they again are decontextualised invariants, not detailed information about specific situations. The resulting representation has the flavour of a detached encyclopedia description in a database of categorical knowledge that describes the world.

Along with being decontextualised, semantic memory representations are typically viewed as relatively stable. For a given category, different people share roughly the same representation, and the same person uses the same representation on different occasions.

Finally, semantic memory is widely viewed as organised taxonomically. Increasingly specific categories are nested in more general ones, with central sets of categories arising at the superordinate, basic, and subordinate levels of taxonomic hierarchies. Similarity plays a central role in establishing the inclusion relations that underlie these hierarchies, with similar categories at one level being nested in the same category at the next higher level. Background theories constrain the similarity computations that produce individual categories and clusters of categories (e.g., Murphy & Medin, 1985).

**Exemplar models**

Beginning with Medin and Schaffer's (1978) context model, exemplar models have provided a strong competitor to semantic memory models. Many important variants of the basic exemplar model have been developed, including Nosofsky (1984), Estes (1986), Heit (1998), and Lamberts (1998).
Architecturally, exemplar models are generally modular in that exemplar knowledge is assumed to reside in memory stores outside sensory-motor systems. Those exemplar models, though, that view exemplar representations as implicit memories can be construed as non-modular, given that they use sensory-motor systems for storing exemplar memories (e.g., Brooks, 1978; Jacoby & Brooks, 1984). According to these latter models, exemplars are perceptual memories of encoded events, and can therefore be construed as residing in sensory-motor systems. Because the dominant exemplar models tend not to view exemplar memories this way, at least explicitly, they are coded as modular in Table 1.

To the extent that exemplar memories are stored outside sensory-motor systems, their representations are amodal, differing from sensory-motor representations. Similar to semantic memory models, redescriptions in an amodal language represent the content of exemplar memories, standing in for the sensory-motor properties experienced for them originally. Typically in these models, symbols represent the values of an exemplar on relevant sensory-motor dimensions. Again, though, exemplar models that view exemplars as implicit memories can be construed as having modal representations, where the representation of an exemplar is a reenactment of the sensory-motor state encoded for it (e.g., Roediger & McDermott, 1993).

Where exemplar models differ most from semantic memory models is on the dimension of abstraction. Whereas semantic memory models distill properties across exemplars and store them as abstractions, exemplar models simply store exemplar memories, which can include much situational detail. Because exemplar models store situation-specific knowledge of category members, rather than abstracting across them, these models are coded as situated for the abstraction dimension in Table 1.

On the dimension of stability, exemplar models, like semantic memory models, are relatively stable. Most exemplar models assume that all exemplar memories for a category are accessed every time the category is processed. Although an exemplar set can be very large, its constant application across different occasions is relatively stable, with all exemplars being applied. Exemplar models that sample small subsets of exemplars, on the other hand, are dynamic (e.g., Barsalou, Fluttenlocher, & Lamberts, 1998; Nosofsky & Palmeri, 1997). Because such models are relatively rare, exemplar models have been coded as stable in Table 1.

Exemplar models typically do not address the dimension of organisation in Table 1. Nevertheless, exemplar models can be viewed as implicitly producing taxonomic organisation via the similarity mechanisms that control exemplar retrieval. Specifically, when a new exemplar is presented to an exemplar model, clusters of similar exemplars tend to become most active. When a new dog is presented, DOG exemplars tend to become the most active, and also MAMMAL and ANIMAL exemplars to lesser extents. In general, an exemplar memory becomes increasingly active as it shares properties with the new exemplar. The clusters that result from these activation gradients can be viewed as implementing implicit taxonomic organisation, where the implicit nature of this organisation is indicated in Table 1 by parentheses around "taxonomic". It is important to add, however, that theorists have not yet developed accounts of how exemplar models utilise this implicit structure to perform taxonomic reasoning (Hampton, 1998).

Feed-forward connectionist nets

Feed-forward nets constitute a relatively recent but increasingly influential theory of the conceptual system. For general accounts of these nets, see Rumelhart, Hinton, and Williams (1986) and Bechtel and Abrahamsen (2002). For specific applications of the feed-forward architecture to representing conceptual knowledge, see Hinton (1989), Kruschke (1992), and Rumelhart and Todd (1993). A variety of other connectionist formalisms have also been used to model the conceptual system, which are not covered here (e.g., Farah & McClelland, 1991; Gluck & Bower, 1988; McClelland & Rumelhart, 1985; Shanks, 1991). Of primary interest here are the properties of feed-forward nets as an account of conceptual knowledge.

Architecturally, feed-forward nets maintain a modular conceptual system. Whereas the input layer of a feed-forward net is typically interpreted as a perceptual system, its hidden layer is typically viewed as a conceptual system. Thus one "module" of units underlies perception, whereas a second underlies conception, thereby maintaining a modular distinction between the two. Complex interactions do indeed arise between these two systems, such that they are not modular in the sense of being impenetrable (cf. Fodor, 1983; Pylyshyn, 1984). Nevertheless different representational systems underlie perception and cognition, thereby maintaining modularity. As will be seen shortly, it is possible to formulate a conceptual system in which the same neural units represent information in both perception and conception. It is also worth noting that other connectionist architectures operate this way as well. Thus modularity only applies to connectionist nets of the feed-forward variety, along with others that have separate pools of units for perception and conception.

Because of this modular architecture, the internal representations in feed-forward nets are amodal. Prior to learning, connections between the input and hidden layers are set initially to small random values, making learning possible. As a result, a somewhat arbitrary mapping develops between the input and hidden layers, with conceptual representations
being redescriptions of the perceptual representations. With each new set of weights, a different mapping develops. The arbitrariness that results is much in the spirit of semantic memory representations. In both cases, conceptual representations on the hidden units differ from perceptual representations on the input units. Clearly details of the representations differ, with connectionist representations being statistical, and semantic memory representations being symbolic. Nevertheless both are amodal redescriptions of perceptual input at a more general level of analysis.

On the dimension of organisation, feed-forward nets implicitly organise categories around taxonomic similarity, as in exemplar models. To the extent that different exemplars share similar properties, the same hidden units represent them. As a result, taxonomic clusters develop attractors in the net’s weight space to represent them implicitly (e.g., Rumelhart & Todd, 1993). On presenting a new exemplar to a net, attractors for the closest taxonomic clusters—at multiple levels—are most likely to become active.

Where feed-forward nets depart from semantic memory models is on abstraction and stability. Rather than establishing decontextualized representations of categories, feed-forward nets store situated representations in two senses. First, these nets store much idiosyncratic information about exemplars (as in exemplar models), rather than discarding it during the abstraction of category invariants. Although invariants may be abstracted, much idiosyncratic information is maintained that plays central roles in processing. Second, feed-forward nets store background information about the settings in which exemplars occur. Rather than extracting focal knowledge of a particular chair from a living room scene, much correlated information about the scene is stored as well (e.g., Rumelhart, Smolensky, McClelland, & Hinton, 1986). As a result, activating an exemplar typically retrieves setting information, and vice versa.

On the dimension of stability, the conceptual representations in feed-forward nets are highly dynamical. Rather than representing a category with a stable representation, as in semantic memory and exemplar models, a connectionist net represents a category with a space of representations. Essentially a category’s representation is an attractor within the possible activation states of the hidden units, with an infinite number of states around the attractor providing possible representations. On a given occasion, the representation activated is a function of the network’s current state, input, and learning history. Thus a concept is a dynamical system that produces a family of representational states, depending on current conditions.

The situated simulation theory

The view of the conceptual system advanced here differs from semantic memory on all five dimensions in Table 1. First, the situated simulation theory is non-modular. Rather than having separate systems for sensory-motor and conceptual processing, a common representational system underlies both. As described shortly, conceptual processing uses reenactments of sensory-motor states—simulations—to represent categories. Although perception and conception are similar, they are not identical, given that bottom-up mechanisms dominate the activation of sensory-motor systems during perception, whereas top-down mechanisms are more important during conception. Furthermore the representations activated in conception are partial reenactments of sensory-motor states, and may often exhibit bias and reconstructive error. Nevertheless perception and conception are far from being modular autonomous systems.

As a result of this non-modular architecture, conceptual representations are modal, not amodal. The same types of representations underlie perception and conception. When the conceptual system represents an object’s visual properties, it uses representations in the visual system; when it represents the actions performed on an object, it uses motor representations. The claim is not that modal reenactments constitute the sole form of conceptual representation. As described later, hidden unit representations, like those in feed-forward nets, may also play a role. The claim is simply that modal reenactments are an important and widely utilised form of representation.

Turning to abstraction and stability, the situated simulation view assumes that conceptual representations are contextualised and dynamical. A concept is not a single abstracted representation for a category, but instead a skill for constructing idiosyncratic representations tailored to the current needs of situated action. As described in more detail later, a concept is a simulator that constructs an infinite set of specific simulations (Barsalou, 1999). Thus the simulator for CAR can construct many simulations of different cars, from different perspectives, used for different purposes. In principle, a simulator can produce an infinite number of simulations, varying dynamically with the agent’s current goal and situation.

More than the focal category is represented in a given simulation. As discussed later, additional information about background settings, goal-directed actions, and introspective states are also typically included in these simulations, making them highly contextualised. Furthermore,
because a simulator tailors simulations to current situations, a wide variety of simulations represents the category across different situations, not just one. The result is a conceptual system that is highly contextualised and dynamical, much like feed-forward nets, but with modal representations instead of amodal ones.

