The Cambridge Handbook of Psycholinguistics

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The human conceptual system contains people's knowledge about the world. Rather than containing holistic images of experience, the conceptual system represents components of experience, including knowledge about settings, objects, people, actions, events, mental states, properties, and relations. Componential knowledge in the conceptual system supports a wide variety of basic cognitive operations, including categorization, inference, the representation of propositions, and the productive creation of novel conceptualizations. In turn, these basic operations support the spectrum of complex cognitive activities, including high-level perception, attention, memory, language, thought, and socio-cultural cognition. Traditional theories of Good-Old-Fashioned Artificial Intelligence (GOFAI), such as semantic memory, constitute the dominant approach to the conceptual system. More recently, researchers have developed alternative approaches, including connectionist theories and simulation/embodied/situated theories.

The distinction between a recording system and an interpretive system is central to characterizing conceptual systems (e.g., Barsalou, 1999b; Dretske, 1995; Haugeland, 1991; Pylyshyn, 1973). A recording system captures information about a situation by creating attenuated (not exact) copies of it. Cameras, video recorders, and audio recorders constitute good examples of recording systems, each capturing records of experience (e.g., photos, videos, audiotapes). A recording system does not interpret what each component of a recording contains—it simply creates an attenuated copy. For example, a photo of a wedding records the light present at each point in the scene without interpreting the types of entities and events present.

Conversely, a conceptual system interprets the entities perceived in an experience or in a recording of one. To interpret a wedding, the human conceptual system might...
construe perceived individuals as instances of *bride*, *chair*, *cake*, and so forth. To achieve interpretation, the conceptual system binds specific individuals in perception to knowledge about components of experience in memory. This is essentially the process of categorization. A system that only records perceptual experience does not categorize individuals in this manner. Instead, it simply records them in the holistic context of an undifferentiated scene.

Interpretation supports other powerful computational abilities besides categorization. Interpretation supports the production of inferences, allowing the cognitive system to go beyond perceptual input. Interpretation supports the formulation of propositions, where a proposition is a representational structure that binds a concept (type) to an individual (token) in a manner that is true or false. Interpretation is productive, supporting the construction of complex conceptual representations from simpler ones. Because the conceptual system supports these basic functions, it provides the larger cognitive system with computational abilities not possible in recording systems. Cameras and other recording devices have limited, if any, ability to implement categorization, inference, propositions, and productivity.

Selective attention and memory integration are central to creating the conceptual knowledge that underlies interpretive processing (Barsalou, 1999b; 2003a). Whenever selective attention focuses consistently on some component of experience, conceptual knowledge about the component develops (cf. Schyns, Goldstone, and Thibaut, 1998). Each time the component is attended, the information extracted becomes integrated with past information about the same component in memory. When attention focuses on a green patch of color, for example, the information extracted is stored with previous memories of *green*, thereby establishing conceptual knowledge for this component. Overtime, myriad components of experience accumulate memories in a similar manner, including objects, events, locations, times, introspective states, relations, roles, properties, and so forth. As conceptual knowledge about these components develops, it can be used to interpret regions of perception and imagery, as described in greater detail later. Thus, perceptual and conceptual representations work together to achieve cognitive processing.

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1 Italics will be used to indicate concepts, and quotes will be used to indicate linguistic forms (words, sentences). Thus, *bride* indicates a concept, and "bride" indicates the corresponding word.
2 Basic operations in a conceptual system

Once a system of conceptual knowledge develops for components of experience, it supports basic conceptual operations, which in turn support more complex cognitive activities. As just described, these basic operations include categorization, inference, propositions, and productivity. Each is described in further detail here. Their roles in complex cognitive activities are addressed later.

2.1 Categorization

During the process of categorization, the cognitive system assigns perceived individuals in perception and imagery to units of conceptual knowledge. While perceiving a soccer match, for example, individual settings (field), people (goalie), objects (ball), actions (kick), mental states (elation), and so forth are assigned to categories. While imagining a soccer match, imagined individuals in the simulated perception can be categorized similarly.

Categorization not only occurs in vision but in all modalities of experience. Thus, auditory events can be categorized (beep), as can actions (walk), tactile sensations (soft), tastes (sweet), smells (pungent), affect (boredom), motivation (hunger), cognitive states (disbelief), and cognitive operations (comparison). Furthermore, categorization is central to processing all units of linguistic analysis, including phonemes ("ba"), verbalized words ("hello"), and written words ("exit"). In each case, a linguistic entity is categorized as an instance of a phoneme or word. Categorization is similarly central to identifying syntactic units (noun phrase) and speech acts (question). Thus, categorization is not only central to processing the meaning of language but also to processing its structure.

The semantic and structural aspects of language are aligned (Langacker, 1986). For example, categorizing nonlinguistic aspects of the world typically (but not always) produces naming. On perceiving a robin, for example, conceptual knowledge for robin becomes active to categorize it. In turn, the word "robin" becomes active to name both the perceived individual and the conceptual knowledge activated, where the actual word produced is an individual instance of the word category. Even when naming is implicit (i.e., subvocal), this can be viewed as the production of a word instance, grounded in a motor and auditory simulation.

