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Chapter 11

Concepts and Categories:

Memory, Meaning, and Metaphysics

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Abstract

The psychological study of concepts has two main goals: explaining how people's knowledge of categories such as tables or cats enables them to classify or recognize members of those categories, and explaining how knowledge of word meanings (e.g., the meaning of *table* and *cat*) enables people to make inferences and to compute the meanings of phrases and sentences. We review current theories and data relevant to these two functions of concepts, including recent insights from cognitive neuropsychology. Both kinds of theories have evolved in ways that suggest that people make use of mental representations at several levels of complexity, from sparse, atomic concepts to complex, knowledge-intensive ones. We examine the implications of this variety for issues including psychological essentialism and domain specificity.

Keywords: concepts, categories, semantics, prototypes, exemplars, generics, polysemy, essentialism, sortals, folk biology

Introduction

The concept of concepts is difficult to define, but no one doubts that concepts are fundamental to mental life and human communication. Cognitive scientists generally agree that a concept is a mental representation. Theories in psychology have concentrated on concepts that pick out certain sets of entities: categories. That is, concepts *refer*, and what they refer to are

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categories. It is also commonly assumed that category membership is not arbitrary but rather a principled matter. What goes into a category belongs there by virtue of some law-like regularities. But beyond these sparse facts, the concept CONCEPT is up for grabs. As an example, suppose you have the concept TRIANGLE represented as “a closed geometric form having three sides.” In this case, the concept is a definition. But it is unclear what else might be in your triangle concept. Does it include the fact that geometry books discuss them (though some don't) or that they have 180 degrees (though in hyperbolic geometry none do)? It is also unclear how many concepts have definitions or what substitutes for definitions in ones that don't.

Our goal in this chapter is to provide an overview of work on concepts and categories in the last half century. There has been such a consistent stream of research over this period that one critic of this literature, Gregory Murphy (2002), felt compelled to call his monograph, *The Big Book of Concepts*. Our task is eased by recent reviews, including Murphy's aptly named one (e.g., Medin, Lynch & Solomon, 2000; Murphy, 2002; Rips, 2001; Wisniewski, 2002). Their thoroughness gives us the luxury of doing a review focused on a single perspective—the relations among concepts, memory, and meaning.

The remainder of this chapter is organized as follows. In the rest of this section, we briefly describe some of the tasks or functions that cognitive scientists have expected concepts to perform. This will provide a roadmap to important lines of research on concepts and categories. Next, we return to developments in the late 1960s and early 1970s that raised the exciting possibility that laboratory studies could provide deep insights into both concept representations and the organization of (semantic) memory. Then we describe the sudden collapse of this optimism and the ensuing lines of research that, however intriguing and

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important, ignored questions about semantic memory. Next we trace a number of relatively recent developments under the somewhat whimsical heading “Psychometaphysics.” This is the view that concepts are embedded in (perhaps domain-specific) theories. This will set the stage for returning to the question of whether research on concepts and categories is relevant to semantics and memory organization. We will use that question to speculate about future developments in the field. In this review, we will follow the usual conventions of using words in all caps to refer to concepts and quoted words to refer to linguistic expressions.

Functions of Concepts

For purposes of this review, we will collapse the many ways people can use concepts into two broad functions: categorization and communication. The conceptual function that most research has targeted is *categorization*, the process by which mental representations (concepts) determine whether some entity is a member of a category. Categorization enables a wide variety of subordinate functions because classifying something as a category member allows people to bring their knowledge of the category to bear on the new instance. Once people categorize some novel entity, they can use relevant knowledge for *understanding* and *prediction*. Recognizing a cylindrical object as a flashlight allows you to understand its parts, trace its functions, and predict its behavior. For example, you can confidently infer that the flashlight will have one or more batteries, will have some sort of switch, and will normally produce a beam of light when the switch is pressed.