Finally, the situated simulation view proposes that the conceptual system is organised around situated action, not around taxonomies. As described later, a fundamental problem in situated action is mapping action effectively into the world, and an intriguing possibility is that the conceptual system develops to facilitate this mapping. In particular, ad hoc and goal-derived categories develop to bind roles in action with instantiations in the environment. As systems of these mappings develop, the conceptual system becomes organised around the action–environment interface. Classic taxonomies play a secondary role in organising subdomains of knowledge to support this interface.

EVIDENCE FOR THE SITUATED SIMULATION THEORY

The remainder of this article reviews evidence that situated simulation underlies the conceptual system. The review will be organised around the five dimensions in Table 1. Because the dimensions of architecture and representation are tightly coupled, evidence showing that conceptual representations are non-modal and modal will be reviewed together in the next section. In the third section (abstraction), findings will show that conceptual representations are contextualised to support situated action. In the fourth section (stability), findings will show that the simulations serving situated action arise from dynamical systems. In the fifth section (organisation), findings will suggest that the conceptual system becomes organised around the action–environment interface.

Evidence for a modal non-modal conceptual system

On the dimensions of architecture and representation, the issues are, first, whether the conceptual system is separate from sensory-motor systems, and second, whether it uses modal vs. amodal representations. At this point it is useful to define the construct of a sensory-motor state. First, such states can be defined as patterns of neural activation in a sensory-motor system. On seeing a chair, for example, its representation in the visual system is a pattern of neural activation along the ventral and dorsal streams. This way of thinking about sensory-motor states is well established and widely accepted (e.g., Palmer, 1999; Zeki, 1993). Second, these states can be viewed as conscious mental experiences. Clearly, though, what becomes conscious is a relatively small subset of the unconscious processing taking place neurally. Furthermore various theoretical issues arise in discussing conscious experience that are tangential to those of interest here. For these two reasons, the remainder of this article focuses on the neural representation of sensory-motor states. The subsets of these states that achieve consciousness will be of secondary interest, although this is certainly an important issue.

Viewing sensory-motor states as active patterns in modality-specific neural systems provides a means of distinguishing modular amodal views from non-modal modal views. According to modular amodal views, a conceptual representation is not a neural pattern in a sensory-motor system—the neural pattern that represents an entity during its perception is not active during its conceptualisation. Instead neural activation in some other brain system represents the object conceptually. Furthermore the neural representation in conception takes a different form than the one in perception, with the same form representing conceptual properties across different modalities.

In contrast, non-modal modal views make a very different claim. When a category is represented conceptually, the neural systems that processed it during perception and action become active in much the same way as if a category member were present (again, though, not identically). On conceptualising CAR, for example, the visual system might become partially active as if a car were present. Similarly the auditory system might reenact states associated with hearing a car, the motor system might reenact states associated with driving a car, and the limbic system might reenact emotional states associated with enjoying the experience of driving (again all at the neural level).

Thus a fairly large and significant difference exists between how the modular amodal and the non-modal modal views represent concepts. As a result, it would seem that much research in the literature would have addressed which is correct. Surprisingly little research has. Instead widespread acceptance of modular amodal views reflects theoretical considerations. As Barsalou (1999) conjectured, the rise of modular amodal systems reflected the development of logic, statistics, and computer science in the early twentieth century, and the later incorporation of these developments into the cognitive revolution. Because amodal representation languages have considerable expressive power, because they can be formalised, and because they can be implemented in technology, they captured the imagination of the field, took over theoretical thinking, and became widely practiced.

Clearly, however, a strong empirical case should exist for such an assumption, even if it is useful theoretically. The next three sub-sections
review findings that question it. In the first, much research indicates that sensory-motor representations are widespread throughout cognition, and therefore should be likely in the conceptual system as well. The second sub-section reviews recent behavioural tests designed explicitly to assess whether categories are represented in modality-specific systems. The third sub-section reviews recent evidence from cognitive neuroscience that bears on this issue.

Behavioural evidence for sensory-motor representations throughout cognition. In studying diverse forms of cognitive processing, researchers have obtained widespread evidence for sensory-motor representations. In some cases, demonstrating such representations was a goal. In most cases, though, researchers were addressing other hypotheses but nevertheless reported findings that can be interpreted post hoc as indicating the presence of sensory-motor representations. Indeed some of these researchers might not agree with this post hoc interpretation of their findings! For this reason, direct a priori tests of this issue are critical, and the results of such tests will be reported in the next two sub-sections, after reviewing more general evidence here.

In perception, filling-in and anticipatory inferences suggest that sensory-motor representations from the conceptual system enter fluently into perceptual processing. In the phoneme restoration effect, hearers simulate the experience of a phoneme—absent in the speech signal—using sensory-motor knowledge about the word that contains it, and also about the speaker’s voice (e.g., Warren, 1970). Recently Samuel (1997) reported that these simulations activate early sensory systems, implicating sensory representations in these linguistic inferences. Similarly, in representational momentum, viewers simulate the visual trajectory of an object beyond the trajectory displayed physically (e.g., Freyd, 1987), implicating visual knowledge in these inferences. Knowledge about whether a particular type of object moves quickly or slowly affects simulated trajectories, suggesting that object representations contain perceptual representations of motion (e.g., Reed & Vinson, 1996). Visual inferences from knowledge about the body similarly influence perceived bodily motion, overriding the minimal transformation law of apparent motion (e.g., Shiffrar & Freyd, 1990, 1993; Stevens, Fonlupt, Shiffrar, & Decety, 2000). Perceivers fill in the blind spot with perceptual representations that underlie conceptual knowledge about object shape (Ramachandran, 1992, 1993). Perceptual representations of objects also drive figure-ground segregation towards representations of known objects (e.g., Peterson & Gibson, 1994). In all these cases, sensory-motor representations in conceptual knowledge appear to fuse with incoming sensory information to construct perceptions (Hochberg, 1998).

Sensory-motor representations have been widely implicated in working memory, particularly in mental imagery. Considerable amounts of behavioural work indicate that mental imagery results from activating sensory-motor representations (e.g., Finke, 1989; Kosslyn, 1980; Shepard & Cooper, 1982), as does much neural work (e.g., Farah, 2000; Kosslyn, 1994). Sensory-motor representations are not only central in visual imagery, they are also central in motor imagery (e.g., Grezes & Decety, 2001; Jeannerod, 1995, 1997; Deschaumes-Molinario, Dittmar, & Vernier-Maury, 1992; Parsons, 1987a,b) and in auditory imagery (e.g., Zatorre, Halpern, Perry, Meyer, & Evans, 1990).

Sensory-motor representations are widely implicated in long-term memory. In the literature on mnemonic strategies, imagery and concreteness effects implicate such representations (e.g., Paivio, 1986). In the boundary extension effect, images of scenes appear responsible for extending a picture’s memory beyond its boundary (e.g., Intraub, Gottesman, & Bills, 1998). In verbal overshadowing, images activated via words appear responsible for distortions of studied pictures and other sensory-motor experiences (e.g., Schooler, Fiori, & Brandimonte, 1997). In haptic priming, images of motor movements prime memory (e.g., Klatzky, Pelligrino, McCloskey, & Dougherty, 1989). In implicit memory, perceptual processing is essential for establishing robust implicit learning (e.g., Jacoby, 1983), and also explains the narrow transfer gradients around it (e.g., Jacoby & Hayman, 1987). Furthermore, imagining a stimulus produces about 60% of the priming produced by actually perceiving it, consistent with the presence of perceptual representations (e.g., Roediger & McDermott, 1995). Finally, neural work has localized both implicit and explicit memory in sensory-motor systems (e.g., Buckner, Petersen, Ojemann, Miezin, Squire, & Raichle, 1995; Nyberg, Habib, McIntosh, & Tulving, 2000; Wheeler, Petersen, & Buckner, 2000). Glenberg (1997) reviews further findings that implicate sensory-motor representations in memory.

Considerable evidence also exists for sensory-motor representations in language. In numerous experiments, Bower and Morrow (1990) found that mental models of text meaning have spatial qualities (also see Glenberg, Meyer, & Lindem, 1987). Much earlier work on comprehension inferences similarly suggested the presence of spatial representations (e.g., Bransford & Johnson, 1973). Other research has shown that readers take spatial perspectives on scenes described in texts (e.g., Black, Turner, & Bower, 1979; Spiwey, Tyler, Richardson, & Young, 2000). Intraub and Hoffman (1992) showed that readers confuse pictures with texts, suggesting that they imaged the texts’ meanings. Gerrnabacher, Varner, and Faust (1990) found that comprehension ability for pictured events correlated highly with comprehension ability for texts, suggesting that sensory-motor representations...
underlie both. Potter, Kroll, Yachzel, Carpenter, and Sherman (1986) showed that replacing words with pictures did not disrupt sentence processing, suggesting that the pictures were integrated effortlessly into a sensory-motor representation of the sentence's meaning (also see Glaser, 1992). Gibbs (1994) reviews findings suggesting that sensory-motor representations are central to the processing of metaphor (also see Lakoff & Johnson, 1980).