Finally, recent work suggests that mental simulations are central to linguistic processing (e.g., Glenberg et al., 2005; Spivey, Richardson, and Gonzalez-Marquez, 2005; Zwaan and Madden, 2005). To the extent that meaning is represented this way, categorizing components of mental simulations is central to linguistic processing. For example, examining a simulation and categorizing its components would be central to the process of language production. Categorizing the components of simulation activates associated words, which are produced in utterances to describe the simulation. Analogously, categorizing components of a perceived scene similarly underlies the production of an utterance to describe an actual perception. In addition, categorizing regions of a simulated or perceived scene not mentioned explicitly produces inferences (e.g., inferring knife from an unlabeled region of the simulation produced by the sentence, "Jeffrey cut the sandwich in half").

2.2 Inference

An important theme in categorization research is that categorization is not an end itself (e.g., Markman and Ross, 2003). Simply knowing the category to which a perceived individual belongs is not particularly useful. What is useful are the inferential capabilities that result.

Once an individual has been assigned correctly to a category, a multitude of useful inferences follow from associated conceptual knowledge that go beyond what has been perceived thus far for the individual. Imagine perceiving and categorizing
an unfamiliar individual as a cat. Useful inferences about the individual's structure, behavior, and internal states include that the cat has teeth and claws, that it can purr and scratch, and that it could be hungry and grateful. Useful inferences about relevant actions that the perceiver could perform follow as well, such as being cautious toward the cat, petting it, and feeding it. Many other potentially useful inferences also follow, including that the cat had a mother and father (potentially relevant for breeding purposes), that it could carry disease (relevant for health purposes), and so on. Once integrated conceptual knowledge about cat becomes active during categorization, a variety of associated inferences follow.

2.3 Propositions

Theories of psycholinguistics typically assume that propositional representations underlie the meanings of comprehended texts (e.g., Kintsch and van Dijk, 1978). Most simply, a proposition can be viewed as a type-token relation that becomes established between an individual and a concept. Thus, the process of categorization described earlier produces propositions. Categorizing an individual chicken, for example, creates a proposition that consists of the individual chicken (a token) being bound to the concept for chicken (a type). In text comprehension, similar type-token propositions arise as the meanings of words are combined. Hearing "Ralph is a chicken," for example, produces the proposition, chicken (Ralph), where the notation used is type (token). As this example illustrates, chicken is a predicate that takes individuals as arguments, such as Ralph. Other concepts take multiple arguments, in particular, verbs and propositions. For example, the verb eat can take arguments for agent, patient, and instrument, as in eat (John, soup, spoon). While comprehending phrases, sentences, and texts, many elemental propositions like these are constructed, which are then assembled hierarchically into larger and more complex propositional structures. Because the types in propositions are concepts, the conceptual system plays a central role in constructing the meaning of a text.

The conceptualizations that underlie language production are similarly assumed to rely on systems of propositions. As people conceptualize what they want to describe, they categorize individuals related to the topic under discussion, which produces type-token propositions (e.g., Bock, 1987). In turn, larger propositions, constructed from conceptual predicates, result from combining simpler ones. As the propositional representation develops, concepts in it activate associated words and syntactic structures, which then surface in utterances. The conceptual system provides a fundamental link between the specific situation being described and the words used to describe it.

2.4 Productivity

The human cognitive system can produce an infinite number of linguistic and conceptual structures that go far beyond those experienced. No one ever experienced a real Cheshire cat, but it is easy to imagine and then describe "a cat whose body fades and reappears while its human smile remains." Similarly, it is possible to begin with the conceptualization of a familiar object and then to imagine it in nonexperienced forms, such as conceptualizing a gray cat and then conceptualizing it as a purple cat or as a purple cat with green polka dots.

Productivity underlies people's creative abilities to combine words and concepts into complex linguistic and conceptual structures compositionally (e.g., Fodor and Pylyshyn, 1988; also see Barsalou, 1999b; 2003a). Productivity generally appears to result from combinatorial and recursive mechanisms. Combinatorial mechanisms allow people to take a word (or concept), and then rotate other words (or concepts) through a particular relation associated with it. Beginning with the noun "cat," for example, noun phrases can be constructed combinatorially by rotating other words through a modifier relation, thereby creating "gray cat," "orange cat," "purple cat," "pink cat,"
and so forth. Similarly, nouns can be combinatorially rotated through the thematic roles associated a particular verb, such as rotating "cake," "pizza," and "tamale" through the patient role of "eat" (other nouns could similarly be rotated through other roles for "eat," such as "fork" and "fingers," for the instrument).

In recursion, complex conceptual and linguistic structures are nested within existing linguistic and conceptual structures. When conceptualizing a face, for example, people could first conceptualize a head. Nested within the conceptualization of the head, people could then conceptualize the eyes, then the eyeballs, then the irises, and so forth. Analogously, people can describe this embedded conceptual structure linguistically, as in "the head contains the eyes, which contain eyeballs, which contain irises, and so forth." Embedding conceptual and linguistic structures within other structures allows people to construct novel conceptualizations and verbalizations not encountered previously.