Not only do people categorize in order to understand new entities, they also use the new entities to modify and update their concepts. In other words, categorization supports *learning*. Encountering a member of a category with a novel property—for example, a flashlight that has a siren for emergencies—can result in that novel property being

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incorporated into the conceptual representation. Relations between categories may also support inference and learning. For example, finding out that flashlights can contain sirens may lead you to entertain the idea that cell phones and fire extinguishers might also contain sirens. Hierarchical conceptual relations support both inductive and deductive reasoning. If you know all trees contain xylem and hawthorns are trees, then you can deduce that hawthorns contain xylem. In addition, finding out that white oaks contain phloem provides some support for the inductive inference that other kinds of oaks contain phloem. People also use categories to instantiate goals in planning (Barsalou, 1983). For example, a person planning to do some night fishing might create an ad hoc concept, THINGS TO BRING ON A NIGHT FISHING TRIP, which would include a fishing rod, tackle box, mosquito repellent, and a flashlight.

Concepts are also centrally involved in *communication*. Many of our concepts correspond to lexical entries, such as the English word “flashlight.” In order for people to avoid misunderstandings, they must have comparable concepts in mind. If A’s concept of cell phone corresponds with B’s concept of flashlight, it won’t go well if A asks B to make a call. An important part of the function of concepts in communication is their ability to combine in order to create an unlimited number of new concepts. Nearly every sentence you encounter is new—one you’ve never heard or read before—and concepts (along with the sentence’s grammar) must support your ability to understand it. Concepts are also responsible for more creative uses of language. For example, from the base concepts of TROUT and FLASHLIGHT, you might create a new concept, TROUT FLASHLIGHT, which in the context of our current discussion would presumably be a flashlight used when trying to catch trout (and not a flashlight with a picture of a trout on it, though this may be the correct

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interpretation in some other context). A major research challenge is to understand the principles of *conceptual combination* and how they relate to communicative contexts (see Fodor, 1994, 1998; Gleitman & Papafragou, Chapter 28; Hampton, 1997; Partee, 1995; Rips, 1995; Wisniewski, 1997).

Overview

So far, we have introduced two roles for concepts: categorization (broadly construed) and communication. These functions and associated subfunctions are important to bear in mind because studying any one in isolation can lead to misleading conclusions about conceptual structure (see Solomon, Medin, & Lynch, 1999, for a review bearing on this point). At this juncture, however, we need to introduce one more plot element into the story we are telling. Presumably everything we have been talking about has implications for human memory and memory organization. After all, concepts are mental representations, and people must store these representations somewhere in memory. However, the relation between concepts and memory may be more intimate. A key part our story is what we call “the semantic memory marriage,” the idea that memory organization corresponds to meaningful relations between concepts. Mental pathways that lead from one concept to another—for example, from ELBOW to ARM—represent relations like IS A PART OF that link the same concepts. Moreover, these memory relations may supply the concepts with all or part of their meaning. By studying how people use concepts in categorizing and reasoning, researchers could simultaneously explore memory structure and the structure of the mental lexicon. In other words, the idea behind this move was to unify categorization, communication (in its semantic aspects), and memory organization. As we’ll see, this marriage was somewhat troubled, and

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there are many rumors about its breakup. But we are getting ahead of our story. The next section begins with the initial romance.

A Mini-History

Research on concepts in the middle of the last century reflected a gradual easing away from behaviorist and associative learning traditions. The focus, however, remained on learning.

Most of this research was conducted in laboratories using artificial categories (a sample category might be any geometric figure that is both red and striped) and directed at one of two questions: (a) Are concepts learned by gradual increases in associative strength, or is learning all or none (Levine, 1971 Trabasso & Bower, 1968) and (b) Which kinds of rules or concepts (e.g., disjunctive, such as RED OR STRIPED, versus conjunctive, such as RED AND STRIPED) are easiest to learn (Bruner, Goodnow, & Austin, 1956; Bourne, 1970; Restle, 1962)?