Finally, sensory-motor representations have been implicated in various forms of thought. In decision making, Kahneman and Tversky (1982) suggested that people use a simulation heuristic to evaluate possible choices. In reasoning, Johnson-Laird (1983) and Fauconnier (1985, 1997) argued that mental models underlie reasoning, where mental models can be viewed as sensory-motor representations. In causal reasoning, Ahn and Bailenson (1996) argued that imagining causal mechanisms is central to causal reasoning, where these imagined mechanisms could be implemented as simulations. Philosophers of science frequently note that scientific and mathematical discoveries arise from imagery (e.g., Barwise & Etchemendy, 1990, 1991; Hadamard, 1949; Nersessian, 1999). Similarly, researchers have argued that children and adults use mental models in basic arithmetic reasoning (e.g., Huttenlocher, Jordan, & Levine, 1994).

Together all of these findings implicate sensory-motor representations across the spectrum of cognitive processes, from perception to abstract thought. It thus seems quite likely that such representations would also occur in the conceptual system. Clearly, however, one must be cautious about post hoc interpretations of previous work, and applying them to the representation of concepts. Direct a priori assessments of sensory-motor representations in conceptual processing are obviously much more desirable. The next two sub-sections review such work.

Direct behavioural assessments of modal vs. amodal representations

For the past 10 years, my students and I have been designing experiments to assess whether perceptual simulations represent concepts (see Barsalou, Solomon, & Wu, 1999, for an early review). We have focused on two tasks that are widely believed to access conceptual knowledge: property generation and property verification. In property generation, a participant hears the word for a category (e.g., “chair”), and then verbally generates characteristic properties of the underlying concept out loud (e.g., “seat, legs, back, you sit on it”). In property verification, a participant reads the word for a category on a computer (e.g., “chair”), and then verifies whether a subsequently presented property is true or false of the category (e.g., “seat” vs. “faucet”). Whereas property generation is an active, production-oriented task extended over time, property verification is a more passive, recognition-oriented task under time pressure.

Nearly all accounts of these tasks have assumed that participants access amodal representations to perform them (e.g., Collins & Quillian, 1969; Conrad, 1972; Kosslyn, 1976; Rosch & Mervis, 1975; Smith, 1978). When producing or verifying properties, participants consult semantic networks, feature lists, frames, etc. to produce the required information. In contrast, we hypothesized that participants simulate a category member to represent a category, and then consult the simulation to produce the requested information. In property generation, participants scan across the simulation, and produce words for properties in its sub-regions. In property verification, participants evaluate whether the test property can be found in a sub-region of the simulation.

Instructional equivalence. To assess these theoretical possibilities, we evaluated two types of evidence: instructional equivalence and perceptual work. To assess instructional equivalence, the performance of neutral participants was compared with the performance of imagery participants. Neutral participants received the standard task instructions used throughout the literature. For property generation, they were asked to generate properties characteristic of each object concept. For property verification, they were asked to verify whether or not each property was true of the object. Imagery participants were explicitly asked to use imagery. For property generation, they were asked to image each object and then describe the image. For property verification, they were asked to image the object and only respond true once they found the property in the image. Much previous work in the imagery literature demonstrates that participants instructed to use imagery do so, and our experiments independently demonstrate this as well.

Of primary interest for instructional equivalence is how the performance of the neutral and imagery participants compares. According to amodal views, these two groups should perform differently. Whereas neutral participants should use amodal representations, imagery participants should use sensory-motor representations (or at least pretend to use them because of task demands). As a result, significant differences should occur between the two groups.

Various amodal views make this prediction. On Pylyshyn’s (1981) tacit knowledge view, subjects only have amodal knowledge, but know how to deploy it so that they appear to be using imagery. If this account is correct, then imagery instructions should induce the tacit knowledge that produces imagery-like performance, but the neutral instructions should not—neutral participants should spontaneously employ amodal representations in a non-imagery-like manner. As a result, the two groups should perform differently.

Similarly, views that postulate modal representations alongside amodal ones also tend to predict differences in performance. In Kosslyn’s (1980)
original theory, imagery primarily arises when task demands induce participants to construct it in working memory. When participants can use amodal representations, they tend to fall back on them, because these representations can be deployed more rapidly and easily. As a result, imagery and neutral performance should differ. Kosslyn (1976) offers empirical evidence for this prediction.

In contrast, the simulation view predicts that neutral and imagery participants should generally perform similarly. Neutral participants should spontaneously run the same sorts of simulations as imagery participants. Because they do not have amodal representations, they simulate categories to represent them, even when not asked explicitly to do so. As a result, neutral and imagery participants produce the same basic patterns of performance.4

Findings from Wu and Barsalou (2003) support the simulation account. In Wu and Barsalou, the properties generated were coded into 37 property types, with the frequency of each type computed once for the neutral condition and once for the imagery condition. The 37 average frequencies for the neutral participants were then correlated with those for the imagery participants. Across three experiments, the correlations were .99, .81, and .96, after correcting for unreliability of the mean frequencies. This high agreement suggests that the neutral and imagery participants accessed the same sorts of representations as they produced properties, not different ones.

One potential concern is that the critical result is a null effect. Thus it is important to show that instructional manipulations can change property distributions. For this reason, a third instructional condition was included in which participants generated associated words for each category name. When the frequency distributions for this condition were compared to the neutral and imagery conditions, the correlations were substantially lower. Clearly an instructional manipulation can change the distribution of properties. Of interest is that the imagery instructions did not change the distribution relative to the neutral condition.4

4 An important caveat is that neutral participants will readily use word associations—instead of simulations—to perform conceptual tasks, when task conditions allow this superficial form of processing. In several papers described shortly, this superficial processing was observed (Ken et al., 2003; Solomon & Barsalou, 2003; Wu & Barsalou, 2003; for a review, see Glaser, 1992). Most importantly, however, when task conditions block superficial responding based on word associations, the conceptual processing enforced appears to consist of simulations, as findings in each paper indicate.

5 One difference that did occur was the imagery participants produced more properties than neutral participants, consistent with the conclusion drawn for property generation that imagery instructions induce participants to construct more detailed simulations than those constructed spontaneously by neutral participants. Again, though, the distributions of properties were virtually identical between the two groups, suggesting that both constructed the same type of representation.

One might worry that participants use simulation in property generation because the task is production oriented, and because they have unlimited time to use all of their resources to represent categories. Perhaps such simulations would not occur in a recognition-oriented task under time pressure (cf. Kosslyn, 1976, 1980). For this reason, we also assessed the presence of simulations in property verification (Solomon & Barsalou, 2003).

To assess instructional equivalence, the average verification time and error rate were first computed for each critical concept-property pair (e.g., CHAIR-seal). The data across 100 or more pairs in a given experiment were then regressed onto a large set of potential predictors, namely, various factors that we thought might predict RTs and errors. These predictors fell into three general groups: linguistic, perceptual, and expectancy. The linguistic predictors included the associative strength between the concept and property words in both directions, the word frequency of the properties, and their length. The perceptual predictors included the size and position of the properties, whether they were occluded, whether they would be handled during situated action, and so forth. The expectancy predictors assessed the polysemy of the property words (i.e., the typical property word takes many different senses across objects; consider leg, handle, button, etc.).

Of primary interest was that the regression equations for the neutral and imagery conditions were qualitatively the same—indeed in some analyses, they were quantitatively identical. The same pattern of predictors explained performance in both conditions. Generally speaking, perceptual variables were most important for both, followed by the expectancy variables, and then the linguistic variables. This finding in two experiments suggests that imagery and neutral participants used similar representations to perform the task. Neutral participants appeared to be using simulations, similar to imagery participants.5

Thus the instructional equivalence found in property generation was not an artifact of the task being production oriented and having no time pressure (i.e., property listing). In a recognition-oriented task under time pressure (i.e., property verification), a similar result occurred. Again, the prediction of a null effect is tempered by the fact that in other conditions not described here, qualitatively different regression equations explained
performance. Different strategies for performing the task are possible, yet imagery instructions did not change performance relative to the neutral condition.

**Perceptual effort.** To further assess the presence of simulations in conceptual processing, we and other researchers have manipulated perceptual variables, such as occlusion, size, shape, orientation, and modality, analogous to previous work in mental imagery. If participants are constructing perceptual simulations to represent categories, then perceptual variables should affect task performance. In contrast, if participants are using amodal representations, it is much less obvious that such variables should have effects. Indeed no amodal theory has ever predicted that variables like size, orientation, and occlusion should affect conceptual processing.

Wu and Barsalou (2003) manipulated occlusion by having half the participants generate properties for noun concepts (e.g., LAWN), and the other half generate properties for the same nouns preceded by revealing modifiers (e.g., ROLLED-UP LAWN). In perception, occluded properties do not receive much attention because they are hidden behind an object’s surface. Thus we predicted that if people simulate LAWN to generate its properties, they should rarely produce its occluded properties, such as dirt and roots. In contrast, when people perceive a rolled-up lawn, its normally occluded properties become visible and more salient. Thus we predicted that when people produce properties for ROLLED-UP LAWN, previously occluded properties would become salient in simulations and be produced more often. Amodal theories of conceptual combination do not readily make this prediction, given that they are relatively compositional in nature (e.g., Smith, Osherson, Rips, & Keane, 1988). Unless additional post hoc assumptions are added that produce interactions between nouns and modifiers, the properties for LAWN are not obviously changed by ROLLED-UP in these theories (e.g., the accessibility of dirt and roots does not vary).