In summary, using combinatoric and recursive mechanisms, people construct an unlimited number of complex representations from finite numbers of words and concepts. This ability appears to result from a productive system for language that is closely coupled to a productive system for conceptualization. It is generally assumed that these two systems have parallel structure (e.g., Langacker, 1986). As a result, constructing linguistic expressions productively produces corresponding conceptual structures. Conversely, constructing conceptualizations productively produces corresponding linguistic descriptions.

3 The conceptual system supports the spectrum of complex cognitive activities

Researchers often assume that the conceptual system resides in the province of higher cognition along with language and thought. Conversely, researchers often assume that the conceptual system is irrelevant to lower cognitive processes such as perception and attention. As we will see, however, conceptual knowledge permeates every aspect of cognition from high to low. Without knowledge, any cognitive process would stumble into ineffectiveness. There is no such thing as a knowledge-free cognitive process. To understand cognition, it is essential to understand the conceptual system and its ubiquitous presence across the spectrum of cognitive activities.

3.1 High-level perception

As people interact with the environment and attempt to achieve goals, the conceptual system supports the construction of perceptions. For example, conceptual knowledge contributes to the mechanisms that separate figure from ground (e.g., Peterson and Gibson, 1994), and also to processes that fill in missing regions of incomplete perceptual experiences (e.g., Palmer, 1999; Samuel, 1997). Conceptual knowledge produces anticipation inferences about what is likely to happen next (e.g., Reed and Vinson, 1996), and also the specific forms that these anticipations take (e.g., Shiffrar and Freyd, 1993; Stevens et al., 2000). Finally, conceptual knowledge helps to predict entities and events likely to be present in the current scene, thereby speeding their categorization (e.g., Biederman, 1981; Palmer, 1975; Yeh and Barsalou, 2006).

3.2 Selective attention

Once a concept becomes active to construe a situation, it controls the distribution of attention across it. For example, when the concept for a spatial preposition becomes active (e.g., above), it directs attention to a likely region where a focal figure will appear relative to the ground below. Specifically, the ideal position is for the figure to be aligned geometrically above the center of the ground, not too far away. On hearing "the square is above the circle," for example, people generally infer that the square is center aligned above the circle, not too far away. Much work demonstrates that spatial concepts
direct attention to prototypical locations in this manner (e.g., Carlson-Radvansky and Logan, 1997; Hayward and Tarr, 1995; Logan and Compton, 1996). After reading the word for a spatial location, the activated spatial concept directs attention to the most likely position in the display.

Additional research shows that inferences about function modify these attentional inferences (e.g., Carlson-Radvansky, Covey, and Lattanzi, 1999; Convery, 1998). Consider the statement “the toothpaste tube is above the toothbrush.” If spatial geometry were the only factor affecting attentional inferences, then a picture of a toothpaste tube centered geometrically over a toothbrush should be verified faster than when the two objects are not centered geometrically. Verification is fastest, however, when the toothpaste tube is positioned functionally (not geometrically) over the end of the toothbrush having the bristles. Thus, the concept above does not trigger a single attentional inference based on idealized geometry. Instead, the noun concepts combined with above during the construction of propositions jointly determine the inference.

3.3 Episodic memory

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 complex cognitive activities, processing a nonpresent situation is often of primary importance, with perception of the current environment being suppressed to facilitate processing the imagined situation (Glenberg, Schroeder, and Robertson, 1998). Humans are much more adept at representing nonpresent situations than other species; with the control of conceptual representations via language appearing central to this ability (e.g., Donald, 1993).

The conceptual system enters into all three classic phases of memory activity: encoding, storage, and retrieval. During encoding, the conceptual system provides diverse forms of elaboration (e.g., Carmichael, Hogan, and Walter, 1932; Craik and Lockhart, 1972; Huttlenlocher, Hedges, and Duncan, 1991). Rather than solely capturing perceptual images as does a camera or video recorder, the brain encodes images together with concepts that interpret them. As a result, the memory of a stimulus contains both perceptual and conceptual information. Once a stimulus is encoded, it becomes stored together with other memories encoded previously with similar conceptual structures. Much work shows that as the number of memories stored with a concept increases (i.e., fan), interference between the memories becomes more severe (e.g., Anderson, 1976; Postman and Underwood, 1973). Finally, concepts further become active during memory retrieval to produce classic reconstruction effects (e.g., Bartlett, 1932; Brewer and Treyens, 1981). Thus, concepts enter ubiquitously into all phases of memory processing.

3.4 Language

The semantics of natural language are closely related to the human conceptual system. Although lexical meanings are not identical to concepts, the two have much in common and influence each other extensively (e.g., Barsalou et al., 1993; Marslen-Wilson, 1992; Schwanenflugel, 1991). The access of word meaning can be viewed as an inferential process. On perceiving a word such as “bird,” retrieving semantic information constitutes inferences about the word’s meaning. American readers are more likely, for example, to infer that “bird” means something having the properties of small, flies, and sings, rather than something having the properties of large, runs, and squawks. Typically, these meanings are highly context dependent, reflecting both the surrounding text and the pragmatics of the communicative situation (e.g., Barsalou, 1999a; Yeh and Barsalou, 2006).