As predicted, the number of internal properties was higher when revealing modifiers were present than when they were not. Internal properties were also produced earlier in the protocols and in larger clusters. This effect occurred not only for familiar noun combinations, such as HALF WATERMELON, but also for novel ones, such as GLASS CAR. Furthermore, the increase in occluded properties was not the result of rules for properties stored with the modifiers, given that a particular modifier did not always increase occluded properties (e.g., ROLLED-UP SNAKE). Occluded properties only increased when the modifiers referred to entities whose internal parts become unoccluded in the process of conceptual combination (e.g., ROLLED-UP LAWN). Together this pattern of results is consistent with the prediction that when a simulation reveals occluded properties, they are produced more often, relative to when they are occluded in a simulation.

Turning to property verification, Solomon and Barsalou (2003) found that perceptual variables predicted performance for neutral participants better than did linguistic and expectancy variables. In particular, property size was the most important of the perceptual variables (as measured by per cent unique variance explained). As a property became larger, it took longer to verify, presumably because a larger region of a simulation had to be processed. Notably property size was the most central predictor of performance in a conceptual task with linguistic materials and no imagery instructions, after removing variance explained by all other variables.

Solomon and Barsalou (2001) similarly found that property shape was a critical factor in property verification. When participants verified a property on one trial, it facilitated verifying the same property later, but only if the detailed shape was similar. Thus verifying mane for PONY was facilitated by previously verifying mane for HORSE but not by verifying mane for LION. This effect was not the result of the greater overall similarity between HORSE and PONY than between HORSE and LION. When the similarity of a property between all three concepts was high, facilitation was the same. For example, verifying belly for PONY was facilitated as much by verifying belly for LION as by verifying belly for HORSE. Thus perceptual similarity of the property was the critical factor, not conceptual similarity.

Zwaan, Stanfield, and Yaxley (2002) similarly reported that property shape affects conceptual processing, but during language comprehension. Participants read a short vignette about an object that implied one of several possible shapes. Whereas some participants read about a flying bird, others read about a sitting bird (i.e., the implied shape of the bird differed between the two vignettes). After reading the vignette, participants named a visually presented object (shown in isolation, not in a scene). When a bird was shown, sometimes it was flying, and other times sitting. As the simulation view predicts, participants named objects faster when their shapes matched the implied shapes in the vignettes than when they did not. As participants read the vignettes, they simulated objects in the implied shapes.

Stanfield and Zwaan (2001) similarly showed that orientation affects conceptual processing during language comprehension. Participants read vignettes that implied objects in particular orientations. Whereas some participants read about a fish lying on its side, others read about a fish lying on its back. Immediately thereafter, participants saw an isolated object and had to indicate whether it had been mentioned in the vignette. Sometimes the orientation of an object matched its implied
orientation in the text, and sometimes it did not (e.g., a horizontal nail vs. a vertical one). Verification was fastest when the orientations matched.

Two other recent findings further support simulations in language comprehension (Glenberg & Robertson, 2000; Kaschak & Glenberg, 2000). When participants read about a novel object performing a function, their comprehension of it was effortless, as long as the object’s affordances produced the function. For example, when a character in a story needed a pillow, participants understood immediately that a sweater filled with leaves would work, but that a sweater filled with water would not. Similarly, in the context of hitting things with a baseball bat, “crutching an apple” to someone made perfect sense, even though it was a novel construction. According to these researchers, people understand such constructions by simulating the corresponding events and assessing the functional affordances in these simulations, much as they would assess them in actual perception. When affordances produce the critical function, comprehension occurs. Most importantly, it is difficult and cumbersome for amodal representation languages to compute these affordances. The fact that they arise so naturally in simulations further supports the presence of simulations in comprehension.

Finally, Pecher, Zeelenberg, and Barsalou (2003) have shown modality-switching effects in conceptual processing. Previous work in perception shows that detecting a signal on a modality suffers when the previous signal was on a different modality than on the same one (e.g., Spence, Nicholls, & Driver, 2000). For example, verifying the presence of a light flash is faster when the previous signal was a light flash than when it was an auditory tone. Pecher et al. demonstrated a similar phenomenon in property verification using linguistic materials and no imagery instructions. When participants verified a conceptual property on one modality, processing was faster when the previous property came from the same modality as opposed to a different one. For example, verifying loud for BLENDER was faster when rustling was verified for LEAVES on the previous trial than when tart was verified for CRANBERRIES. Scaling of the materials found that properties drawn from the same modality were more associated than the properties from different modalities. Furthermore, when highly associated properties were verified on contiguous trials, they were verified no faster than unassociated properties. Thus switching between modalities was responsible for the obtained effects, not associative strength.

Evidence from cognitive neuroscience. As the previous two sections illustrate, a strong behavioural case is developing for simulations in the conceptual system. A strong neural case is developing as well in the lesion and neuroimaging literatures. In these latter areas, researchers have explored the hypotheses that categories are represented in sensory-motor areas of the brain, and have reported much evidence for it.

In the lesion literature, researchers have reported that a lesion in a particular sensory-motor system increases the likelihood of losing categories that rely on that system for processing exemplars online. For example, damage to visual areas increases the chances of losing LIVING THINGS, because visual processing is often the dominant modality when interacting with these entities (e.g., Damasio & Damasio, 1994; Gainotti, Silveri, Daniele, & Giustolisi, 1995; Humphreys & Forde, 2001; McRae & Cree, 2002; Warrington & Shallice, 1984). Conversely, damage to motor areas increases the chances of losing MANIPULABLE ARTIFACTS such as TOOLS, because motor processing is often the dominant modality (e.g., Damasio & Damasio, 1994; Gainotti et al., 1995; Humphreys & Forde, 2001; McRae & Cree, 2002; Warrington & McCarthy, 1987). Similarly, damage to colour processing areas produces deficits in colour knowledge (e.g., DeRenzi & Spinelli, 1967; Damasio & Damasio, 1994), and damage to spatial processing areas produces deficits in location knowledge (e.g., Levine, Warsch, & Farah, 1985).

Controversy currently surrounds these findings, with some theorists stressing the importance of other factors besides damage to sensory-motor systems. For example, Caramazza and Shelton (1998) propose that localized brain areas represent specific categories that are evolutionarily important, such as ANIMALS. Tyler, Moss, Durrant-Parfield, and Levy (2000) propose that the statistical distribution of property information determines the localization of categories and their vulnerability to lesion-based deficits.

Simmons and Barsalou (2003b) argue that all these views are correct and propose a theory that integrates them. Following Damasio (1989), Simmons and Barsalou propose that two levels of representation underlie conceptual knowledge. At one level, reenactments of sensory-motor states are central to representing categories. At a second level, statistical representations in association areas—much like those on the hidden layers of feed-forward nets—conjoin sensory-motor states into coherent representations. Simmons and Barsalou argue that these conjunctive hidden units cluster spatially by similarity. For example, the hidden units that organise sensory-motor features for ANIMALS cluster spatially together, whereas the hidden units that organise sensory-motor features for ARTIFACTS cluster spatially elsewhere (in a more distributed manner, due to lower within-category similarity). Such organisation implements the localised category representations important for Caramazza and Shelton, and also the statistical structure important for Tyler et al. Nevertheless the reenactment of sensory-motor states is also central. A primary function of statistical representations in association areas is to reactivate sensory-
motor states in feature maps so that information relevant to the current task can be extracted from these simulations.

Most importantly, lesions at various levels of this system can produce the diverse forms of deficits found throughout the lesion literature. Whereas lesions in association areas can produce deficits for individual categories, lesions in feature maps can produce deficits across multiple categories that rely on them (e.g., McRae & Cree, 2002). Depending on which mechanism of the simulation process is lesioned, different deficits result.

The neuroimaging literature offers further support for simulations in conceptual processing. Consistent with the lesion literature, different sensory-motor areas become active for different types of categories. When people process categories for which the visual modality is important (e.g., ANIMALS), visual areas become active (e.g., Martin, Ungerleider, & Haxby, 2000; Martin, Wiggs, Ungerleider, & Haxby, 1996; Perani, Schnur, Tettamanti, Gorno-Tempini, Cappa, & Fazio, 1999; Pulvermüller, 1999; Spitzer et al., 1998). Conversely, when people process categories for which the motor modality is important (e.g., TOOLS), motor areas become active (e.g., Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Martin et al., 2000; Martin et al., 1996; Perani et al., 1999; Pulvermüller, 1999; Spitzer et al., 1998). Similarly, when people process colour, colour areas become active (e.g., Chao & Martin, 1999; Rösler, Heil, & Hermgåusen, 1995; Martin et al., 1995; Martin et al., 2000). Finally, when people process locations, spatial systems become active (e.g., Rösler et al., 1995). All these results are consistent with the conclusion that people simulate categories in sensory-motor systems.

Notably, however, the sensory-motor areas identified by fMRI studies of conceptual processing are typically not identical to the primary sensory-motor areas active in actual perception and action. Instead, the two sets of areas are usually immediately adjacent within the same modality-specific system (e.g., both in the visual system). An important issue for future work is to provide greater insight into the specific roles that these two sets of areas play. For example, the areas active in conceptual processing could be feature maps common to both conception and sensory-motor processing, whereas the areas active only in sensory-motor processing are used exclusively in bottom-up processing and execution. Alternatively, the areas active in conceptual processing could be the association areas described earlier that conjoin sensory-motor features (Damasio, 1989; Simmons & Barsalou, 2003b). Still another possibility is that these areas implement classic amodal symbols. Much further work of many types is necessary to resolve this issue. Single-cell recording studies may be particularly informative, especially on the question of whether associative neurons reactivate feature map neurons to produce simulations.

Finally, neural support has accumulated for three lines of the behavioural work described earlier. Kan et al. (2003) repeated Solomon and Barsalou's (2003) property verification study in an fMRI scanner (only using neutral subjects), and found activation in the fusiform gyrus, a visual area important in high-level object processing and imagery. Notably, when conditions of the experiment allowed participants to use word association instead of imagery, the fusiform was no longer active, indicating its role only when simulations were predicted to represent categories. Whereas superficial conceptual processing can effectively utilize word representations, deeper conceptual processing appears to trigger—and perhaps require—simulations (also see Solomon & Barsalou, 2003; Wu & Barsalou, 2003).

Simmons, Pecher, Hamann, Zeelenberg, and Barsalou (2003) repeated the Pecher et al. (2003) modality-switching study in an fMRI scanner. In this particular version of the experiment, participants verified properties in blocks organised into six modalities: vision, audition, movement, touch, smell, and taste. For each modality, a profile of sensory-motor modalities became active, which corresponded to the profile of modalities that people reported experiencing subjectively for the respective concept-property pairs. Thus, processing these pairs engaged multi-modal sensory-motor processing.

Finally Zwaan, Stanfield, Yaxley, and Scheffers (2001) measured ERPs in further studies on object shape. When an object's shape in a text and a picture mismatched, ERPs occurred that indicate visual mismatches, further implicating visual representations in language processing.

Theoretical issues. If one is convinced by the empirical case for simulation in the conceptual system, a problem arises. For decades, theorists have argued that perceptual representations do not have sufficient expressive power to represent conceptual knowledge (e.g., Pylyshyn, 1973). Even if empirical evidence exists for simulations, it remains to be shown how they could implement a fully functional conceptual system.

Barsalou (1999) offers an existence proof that a fully functional conceptual system could rest on sensory-motor simulations. In principle, such a system can distinguish types from tokens, produce categorical inferences, generate novel concepts productively in conceptual combination, represent the propositional hierarchies that underlie text comprehension, and represent abstract concepts. Clearly a computational implementation of such a theory must be developed, and considerable empirical evidence must be gathered for its specific mechanisms. In principle, though, it appears feasible, at least, that sensory-motor mechanisms could help implement the human conceptual system.
Furthermore the following empirical conclusions appear warranted at this time. The conceptual system appears neither fully modular nor fully amodal. To the contrary, it is non-modular in sharing many important mechanisms with perception and action. Additionally it traffics heavily in the modal representations that arise in sensory-motor systems.

Evidence for situated simulations

Two metaphors capture the opposing positions on the issue of abstraction (i.e., Dimension 3 in Table 1). At one extreme, the conceptual system is a detached database. As categories are encountered in the world, their invariant properties are extracted and stored in descriptions, much like an encyclopaedia. The result is a database of generalised categorical knowledge that is relatively detached from the goals of specific agents. At the other extreme, the conceptual system is an agent-dependent instruction manual. According to this metaphor, knowledge of a category is not a general description of its members. Instead a concept is a skill that delivers highly specialised packages of inferences to guide an agent’s interactions with specific category members in particular situations. Across different situations, different packages tailor inferences to different goals and situational constraints. According to this view, the information stored for a category is organised into situation-specific units, not into a general description.

A package of situation-specific inferences will be referred to as a situated conceptualisation. Across different situations, a concept generates different conceptualisations, each designed to optimise one particular type of situated action with the respective category. A given situated conceptualisation contains four types of information:

1. contextually-relevant properties of the focal category;
2. information about the background setting;
3. likely actions that the agent could take to achieve an associated goal;
4. likely introspective states that the agent might have while interacting with the category, such as evaluations, emotions, cognitive operations, etc.6

Following the previous section, it will be assumed that these four types of inferences are delivered via neural simulations in the respective modality-specific areas. Specifically, contextually relevant object properties are simulated in the ventral stream, settings are simulated in parietal areas, actions are simulated in the motor system, and introspective states are simulated in areas that process emotion and reasoning. Together, simulations of these four inference types produce the experience of being there conceptually (Barsalou, 2002). When it becomes necessary to process a category, its concept delivers a situated conceptualisation that creates a multi-modal representation of what it would be like to process the category in that situation.7

The next four sub-sections review evidence that the conceptual system delivers situated conceptualisations, with each sub-section providing evidence for one type of situated inference: contextualised category representations, background settings, actions, and introspective states.

Evidence for contextualised category representations. Much research across multiple literatures demonstrates that concepts do not produce the same representation over and over again across situations. Instead a concept produces one of many possible representations that is tailored to the current context.

Barsalou (1982) provides a typical example of this finding. Participants read a sentence and then verified whether a subsequent property was true or false of the underlined subject noun. Between participants, the predicate of the sentence varied to manipulate the situation, as between:

The basketball was used when the boat sank.

The basketball was well worn from much use.

As this example illustrates, the predicate in each sentence situates BASKETBALL in a different context. Immediately after reading one of these sentences, participants verified whether floats was true of BASKETBALL. When floats was relevant to the sinking situation in the first sentence, participants verified it faster than when it was irrelevant to the normal use situation in the second sentence. As participants read about the boat sinking, the concept for BASKETBALL produced relevant inferences—it did not produce the same representation in both contexts.

6 An unaddressed issue is whether contextual information about settings, actions, and mental states resides within concepts proper or is associated to them externally. Alternatively no clear demarcation may exist between them, with one shading into the other. Resolution of this issue is not critical to the thesis here, which is simply that packages of correlated inferences are delivered to support situated action, regardless of where they originate.

7 The phrase “being there conceptually” could be taken to mean that agents experience these contexts of action consciously. The sense of “being there conceptually” intended here is that neural systems ready themselves for perceptions and actions likely to be present while processing a category in the current situation. Clearly these neural systems may produce conscious states as they prepare themselves for situated action. Again, though, much more neural processing takes place (but consciousness reveals, and the focus continues to be on the neural processing that underlies consciousness).
Evidence for setting inferences. When the conceptual system represents a category, it does not represent the category in isolation. Instead it typically situates the category in a background setting. Again much work supports this conclusion, as reviewed in Yeh and Barsalou (2003).

Consider an experiment by Vallée-Tourangeau, Anthony, and Austin (1998). Participants performed the instance generation task, namely, they received a category (e.g., FRUIT) and produced instances of it (e.g., APPLE, KIWI, PEAR). Virtually all accounts of this task assume that participants generate instances from conceptual taxonomies. For FRUIT, participants might first produce instances from CITRUS FRUIT, then from TROPICAL FRUIT, then from WINTER FRUIT, and so on. In contrast, Vallée-Tourangeau et al. (1998) conjectured that participants situate the category in a background setting, scan across the setting, and report the instances present. To produce FRUIT, for example, participants might imagine being in the produce section of their grocery store and report the instances found while scanning through it.

To assess this possibility, Vallée-Tourangeau et al. (1998) first had participants produce the instances of common taxonomic categories (e.g., FRUIT) and also of ad hoc categories (e.g., THINGS PEOPLE TAKE TO A WEDDING). After producing instances for all the categories, participants were asked how they produced instances for each category, indicating one of three possible strategies. First, if the instances came to mind automatically, participants indicated the unmediated strategy. Second, if the instances were retrieved in clusters from a taxonomy, participants indicated the semantic strategy. Third, if the instances were retrieved from a situation, participants indicated the experiential strategy.

As Vallée-Tourangeau et al. predicted, searching situations was the dominant strategy for producing instances. Participants used the experiential strategy 54% of the time, followed by the semantic strategy (29%) and the unmediated strategy (17%). Surprisingly this pattern was the same for taxonomic and ad hoc categories. Because ad hoc categories arise in goal-directed events, it is not surprising that they would be associated with situations. Surprisingly, though, taxonomic categories were equally situated. Walker and Kintsch (1985) and Backs (1998) report similar findings.

The Wu and Barsalou (2003) experiments described earlier further demonstrate that categories are situated in background settings. Participants were explicitly asked to produce characteristics true of the target objects (e.g., WATERMELON). Nothing in the instructions requested or even implied the relevance of background settings. As Figure 1 shows, however, participants produced setting information regularly. Across four experiments, the percentage of setting information ranged from 19% to 35%, averaging 25%. As participants simulated the target objects, they implicitly situated them in background settings, leading to the inadvertent production of many setting properties (e.g., park, picnic table, etc. for WATERMELON).

Much evidence further demonstrates a tight coupling between object representations and situations (as reviewed in Yeh & Barsalou, 2003). For example, work on visual object processing shows that objects are strongly linked to background scenes (e.g., Biederman, 1987; Bar & Ullman, 1996; Intraub, Gottesman & Bills, 1998; Mandler & Parker, 1976; Mandler & Stein, 1974; Murphy & Wisniewski, 1989). When an isolated object is perceived, a background scene is typically inferred immediately.

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Figure 1. Proportion of property types across the four experiments in Wu and Barsalou (2003). Properties of the target objects were explicitly requested in the instructions to participants (Object). However, participants also produced related taxonomic categories (Category), along with information about the background settings (Settings) and agents' introspective states (Introspections).
Evidence for action inferences. Thus far we have seen that conceptual representations contain contextually relevant properties, and that they are situated in background settings. As the results in this next sub-section show, the conceptual system places agents squarely in these settings, producing inferences about the actions they could take on situated objects.