As the meanings of words become combined during the construction of propositions, background conceptual knowledge is used extensively. In particular, knowledge of conceptual relations is often central to
integrating word meanings (e.g., Gagné and Shoben, 1997; Wisniewski, 1997). For example, integrating the meanings of lake and trout to understand “lake trout” requires activating knowledge about the relation LOCATION \((X, Y)\), whereas integrating the meanings of swinging and vine to understand “swinging vine” requires activating knowledge about the relation MOTION \((X, Y)\).

Inference production beyond individual words is a well-established aspect of language comprehension (e.g., Bransford and Johnson, 1973; Schank and Abelson, 1977). As people comprehend a text, they infer considerable amounts of background knowledge not stated explicitly. For example, comprehenders infer a variety of thematic roles, such as hearing “Mary pounded a nail into the wall” and inferring that a hammer was used (e.g., McRae, Spivey-Knowlton, and Tanenhaus, 1998). Similarly, when people hear the sentence “The surgeon put on gloves before beginning the operation,” they are surprised when the next sentence begins “She was tired from the previous operation,” because they make default gender inferences (e.g., Carreiras et al., 1996). In general, the more deeply people comprehend a text, the richer the inferences they produce, not only about thematic roles but about explanations and a wide variety of other conceptual structures (e.g., Graesser, Singer, and Trabasso, 1994). Researchers typically assume that these rich comprehension inferences arise via the conceptual system as relevant conceptual knowledge becomes active.

### 3.5 Thought

Thought requires extensive use of conceptual representations. As people perform decision making, reasoning, and problem solving, conceptual representations become activated as the objects of thought. During decision making, the choice objects under consideration are represented conceptually (e.g., Markman and Medin, 2002). As possible choice objects are evaluated, features, relations, values, and diverse forms of background knowledge are retrieved and incorporated into the decision making process. Loken, Barsalou, and Joiner (2008) document a wide variety of roles that conceptual processes play in consumer decision making.

The conceptual system is also central to reasoning. While performing deductive reasoning, people do not simply manipulate abstract logical expressions. Instead, they appear to manipulate conceptual representations about the reasoning domain, thereby exhibiting widespread content effects (e.g., Cheng and Holyoak, 1985; Johnson-Laird, 1983). Conceptual representations are also central to inductive reasoning, especially when it concerns categories (e.g., Medin et al., 2003). Finally, conceptual representations are central to causal reasoning across a wide variety of domains, including clinical diagnosis (e.g., Kim and Ahn, 2002) and artifact function (e.g., Barsalou, Sloman, and Chaigneau, 2005).

Problem solving also relies extensively on conceptual processes. Similar to reasoning, widespread effects of domain-specific knowledge occur (e.g., Newell and Simon, 1972). The same abstract problem can be difficult to solve when grounded in one domain but easy when grounded in another, depending on the availability of relevant knowledge. Ross (1996) argues further that knowing how to use artifacts for solving problems constitutes a significant aspect of category knowledge. Rather than simply containing physical features that identify category members, a category representation contains extensive knowledge about how to use its exemplars for achieving goals (also see Barsalou, 1991).

### 3.6 Social and cultural cognition

The conceptual system plays extensive roles in social cognition (e.g., Fiske and Taylor, 1991; Kunda, 1999). During social interaction, people use social knowledge to categorize perceived individuals into social groups. Stereotypes for these groups can be viewed as conceptual representations that have been distorted by various sources of background
knowledge. Once a perceived individual has been assigned to a social category, rich inferences (attributions) result about the causes of the person's behavior, their mental state, and likely actions. Self-concepts constitute another central form of conceptual knowledge in the social domain.

Although the basis of a culture can be localized in its artifacts, activities, organizations, and institutions to a considerable extent, it can also be localized in conceptual knowledge of these external entities (e.g., Shore, 1996). Cultural transmission can be viewed, in part, as the propagation of conceptual knowledge from generation to generation, along with the transmission of other things, such as skills. Much recent work illustrates that different conceptual knowledge produces major cognitive and behavioral differences among cultures (e.g., Atran, Medin, and Ross, 2005).

4 Theories of the conceptual system

Three approaches to theorizing about the conceptual system enjoy varying degrees of acceptance in psychology, cognitive science, and cognitive neuroscience. The most traditional theories, and perhaps still the most dominant, originated in what Haugeland (1985) dubbed "GOFAI" for Good Old Fashioned Artificial Intelligence. In particular, the theory of semantic memory constitutes perhaps the best known and most widely accepted view of the conceptual system. Connectionist theories constitute a second major class of theories. This approach reflects an increasing appreciation of neural mechanisms and statistical processing, both relatively absent in GOFAI theories. Simulation, embodied, and situated theories constitute the most recent class. While incorporating neural and statistical mechanisms, they further emphasize the brain's modality-specific systems, the body, and the environment.

Each of these three approaches is described next. Within each approach, a wide variety of models exists, and an even wider variety is possible. A relatively generic description of each approach will serve to illustrate it.

4.1 GOFAI theories

GOFAI theories of the conceptual system originated in artificial intelligence during the cognitive revolution (e.g., Haugeland, 1985). To represent knowledge in computers, artificial intelligence researchers developed new representation languages based on predicate calculus (e.g., Charniak and McDermott, 1985; Newell and Simon, 1972). Typically, these representation languages included predicates to represent conceptual relations, arguments that become bound to values, and recursive nesting that embeds predicates within predicates (e.g., Barsalou, 1992). Reflecting the goals of knowledge engineering, the GOFAI representation of a concept typically contains an extensive amount of information, such that a given concept contains many propositions. If a computer is to have sufficient knowledge for understanding language, answering questions, and solving problems, its knowledge must be extensive.

In contrast, psychological versions of GOFAI theories are typically much sparser, reflecting the goal of testing psychological models in a controlled and rigorous manner. Thus, psychological versions likely considerably underestimate the complexity of naturally occurring conceptual representations (e.g., Barsalou and Hale, 1993). Two general subclasses of the GOFAI approach have dominated theories of the conceptual system and continue to do so: semantic memory and exemplar models. The semantic memory view, in particular, continues to constitute the primary way that researchers in many communities think about the conceptual system. Researchers across psychology, cognitive science, and cognitive neuroscience implicitly adopt the semantic memory framework when they must address knowledge in their respective research areas. Semantic memory and exemplar models are each addressed in turn.
4.1.1 SEMANTIC MEMORY

The construct of semantic memory arose from a proposed distinction between semantic and episodic memory (Tulving, 1972). 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 and Mervis, 1975) are roughly equivalent to their network counterparts, together forming a more general class of semantic memory models. Thus, semantic network, feature list, and prototype models will be subsumed here under the larger rubric of semantic memory. For further review of these models, see Smith (1978).

Following Tulving's classic proposal, semantic memory is widely viewed as modular, that is, as an autonomous system separate from the episodic memory system. Less explicitly, but equally true, semantic memory is also viewed widely as separate from the brain's modality-specific systems. It is generally assumed that semantic memory does not share representation and processing mechanisms with perception, action, and interoception, but is instead a relatively independent system with its own principles of representation and processing.

One of these distinguishing principles is representational format, namely, representations in semantic memory are widely viewed as amodal. Rather than being representations in modality-specific systems, semantic memory representations are typically viewed as redescriptions of modality-specific states in an amodal representation language, namely, one that lacks modality-specific qualities. For example, the conceptual representation of the visual property red is an amodal symbol that stands for perceptual states of red in the visual system and their physical counterparts in the world. In general, amodal representations in semantic memory stand for representations in the modalities and for the environmental entities they represent.

Representations in semantic memory are also generally assumed to be relatively abstract and decontextualized. In the typical theory, the representation of a category is a prototype or rule 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 decontextualized prototype that includes seat, back, and legs, with idiosyncratic properties and background situations filtered out. Although functional properties may be extracted and stored, they typically tend to be decontextualized invariants, not detailed information about specific situations. The resulting representations have the flavor of detached encyclopedia descriptions in a database of categorical knowledge about the world.

Similar to being decontextualized, semantic memory representations are typically viewed as relatively stable. For a given category, these theories assume that different people share roughly the same representation, and that the same person uses the same representation on different occasions.

Finally, semantic memory models excel in implementing the basic operations of propositions and productivity described earlier. Because the representations in these models typically include predicates whose arguments become bound to values, with the potential for predicates to embed recursively, they naturally implement propositions and productivity. Although semantic memory models can implement categorization and inference using prototypes and definitions, they have been widely criticized as being too abstract and rigid in how they perform these basic operations. Typically, semantic memory models are not sensitive to the details of exemplars and situations and do not contain adaptive mechanisms that implement learning.

4.1.2 EXEMPLAR MODELS

Since 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), Heit (1998), and Lamberts (1998). Exemplar models are included within the broader class of GOFAI models because they tend to use standard symbolic notation for expressing the properties of exemplars, unlike connectionist theories and simulation/embodied/situated theories, which use statistical and neural representation languages.

Architecturally, exemplar models tend to be modular in that exemplar knowledge is again assumed implicitly to reside in memory stores outside the brain’s modality-specific systems. Similar to semantic memory models, redescriptions in an amodal representation language typically capture the content of exemplar memories, standing in for the modality-specific states experienced originally.

Notably, however, some exemplar models view exemplar representations as implicit memories in modality-specific systems (e.g., Brooks, 1978; Jacoby and Brooks, 1984; cf. Roediger and McDermott, 1993). According to this approach, for example, an exemplar for a visual category is stored as a visual memory in the visual system, not as an amodal description outside it. Exemplar models that store exemplars in modality-specific systems can be construed as nonmodular, given that common representations underlie both conceptual and modality-specific processing.