Consider an fMRI experiment by Chao and Martin (2000). As participants viewed pictures in the scanner, their task was to name them implicitly. Four types of pictures were presented: manipulable objects (e.g., hammer), dwellings, animals, and human faces. All participants were right-handed and lay motionless in the scanner. Nevertheless a circuit involving the motor system became active while participants perceived the manipulable objects. Notably this circuit did not become active for the other pictures. Furthermore it was only active in the left hemisphere, namely, the side that controls right-handed movements—again the participants were right handed. This finding suggests that seeing a manipulable object, such as a hammer, the conceptual system generated appropriate motor inferences for handling it with the right hand. Even though the target task was visual categorisation, and even though participants were required to lie still in the scanner, their motor systems nevertheless implicitly generated movements for interacting with the manipulable objects. Presumably such inferences prepare agents for situated action.

Consider a similar finding from Adolphs, Damasio, Tranel, Cooper, and Damasio (2000). Again participants' task solely involved visual processing, but this time the visual categorisation of facial expressions. On each trial, participants saw a face and had to indicate whether the expression was happy, sad, angry, etc., with the correct response being defined as the dominant emotion categorisation across a large group of judges. Of interest to Adolphs et al. were the brain areas that produce these categorisations. To assess this, they sampled from a registry of patients having lesions in different brain areas. If an area is important for categorising visual expressions of emotion, then lesions in the area should produce task deficits. The critical finding was that large deficits were found for patients with lesions in somatosensory cortex. Why would somatosensory lesions produce deficits on a visual task? Adolphs et al. argue that simulating facial expressions on one's own face is central to visually recognising expressions on other faces. When somatosensory cortex is damaged, such simulations become difficult, and facial categorisation suffers.

Work in social cognition supports this conclusion. Wallbott (1991) videotaped participants' faces as they visually categorised emotional expressions on other faces. Interestingly, participants regularly simulated the emotional expressions that they were categorising on their own faces. More importantly, when a participant correctly simulated the expression being categorised, their accuracy increased. Similarly Niedenthal, Brauer, Halberstadt, and Innes-Ker (2001) found that preventing participants from simulating expressions decreased their ability to categorise facial expressions on others, relative to participants free to move their faces. Together all these findings illustrate that the motor and somatosensory systems become involved in the visual processing of faces.

Such simulations can be viewed as motor inferences produced by the conceptual system to support situated action. In many settings, if another person is experiencing an emotion, it is often useful for the perceiver to enter the same state. Thus, if another person is angry about something, it may be supportive to be angry as well. Social contagion similarly supports being jointly happy or jointly sad about a shared event. In these cases, once the concept for a particular emotion becomes active, appropriate motor and somatosensory states for entering into it follow.

Other recent studies further support the importance of action inferences in high-level cognition. Smith, Thelen, Titzer, & McLin (1999) concluded that the motor system plays a central role in the A-not-B error (i.e., misremembering that an object is hidden at an earlier location rather than at its current one). Rather than being a purely cognitive phenomenon reflecting factors such as object permanence, this error results from the close coupling of the cognitive and motor systems. Perseverative reaches by the motor system to old locations interfere with spatial memory, when these actions are inconsistent with an object's current location.

Glenberg and Kaschak (2002) similarly show that comprehending a sentence about a motor movement can interfere with the act of responding. For example, when participants used a forward hand movement to indicate that sentences are coherent and not anomalous, they responded faster when the judged sentence described a forward movement than a backward one (e.g., "Close the drawer" vs. "Open the drawer"). Glenberg (1997) discusses other such findings.

Finally, when participants perform motor actions while generating properties, the actions change conceptual simulations in predictable ways. In Barbey and Barsalou (2003), participants believed that the experiment addressed the ability to perform factory operations while communicating with a supervisor. Following Wu and Barsalou's (2003) occlusion effect, Barbey and Barsalou (2003) had participants occasionally perform an action that would open up an object and reveal its internal properties (e.g., the motion of opening a drawer while producing properties for DRESSER). As predicted, participants produced more internal properties (e.g., socks and sweater for DRESSER) when they performed revealing actions (e.g., opening a drawer) than when they performed non-revealing actions (e.g., turning a wheel chair's wheels). Only a few participants had
an inkling of the hypothesis (never a complete understanding), and the effect was no stronger for these participants than for the others. Furthermore, a control group was generally unable to label the actions correctly, and the probability of labelling actions correctly was unrelated to the production of action-related properties. Thus revealing actions appeared to produce object simulations that prepared participants for situated action. Simmons and Barsalou (2003a) similarly show that motor actions affect visual categorisation. When an action is consistent with a visual object, the object is categorised faster than when the action is inconsistent (e.g., categorising a FAUCET while performing the motion of turning a faucet vs. turning a dial).

Together all these results suggest a close coupling between the motor and conceptual systems. On the one hand, when people conceptualise a category, they infer relevant actions that they could take on it. On the other, when people perform an action, it influences the construction of conceptual representations. Barsalou, Niedenthal, Barbey, and Ruppert (in press) review many additional findings in social psychology that point to the same conclusion.

Evidence for introspective state inferences. Not only do people infer possible actions that they could take on categories in background settings, they further infer introspective states likely to arise during these interactions. Again consider the Wu and Barsalou (2003) data in Figure 1. As we saw earlier, participants produced many properties about background settings when the explicit instruction was to produce properties of target objects. Of interest here is the fact that participants also produced many properties about the likely introspective states of agents during situated action. These included evaluations of whether objects are good, bad, effective, etc. They also included emotional reactions to objects, such as happiness, along with other cognitive states and operations relevant to interacting with them (e.g., comparing an object to alternatives). On the average, 10% of the properties produced were about introspective states, ranging from 6% to 15% across experiments. As participants simulated the target objects, they situated them in background settings that included themselves as agents. Because these simulations of "being there" included introspective states, properties of these states entered the protocols.

Perspective effects in various tasks further implicate introspective states in conceptual simulations. Spivey et al. (2000) had participants listen to a vignette while wearing an eye-tracking helmet (which they believed was turned off at the time). Different participants heard different vignettes, where the critical variable was the implied perspective for viewing a scene. Some participants, for example, heard about the top of a skyscraper, whereas others heard about the bottom of a canyon. As participants listened to their story, they tended to adopt the relevant perspective motorically. Participants hearing about the skyscraper top were most likely to look up, whereas participants hearing about the canyon bottom were most likely to look down. Participants adopted the relevant perspective on the situation, acting as if they were "there". Other findings similarly show that the cognitive system produces the perspective of "being there" while comprehending language and retrieving information from memory (e.g., Anderson & Pichert, 1978; Black et al., 1979; Spivey & Geng, 2001).

Further work demonstrates the role of perspective in conceptual processing. Barsalou, Barbey, & Haas (2003) videotaped participants as they produced properties for object concepts. Occasionally the object was something that would typically be above a person (e.g., BIRD) or on the ground (e.g., WORM). When participants produced properties for objects above them, their eyes, face, and hands were more likely to drift up than for objects below them, and vice versa. These findings suggest that participants simulated "being there" with the objects as they produced their properties.

Finally Borghi and Barsalou (2003) found that participants typically generate properties from perspectives relevant to situated action. Thus participants tended to produce properties that would be experienced up close to an object and from its front, as if interacting with it.

"Being there" conceptually. Results reviewed in the previous four sub-sections support the conclusion that the conceptual system is not a detached database of encyclopaedic knowledge. Instead the conceptual system is more like an agent-dependent instruction manual, tailoring conceptual representations to the current needs of situated action. Furthermore these situated conceptualisations take the form of simulations that create the experience of "being there" with category members. These simulations include contextually relevant properties of the focal category, background information about the setting, inferences about likely actions, and inferences about likely introspective states. Together these packages of simulated inferences prepare agents for situated action.

Evidence for dynamical simulations

Rosch (1975) assessed the stability of typicality gradients and reported stabilities over 30. On the basis of such findings, many researchers concluded that stable prototypes represent concepts in semantic memory (i.e., Dimension 4 in Table 1). Different people share the same
prototype, and the same individual uses the same prototype on different occasions.

We have just seen, however, that the conceptual system tailors conceptualisations to specific situations. Thus it would appear that stable representations do not underlie concepts. Instead a concept produces many different conceptualisations, depending on current goals and constraints. How do we reconcile these findings with empirical reports of stability?

The measures that Rosch reported assessed the stability of mean typicality judgements. What she showed is that stable typicality judgements can be obtained when enough participants contribute to average ratings (i.e., the central limit theorem). To assess agreement between individual participants, other measures of stability are required. Barsalou (1987, 1989, 1993) reported such measures, and they tell a very different story. For typicality judgements, the average correlation between pairs of participants averaged around .40 across studies. Different participants appeared to use very different prototypes for judging typicality. Furthermore, the same participant appeared to use different prototypes on different occasions. When the same participant judged typicality again 2 weeks later, the average correlation with their earlier judgements was around .80, suggesting a modest change in how they represented the categories.

One possibility is that variability in typicality judgements simply reflects noise. An unpublished study, however, obtained .94 agreement between participants and .98 agreement within participants when the task was to rank the same exemplars by physical weight instead of by typicality. Thus the ranking task is highly sensitive and relatively noise free when weight is judged. In typicality judgements, though, much larger variability results from different participants retrieving different information to represent a category. Additional findings also ruled out the interpretations that atypical exemplars, stochastic sampling, and knowledge differences underlie this variability (Barsalou, 1993).

Other tasks besides typicality judgement show similar variability in how people conceptualise categories. McCloskey and Glucksberg (1978) had participants assign basic level categories to superordinates in two sessions separated by a month. Roughly 25% of the basic level categories changed superordinate membership across the two sessions for natural kinds as well as for artifacts, indicating considerable variability in the criteria used to assign membership. Similarly Barsalou (1989) reported considerable variability in property generation. On average, two participants only produced 44% of the same properties for a given category. Across a 2-week delay, the same participant only produced 66% of the same properties in the two sessions. Together with the typicality and member-

ship data, these findings suggest that stable representations do not underlie concepts.

Instead Barsalou (1987, 1989, 1993) concluded that a concept is a dynamical system, which produces a wide variety of representational states, depending on current conditions. Smith and Sumalson (1997) reached a similar conclusion after reviewing similar findings from the conceptual development literature. In long-term memory, a tremendous amount of stored information underlies a concept. On a given occasion, only a small subset of this information is retrieved, namely, the information that is currently most accessible.

Three factors dynamically determine the most accessible subset of a concept's content on a given occasion: frequency, recency, and context. As information is processed frequently for a category, it becomes better established in memory, and more accessible across contexts. If one person regularly experiences large dogs, whereas another regularly experiences small ones, large and small will become relatively more accessible for each individual, respectively. Similarly information processed recently for a category becomes temporarily elevated in accessibility, such that its inclusion in concepts increases during a brief temporal window. If a person was recently licked by a dog, licks becomes temporarily elevated for a limited time, and is more likely to be included in representations of DOG.

Finally the current context affects the accessibility of conceptual information. As shown earlier, floats becomes more accessible for BASKETBALL in the context of needing a life preserver than in other contexts (Barsalou, 1982). Presumably, associations from the current context prime related properties in the knowledge for a concept, increasing their accessibility temporarily.

As these examples illustrate, frequency, recency, and context together determine the category information most accessible for a particular conceptualiser in a particular context. From individual to individual, and from context to context, the information most accessible for a category fluctuates dynamically, producing conceptualisations that vary considerably.

Viewing conceptual variability from the perspective of situated action. The earlier theme of situated action is consistent with the results on conceptual variability. According to the situated action view, a concept is not a general description used over and over again across situations. Instead a concept is an ability or skill to construct specific representations that support different courses of situated action. Because a concept produces a wide variety of situated conceptualisations, substantial variability in its representation arises. Because different information about
a category is needed in different situations, different conceptualisations are constructed.

Finally we saw earlier that a concept produces experiences of “being there” with a category. For this reason, Barsalou (1999) proposed that a concept is a *simulator*. Rather than being a detached database of category information, a simulator produces a wide variety of simulations that create the experience of “being there” in different contexts of situated action. Thus the simulator for *CHAIR* produces simulations of interacting with a living room chair, an office chair, a theatre chair, a jet chair, a ski-lift chair, and so forth. To create the experience of “being there” in each of these situations, the simulator produces situation-relevant information about the relevant chair, along with situation-relevant information about the setting, actions, and introspective states. As a person’s expertise with a category develops, the ability to simulate the relevant contexts of situated action grows. The result is a dynamical system that supports skilled interaction with the category across contexts.

**Evidence for organisation around the action–environment interface**

The three previous sections have focused on the internal structure of individual concepts, addressing their representational format, situatedness, and dynamical character. This final section addresses the broader organisation of the conceptual system (i.e., Dimension 5 in Table 1). Two metaphors capture the opposing positions on this dimension.

At one extreme, people are intuitive taxonomists. Their goal is to discover the categorical structure of the world, develop taxonomic systems that represent this structure, and establish background theories that frame these taxonomies. At the other extreme, people are goalAchievers who organise knowledge to support situated action. On this view, the primary organisation of the conceptual system supports executing actions effectively in the environment, with taxonomic hierarchies constituting a secondary-level of organisation that supports this activity.

**Ad hoc and goal-derived categories.** The presence of categories that arise specifically to achieve goals intimates the importance of goal achievement in organising the conceptual system. In particular, ad hoc categories, such as *THINGS TO PACK IN A SUITCASE*, are derived in the course of achieving specific goals (e.g., taking a trip). Over time, some of these categories become well established in memory, as when a frequent traveller packs the same things repeatedly in a suitcase (e.g., Barsalou & Ross, 1988). Barsalou (1983, 1985, 1991) refers to this general class of categories as *goal-derived categories*, and to novel ones constructed online as *ad hoc categories* (see Ross & Murphy, 1999, for related work).

Various properties of these categories indicate that they originate in situated action. Barsalou and Borghi (in prep.) collected protocols of participants talking about goal-directed events and found that for every action mentioned, there was a 75% chance of a goal-derived category being mentioned along with it. Thus these categories are ubiquitous in everyday cognitive processing of events. At a given moment in time, one is likely to find them operative.

Barsalou (1983) demonstrated that ad hoc categories only become salient in the context of pursuing the goals they serve. For example, people have trouble seeing the category that *CHAIR, WASTEBASKET, BOX,* and *ROCK* form. When a story character has the problem of holding a door open on a hot windy day, however, the category *THINGS TO HOLD A DOOR OPEN* comes to mind immediately. Such context effects suggest that ad hoc categories are closely coupled with reasoning about goals.

Barsalou (1985) reports that goal-derived categories are organised internally to optimise goal achievement. When the typicality gradients of these categories are assessed, ideals associated with goal-achievement underlie them. The members of a goal-derived category do not become more typical as they approach its prototypical (average) properties. Instead they become more typical as they approach ideal values. Thus members of *THINGS TO PACK IN A SUITCASE* do not become more typical as they approach average size and weight for the category; instead they become more typical as they approach ideally small size and ideally light weight.

The association of ideals with goal-derived categories further indicates their close coupling with goals. When achieving a goal, it is usually necessary to instantiate relevant goal-derived categories to implement a plan (Barsalou, 1991). When taking a trip, for example, it is necessary to instantiate *THINGS TO PACK IN A SUITCASE*. The association of ideals with these categories helps maximise goal achievement. By comparing possible instantiations to a category's ideals, an agent can find instantiations that will be optimally effective. For example, comparing *THINGS TO PACK IN A SUITCASE* with *ideally small and light* helps identify those instantiations that contribute to optimal travel.6

Notably taxonomic categories are also associated with ideals, further showing that even these categories serve situated action. For example, the ideal of *sweetness* is associated with *FRUIT,* whereas the ideal of *nutritiousness* is associated with *VEGETABLES* (Barsalou, 1985). By

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6 Although ideals are useful for optimising instantiations in planning, they aren’t sufficient for determining category membership. Other properties must typically be considered as well.
selecting instantiations close to these ideals while eating, goals related to
taste and diet are optimised. Additional research similarly demonstrates
the centrality of ideals across a wide variety of conceptual domains (e.g.,
Borkenau, 1990; Chaplin, John, & Goldberg, 1988; Lehrer, 1992; Loken &
In summary, goal-derived categories arise during the process of
achieving goals. They are mentioned frequently during goal-related
events, they typically become salient during goal pursuit, and their internal
representations optimise goals.

The role of goal-derived categories in the cognitive system. One might
think that goal-derived categories are merely a quaint curiosity of the
conceptual system. Although interesting, they are relatively peripheral,
with taxonomic categories constituting the core. Thus the question arises:
What role do goal-derived categories play in the conceptual system?
To answer this question, it is instructive to consider standard models of
problem solving and planning (e.g., Newell & Simon, 1972). Perhaps by
examining these models, the role of goal-derived categories in them can be
ascertained. According to standard models of problem solving and
planning, goal achievement has the following basic phases:
(1) An agent selects a goal to pursue.
(2) The agent selects a sequence of actions to achieve the goal.
(3) The agent executes the action sequence in the environment.
(4) The agent evaluates the outcome of the action sequence. If the
outcome is satisfactory, goal pursuit ends; if it is not, the agent
iterates through Steps 1, 2, and 3 until the goal is achieved or
abandoned.

Where might goal-derived categories arise in this sequence? One
possibility is in Step 3 during the execution of action sequences in the
environment. To implement an action sequence, it is necessary to solve the
interface problem, that is, the problem of integrating action with the
environment effectively (see meshing in Glenberg, 1997, for a similar
construct). Consider shopping for groceries. To buy groceries successfully,
it is necessary to interface the shopping sequence with the environment.
The instantiation of roles in event sequences is central to this process
(Barsalou, 1991). Roles in grocery shopping include STORES THAT
SELL GROCERIES, TRANSPORTATION TO THE STORE, PAY-
MENTS THE STORE ACCEPTS, and STORE HOURS. To successfully
achieve grocery shopping, it is necessary to map each of these roles into
environmental instantiations appropriately (e.g., a particular store,
transportation, payment, hours). When one of these roles is not
instantiated successfully, the goal may fail.

For highly routinised action sequences in familiar environments, the
interface problem is not salient. Because mappings from roles to the
environment have become well-established in memory, people integrate
action with the environment effortlessly (e.g., in weekly grocery shopping).
The interface problem becomes salient when knowledge of these mappings
is absent, as while grocery shopping in a country very different from one's
own. Under such conditions, the importance of mappings between roles in
action and entities in the environment becomes apparent.
Based on the above analysis of the interface problem, Barsalou (1991)
concluded that goal-derived categories constitute the mappings between
roles in event sequences and instantiations in the environment. Further-
more, establishing these mappings is essential to achieving the four basic
phases of problem solving and planning just described. In the absence of
successful mappings, problem solving and planning fail. Goal-derived
categories appear to be a fundamental component of goal-directed
behaviour.