Where exemplar models differ most from semantic memory models is on abstraction and decontextualization. Whereas semantic memory models distill properties across exemplars and store them as abstractions (e.g., prototypes and rules), exemplar models simply store exemplar memories, thereby capturing idiosyncratic information about category instances along with details about the situations in which they occur.

Perhaps counterintuitively, exemplar models tend to assume that category representations are relatively stable, much like semantic memory models. Stability exists in most exemplar models because they tend to 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, Huttenlocher, and Lamberts, 1999; Nosofsky and Palmeri, 1997).

Where exemplar models excel is in categorization. Because extensive detail about a category is stored—both in terms of idiosyncratic exemplar properties and background situations—these models are highly accurate during categorization and can adapt quickly to changing category information. Although exemplar models have not been developed to explain inference, they can in principle produce highly accurate inferences following categorization, again because of the large amounts of information stored and the context-specificity of retrieval processes that operate on it. Where exemplar models are weakest is on symbolic operations. Thus far, this approach has not attempted to implement predicates, arguments, and recursion, and therefore does not implement the basic operations of propositions and productivity.

4.2 Connectionist theories

Feedforward connectionist networks constitute a relatively recent but increasingly influential theory of the conceptual system. For general accounts of feedforward nets, see Rumelhart, Hinton, and Williams (1986) and Bechtel and Abrahamsen (2002). For specific applications of the feedforward architecture to representing conceptual knowledge, see Hinton (1989), Kruschke (1992), Rumelhart and Todd (1993), Tyler et al. (2000), and Rogers and McClelland (2004). A variety of other connectionist architectures have also been used to model the conceptual system, which are not addressed here (e.g., Cree, McRae, and McNorgan, 1999; Farah and McClelland, 1991; Humphreys and Forde, 2001; McClelland and Rumelhart, 1985; Rumelhart et al., 1986).
Perhaps surprisingly, feedforward nets, like GOFAI theories, implement a modular conceptual system. Whereas the input layer of a feedforward net is interpreted as a perceptual system, its hidden layer is viewed as implementing conceptual representations. Thus one "module" of units underlies perception, and a second module underlies conception, thereby establishing a modular distinction between them. Because complex interactions can arise between these two systems, they are not modular in the sense of being impenetrable (cf. Fodor, 1983; Pylyshyn, 1984). Nevertheless different representational systems underlie perception and cognition, such that modularity exists in a somewhat nonstandard sense. As will be seen shortly, it is possible to formulate a conceptual system in which shared neural units represent information in perception and conception. It is also worth noting that some of the alternative connectionist architectures mentioned earlier operate in this latter manner. Thus, modularity only applies to connectionist nets that have feedforward architectures, along with other architectures that use separate pools of units for perception and conception.

Because of this modular architecture, internal representations in feedforward nets are amodal. Before learning begins, connections between the input and hidden layers are set initially to small random values so that learning is possible. As a result, the particular units in the hidden layer that become positively (or negatively) associated with particular units in the input layer are determined arbitrarily. The surprising implication is that statistical patterns on the hidden units associated with particular categories function as "fuzzy" amodal symbols, standing in for their perceptual counterparts. With each new set of random starting weights, a different mapping develops. The arbitrariness that results is much in the spirit of semantic memory representations. In both approaches, modality-specific and conceptual representations reside in different modular systems, with arbitrary mappings between them. No doubt, other significant aspects of the representations differ, with connectionist representations being statistical, and semantic memory representations being discrete. Nevertheless both approaches contain amodal redescriptions of perceptual input at a general level of analysis.

Where feedforward nets depart most notably from semantic memory models is on abstraction and stability (similar to exemplar models). Rather than establishing decontextualized representations of categories, feedforward nets store situated representations in two ways. First, these nets acquire much idiosyncratic information about exemplars (as in exemplar models), rather than discarding this information during the abstraction of category invariants. Although invariants may be abstracted implicitly, much idiosyncratic information is maintained that plays central roles in processing. Second, feedforward nets store extensive information about the situations in which exemplars occur. Rather than extracting focal knowledge of a particular category instance from a background situation, much correlated information about the situation is stored as well (e.g., Rumelhart et al., 1986). As a consequence, activating an exemplar typically retrieves situational information and vice versa.

Feedforward nets are also highly dynamic. Rather than representing a category with a stable representation, as in semantic memory and exemplar models, a feedforward net uses a space of representations. Specifically, a category's representation is an attractor within the possible activation states of the hidden units, with an infinitely many states around the attractor providing possible representations. On a given occasion, the representation activated to represent the category is a function of the network's current state, input, and learning history. Thus a concept in a feedforward net is a dynamic system that produces a family of representational states, depending on current conditions.

Like exemplar models, feedforward nets excel in categorization and inference.
Because extensive detail about a category is stored—both in terms of idiosyncratic exemplar properties and background situations—feedforward nets are highly accurate during categorization, and can adapt quickly to changing category information. For the same reason, feedforward nets produce highly accurate inferences following categorization.