Figure 2 illustrates this account within the framework of situated
simulation theory (see Barsalou, 1999, for further discussion). Imagine
having the goal of changing a burned-out light bulb on the ceiling. Panel B
of Figure 2 illustrates the scene that the agent might see. Panel A
represents the agent's simulated attempt to change the light bulb. After
simulating a failed reach to the bulb while standing on the floor, the agent
concludes that it is beyond reach. Thus the agent simulates something to
stand on and tries again. Notably at this point, the agent may not simulate
a particular thing to stand on, but only the idea of standing on a large
sturdy object that resides in a schematic space-time region of the
simulation. As Barsalou (1999) illustrates, simulations can contain
schematic components that partially represent entities, not just detailed
representations of them. One can imagine standing on a large sturdy object
without knowing exactly what it is—one simply knows that it can be
stepped onto safely and extend one's reach significantly.
Once the agent has simulated standing on something to reach the bulb,
the environment is searched for possible instantiations of the schematic
region. As the mapping between Panels A and B illustrates, several objects
in the scene might seem likely to work, based on running them as
instantiations in the simulation (i.e., the stool, chair, and table). Once this
mapping from the schematic role to the environment has been established,
it creates an ad hoc category, namely, THINGS THAT COULD BE
STOOD ON TO CHANGE THE LIGHTBULB.

Broadly speaking, the account just provided could underlie ad hoc and
goal-derived categories in general. By and large, these categories can be
viewed as mapping a space-time region in a simulated action sequence to a
set of possible instantiations in the environment. Panel C of Figure 2
Figure 2. Accounting for the ad hoc categories of **THINGS THAT COULD BE STOOD ON TO CHANGE A LIGHTBULB (A)** and **THINGS THAT COULD BE USED TO HOLD A DOOR OPEN (C)**, which construe common entities in the same scene differently (B). From Barsalou (1999), with permission from Cambridge University Press.

illustrates another example, namely, **THINGS THAT COULD BE USED TO HOLD THE DOOR OPEN**.

Furthermore, many of these mappings are so conventionalized that simple lexemes name them (Barsalou, 1991). For **BUY**, the lexemes “seller”, “buyer”, “merchandise”, and “payment” name roles in the verb’s meaning for **AGENT, PATIENT, THEME, and INSTRUMENT**, respectively. Each of these roles can be viewed as a space-time region in a simulation that maps into possible instantiations in the environment. Lexemes similarly name mappings for many other common verbs, projecting from their associated roles to goal-derived categories (e.g., **FOOD** and **UTENSIL** for **EAT**).

To the extent that this account is correct, it suggests that the action-environment interface is central to the conceptual system. Most notably, it suggests that an important class of categories arises at this interface. Categories do not simply arise from discovering structure in the environment, as is typically assumed for common taxonomic categories. Instead, a central class of categories arises from binding space-time regions in simulated action sequences with instantiations in the environment. Without this sort of conceptual structure, people could not achieve goals effectively.

**Organisation around the action-environment interface.** If important categories originate at the action-environment interface, it suggests a larger organisation of the conceptual system (Barsalou, 1991). Rather than being organized around taxonomic categories, the conceptual system may be organised around this interface, with taxonomic categories playing a supporting role. On this view, the three most basic domains of the conceptual system represent **action**, the **environment**, and the mapping between them. Each of these domains is addressed briefly in turn.

The domain of action represents conceptual knowledge about how to achieve goals. Included in this domain is knowledge about particular goals, the action sequences used to achieve them, and the roles within these action sequences. Classic theories of scripts and frames provide preliminary accounts of what this knowledge might look like (e.g., Schank & Abelson, 1977).

The domain of the environment contains two important kinds of information. First, it contains knowledge of specific settings that an agent knows, such as homes, work environments, neighbourhood environments, and so forth. A given person has a **world model** that represents the settings he or she has experienced. Surprisingly little work has addressed such knowledge, with most related work addressing either route finding in cognitive maps or generic concepts for settings (e.g., Tversky & Hemenway, 1983). Much more work seems necessary to explore how people represent the **specific** physical settings that they experience regularly in their respective worlds (cf. Minsky, 1977).

Second, conceptual knowledge of the environment contains classic taxonomies. To represent specific settings in one’s environment, it is useful to have knowledge about the particular kinds of things encountered in them. As one enters a new office, for example, knowledge of **CHAIRS** and **TABLES** is retrieved to recognize and interact with new category members, and to establish representations of them in knowledge for the specific setting. In a sense, common taxonomies are like palettes in object-oriented drawing programs. They provide a tool for creating tokens of known categories in the representation of new settings. On this account, taxonomic categories play a secondary role in supporting the action-environment interface.
Finally, the third knowledge domain is the system of mappings between the first two. As agents increasingly solve the interface problem, they establish goal-derived categories that link roles in action sequences with instantiations in the environment. The result is a much more complicated system of relations than shown in Figure 2. In Figure 2, direct mappings link roles directly to instantiations. In actuality, deep hierarchies of mappings appear to mediate action and the environment. In Barsalou (1991), participants often described subcategories of mappings between a role and its instantiations (also see Barsalou & Borghi, in prep.). Consider PAYMENTS. This role in BUY does not map directly into the concrete forms of payment available to an agent. Instead it first maps into subcategories such as CASH, CHECKS, CREDIT CARDS, LOANS, etc. In turn, each of these may map into more specific subcategories, such as CREDIT CARDS breaking down into CREDIT CARDS WITH AVAILABLE BALANCE and CREDIT CARDS WITH LOW INTEREST RATES. Eventually this taxonomy maps into particular instances in the environment. As expertise with achieving an action sequence develops, extensive systems of mappings like these grow to support it, thereby constituting a third basic domain of the conceptual system.

CONCLUSIONS

Three general conclusions follow from the work reviewed here. First, the conceptual system develops to serve situated action. At the broad level of organisation, an important class of categories arises to streamline the action–environment interface. During goal pursuit, goal-derived categories provide mappings from roles in action sequences to instantiations in the environment. At the level of individual categories, simulators produce situated conceptualisations that support goal achievement. Each conceptualisation is a package of inferences that specifies contextually relevant properties of the focal category, information about a likely background setting, possible actions that an agent could take, and likely introspective states that might arise. Together these inferences produce the experience of "being there" with a category member, preparing an agent for situated action in a particular context.

Second, these situated conceptualisations are delivered via multimodal simulations. Whereas inferences about objects are delivered via sensory systems, inferences about actions are delivered via motor and somatosensory systems. Similarly inferences about introspective states are delivered via limbic and frontal areas that process emotion and thought. Rather than arising in a modular and amodal conceptual system, these representations arise as simulations or partial reenactments in modality-specific brain areas. As a result, each type of inference is represented in a different representation language native to its modality—a single representation language does not redescribe them all amodally.

Third, a concept is a dynamical system. A given simulator can construct an indefinitely large number of specific simulations to represent the respective category. Rather than a concept being a fixed representation, it is a skill for tailoring representations to the constraints of situated action. Because the same category can take different forms, be encountered in a variety of settings, and serve many goals, a fixed representation would not be optimal. No single representation could possibly serve all of these different situations well. A much better solution arises from having a simulator tailor conceptualisations to particular situations.

Clearly many open questions remain. Empirically the literature reviewed earlier is certainly not the final say on the matter. Nevertheless, these findings are sufficiently compelling to indicate that the situated simulation view should be entertained seriously. Theoretically a host of issues arises in explaining how situated simulations achieve important conceptual functions, such as productivity, propositions, and abstract concepts. Although Barsalou (1999) and Barsalou (in press) present preliminary solutions, further development is clearly necessary, as well as empirical support. Again, though, these proposals offer hypotheses of the conceptual system that seem sufficiently plausible to be entertained seriously.

Furthermore this approach offers solutions to problems that have been relatively intractable for amodal views. As Barsalou (1999) notes, simulations provide a powerful interface between cognition and perception. Not only does this provide a solution to the symbol grounding problem (Searle, 1980), it explains how conceptual representations can be brought to bear so effortlessly on perception, and how the two can be fused together so easily. This approach also offers a natural account of how the human conceptual system could have evolved from earlier species. It is easy to imagine non-humans having a similar representational system that evolved into ours, whereas it is much harder to imagine how an amodal system could have evolved uniquely for humans. As many theorists have suggested, the major change in humans was a linguistic system that provided powerful control over the same basic sort of conceptual system found in earlier species.

Another outstanding question is whether amodal theories can account for the sorts of findings reviewed in this paper. In principle, they probably can, given their expressive power. As Barsalou (1999) notes, however, these explanations are typically provided post hoc within a framework that is unfalsifiable. Thus these accounts should be viewed cautiously.
Ultimately, the issue boils down to a priori evidence. Empirically and theoretically, what a priori cases can be made for these differing views? The matter is clearly far from being settled at this time.

Nevertheless, one's view of the conceptual system affects how one thinks about the rest of cognition. It is difficult, if not impossible, to think about the cognitive system without committing to a particular theory of concepts. As we saw at the outset, representations in the conceptual system underlie all forms of cognitive activity, including high-level perception, working memory, long-term memory, language, and thought. One's view of the conceptual system affects theorising about all these other activities. As Barsalou (1999, Section 4) shows, viewing conceptual processes. As recent research further indicates, entertaining the possibility of simulation stimulates new hypotheses that future research can explore. At a minimum, the situated simulation theory has the potential to provoke thinking and research on the nature of the human conceptual system, as the field evolves towards increasingly sophisticated theories.

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