Where connectionist models are weakest (like exemplar models) is on symbolic operations (Fodor and Pylyshyn, 1988). Although some attempts have been made to implement predicates, arguments, and recursion (e.g., Pollack, 1990; Smolensky, 1990), these approaches have not been widely accepted as plausible psychological or neural accounts of the conceptual system. So far, connectionism has not succeeded in convincing the cognitive psychology, cognitive science, and cognitive neuroscience communities that this approach explains the basic conceptual operations of propositions and productivity.

4.3 Simulation, embodiment, and situated theories

Recent theories have focused on the roles of modality-specific simulation, embodiment, and situations in conceptual processing. Damasio (1989), Martin (2001), Barsalou (1999b; 2003a), and Simmons and Barsalou (2003) focus on modality-specific simulation. Glenberg (1997) and Barsalou et al. (2003) focus on embodiment. Barsalou (1999a; 2003b; 2005) and Barsalou, Niedenthal et al. (2003) focus on situations. Although these approaches differ somewhat in emphasis, they all assume that the conceptual system specifically and cognition in general are grounded in the brain’s modality-specific systems, in the body, and in the environment. According to these approaches, the cognitive system is not self-sufficient but depends in important ways on its groundings. Indeed, these approaches assume that grounding mechanisms are central parts of the cognitive system, not merely a peripheral interface. For a recent collection of papers on this approach, see Pecher and Zwaan (2005). Much additional work in cognitive linguistics adopts similar views (e.g., Fauconnier, 1985; Lakoff and Johnson, 1980, 1999; Langacker, 1986; Talmy, 1983), but have not yet typically drawn strong connections to cognitive and neural mechanisms (although see Gallese and Lakoff, 2005).

All of these approaches assume that the conceptual system is nonmodular. Rather than having separate systems for modality-specific and conceptual processing, a common representational system is assumed to underlie both. According to this view, conceptual processing relies heavily on modality-specific simulations to represent categories (for more detail on the simulation process, see Barsalou, 1999b; 2003a).

A consequence of this nonmodular architecture is that 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. Depending on the distribution of modalities on which people experience a category, a particular distribution of modality-specific information becomes established for it (e.g., vision and taste for fruit versus vision and action for tools; Cree and McRae, 2003).

Although perception and conception are similar in this framework, they are not identical. Whereas bottom-up mechanisms dominate the activation of modality-specific systems during perception, top-down mechanisms dominate during conception. Furthermore, the representations activated in conception are partial reenactments of modality-specific states, and may often exhibit bias and reconstructive error. Nevertheless, perception and conception are far from being modular autonomous systems.

The claim is not that modal reenactments constitute the sole form of conceptual representation. As Simmons and Barsalou (2003) suggest, representations in the brain’s association areas also play a role, perhaps somewhat analogous to the hidden unit representations in connectionist nets. This is
consistent with the widespread finding that other factors influence conceptual processing besides the modalities (e.g., statistical strength, correlation, and uniqueness; Cree and McRae, 2003; Tyler et al., 2000). Thus, the claim is simply that modal simulations are one important and widely utilized form of representation during conceptual processing.

Regarding abstraction and stability, this approach assumes that conceptual representations are dynamic and situated. Rather than being a single abstracted representation for a category, a concept is a skill for constructing idiosyncratic representations tailored to the current needs of situated action (Barsalou, 2003b). Actually, Barsalou, et al. (2003) advocate discarding the use of concept altogether and replacing it with accounts of the specific mechanisms that represent categories. In this spirit, Barsalou (1999b; 2003a) proposes the construct of a simulator as a distributed neural mechanism that constructs an infinite set of specific simulations to represent a category, property, or relation dynamically. Thus, the simulator for chair can construct many simulations of different chairs, from different perspectives, used for different purposes, reflecting the agent’s current goal and situation.

A given simulation is assumed to represent more than the focal category of interest. Additional information about background settings, goal-directed actions, and introspective states is also assumed to be included, making simulations situated (e.g., Barsalou, 1999a, 2003b, 2005; Barsalou, Niedenthal, et al., 2003). On a given occasion, a specific simulation is tailored to the computational and pragmatic demands of the current situation. Thus, the conceptual system is dynamic and situated, similar to feedforward nets, but with modal representations instead of amodal ones.

A related theme is that the conceptual system is organized around situated action (cf. Glenberg, 1997). A fundamental problem in situated action is mapping action effectively into the world, and one possibility is that the conceptual system develops to facilitate this process. According to Barsalou (1991; 2003b), ad hoc and goal-derived categories develop to bind roles in action schemata with their instantiations in the environment. As systems of these mappings develop, the conceptual system becomes organized around the action–environment interface.

4.3.1 COMMON MISCONCEPTIONS

Three common misconceptions arise frequently about simulation/embodied/situated views. One is that they are purely empiricist with no nativist contributions. Although extreme empiricist views are possible and sometimes taken, there is no a priori reason why strong genetic constraints could not underlie a system that relies heavily on simulation, embodiment, and situatedness. For example, specific simulations could in principle be determined genetically. More plausibly, however, strong genetic constraints may exist on the mechanisms that capture and implement simulations. In this spirit, Simmons and Barsalou (2003) propose that the association and feature areas underlying simulations reflect constraints on categories that developed over the course of evolution (also see Caramazza and Shelton, 1998).

A second common misconception about simulation/embodied/situated approaches is that they necessarily implement recording systems and cannot implement conceptual systems for interpreting the world. As Barsalou (1999b; 2003a) proposes, however, modality-specific systems can implement basic conceptual operations, such as categorization, inference, propositions, and productivity. The essential idea is that selective attention extracts information about the components of experience to establish simulators for these components. Once these simulators exist for object, events, mental states, relations, properties, and so forth, the argument is that they naturally implement basic conceptual operations.

A third common misconception is that abstract concepts cannot be represented in simulation/embodied/situated approaches. Various researchers, however, have argued that mechanisms within this approach are capable of representing these concepts.
For example, Lakoff and Johnson (1980; 1999) propose that abstract concepts are grounded metaphorically in concrete concepts (but see Murphy, 1996 for a critique). Alternatively, Barsalou (1999b) and Barsalou and Wiemer-Hastings (2005) propose that abstract concepts are grounded in situated simulations, just like concrete concepts, but focus on different situational content, especially on interoceptions and events.

4.3.2 COMPUTATIONAL IMPLEMENTATION

One major limitation of the simulation/embodied/situated approach to date is the relative lack of computational frameworks for implementing it. Increasingly, however, implementations are being developed. For example, Cangelosi and his colleagues have recently begun implementing the grounding mechanisms in simulation/embodied/situated theories (e.g., Cangelosi, Greco, and Harnad, 2000; Cangelosi et al., 2005; Cangelosi and Riga, 2005; Joyce et al., 2003). Also, the top-down mechanisms in O’Reilly’s neural net architectures have significant potential for implementing simulations (e.g., O’Reilly, 1998, 2006). Other recent attempts to ground computational accounts of cognition in modality-specific processing include Roy (2005) and Clark and Mendez (2005). Acceptance of the simulation/embodied/situated approach clearly depends on increasing formalization, but there appears to be no a priori reason why formalization is not possible. Given the relative recency of this approach, together with the complexity of the mechanisms that must be implemented, it is not surprising that mature formal accounts do not yet exist (for discussion of these complexities, see Barsalou, 1999b, pp. 651–2). Of interest will be whether viable computational accounts can be constructed in the coming years.

4.3.3 RELATIONS BETWEEN LANGUAGE AND SIMULATION

Finally, several lines of research propose that the linguistic system is closely coupled with the simulation system. As mentioned earlier, a central tenet of Langacker’s (1986) approach to cognitive linguistics rests on this assumption, namely, the linguistic system serves as an instrument for controlling the conceptual system.

Increasing empirical research suggests that both the linguistic and conceptual systems are active as people perform conceptual tasks (see Glaser, 1992 for a provocative review). Depending on task materials (e.g., words versus pictures) and task conditions (e.g., superficial versus deep processing), conceptual processing relies on varying mixtures of the linguistic and conceptual systems. Further evidence for this view comes from Solomon and Barsalou (2004) and Kan et al., (2003). In these experiments, subjects used different mixtures of linguistic processing and simulation while verifying the conceptual properties of objects under different task conditions. Barsalou et al. (2005) offer further behavioral and neural evidence that conceptual processing utilizes varying mixtures of linguistic processing and simulation.

5 Conclusion

As reviewed here, three basic accounts of the conceptual system exist in modern cognitive psychology, cognitive science, and cognitive neuroscience: (1) classic GOFAI approaches, such as semantic memory and exemplar models, that utilize amodal symbols in a modular conceptual system; (2) statistical approaches, such as connectionism and neural nets, that implement dynamic and situated conceptual representations; (3) simulation/embodied/situated approaches that ground conceptual knowledge in modality-specific systems, in the body, and in the environment.

Claiming that significant value exists in all three approaches might seem unduly diplomatic. To the contrary, however, each of these approaches has discovered something fundamentally important about the human conceptual system. Classic GOFAI approaches have established the importance of propositional representations and productivity in conceptual processing.
Statistical approaches have highlighted the importance of adaptation, generalization, partial matching, frequency effects, and pattern completion. Simulation/embodied/situated approaches have drawn attention to the importance of grounding knowledge in the brain’s modality-specific systems, in the body, and in the environment.

Barsalou (1999b) ends with the following conjecture: Successful theories in the future are likely to integrate all three frameworks into a single system (p. 652). It is unlikely that theories implementing only one or even two of these approaches will succeed. What each approach offers appears essential to the human conceptual system.

It is probably fair to say that GOFAI and connectionist theories have generally attempted to incorporate only one, or occasionally two, of these approaches. In contrast, simulation/embodied/situated views have typically attempted to incorporate two and sometimes three approaches, not only emphasizing grounding, but also emphasizing statistical processing and symbolic operations. Again, however, we have yet to see fully developed computational accounts that integrate all three approaches. Nevertheless, this seems like a potentially productive direction for theory development, and it will be interesting to see what form theories of the conceptual system take in coming years.

References


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