This early work tended either to ignore real-world concepts (Bruner et al., 1956, represent something of an exception here) or to assume implicitly that real-world concepts are structured according to the same kinds of rules that defined the artificial ones. According to this tradition, category learning is equivalent to identifying the definitions that determine category membership.

Early Theories of Semantic Memory

Although the work on rule learning set the stage for what was to follow, two developments associated with the emergence of cognitive psychology dramatically changed how people thought about concepts.

Turning Point 1: Models of Memory Organization

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The idea of programming computers to do intelligent things (artificial intelligence or AI) had an important influence on the development of new approaches to concepts. Quillian (1967) proposed a hierarchical model for storing semantic information in a computer that was quickly evaluated as a candidate model for the structure of human memory (Collins & Quillian, 1969). Figure 11.1 provides an illustration of part of a memory hierarchy that is similar to what the Quillian model suggests.

<Insert Figure 11.1 about here>

First, note that the network follows a principle of cognitive economy. Properties true of all animals, like eating and breathing, are stored only with the animal concept. Similarly, properties that are generally true of birds are stored at the bird node, but properties distinctive to individual kinds (e.g., being yellow) are stored with the specific concept nodes they characterize (e.g., CANARY). A property does not have to be true of all subordinate concepts to be stored with a superordinate. This is illustrated in Figure 11.1, where CAN FLY is associated with the bird node; the few exceptions (e.g., flightlessness for ostriches) are stored with particular birds that do not fly. Second, note that category membership is defined in terms of positions in the hierarchical network. For example, the node for CANARY does not directly store the information that canaries are animals; instead, membership would be “computed” by moving from the canary node up to the bird node and then from the bird node to the animal node. It is as if the network presupposes a deductive argument of the form, “All canaries are birds and all birds are animals and therefore all canaries are animals.”

Although these assumptions about cognitive economy and traversing a hierarchical structure may seem speculative, they yield a number of testable predictions. Assuming that traversal takes time, one would predict that the time needed for people to verify properties of

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concepts should increase with the network distance between the concept and the property. For example, people should be faster to verify that a canary is yellow than to verify that a canary has feathers and faster to determine that a canary can fly than that a canary has skin. Collins and Quillian found general support for these predictions.

Turning Point 2: Natural Concepts and Family Resemblance

The work on rule learning suggested that children (and adults) might learn concepts by trying out hypotheses until they hit on the correct definition. In the early 1970s, however, Eleanor Rosch and her associates (e.g., Rosch, 1973; Rosch & Mervis, 1975) argued that most everyday concepts are not organized in terms of the sorts of necessary and sufficient features that would form a (conjunctive) definition for a category. Instead, such concepts depend on properties that are generally true but need not hold for every member. Rosch's proposal was that concepts have a "family-resemblance" structure: What determines category membership is whether an example has enough characteristic properties (is enough like other members) to belong to the category.

One key idea associated with this view is that not all category members are equally "good" examples of a concept. If membership is based on characteristic properties and some members have more of these properties than others, then the ones with more characteristic properties should better exemplify the category. For example, canaries but not penguins have the characteristic bird properties of flying, singing, and building a nest; so one would predict that canaries would be more typical birds than penguins. Rosch and Mervis (1975) found that people do rate some examples of a category to be more typical than others and that these judgments are highly correlated with the number of characteristic features an example

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possesses. They also created artificial categories conforming to family-resemblance structures and produced typicality effects on learning and on goodness-of-example judgments.

Rosch and her associates (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) also argued that the family-resemblance view had important implications for understanding concept hierarchies. Specifically, they suggested that the correlational structure of features (instances that share some features tend to share others) created natural “chunks” or clusters of instances that correspond to what they referred to as *basic-level categories*. For example, having feathers tends to correlate with nesting in trees (among other features) in the animal kingdom, and having gills with living in water. The first cluster tends to isolate birds, while the second picks out fish. The general idea is that these basic-level categories provide the best compromise between maximizing within-category similarity (birds tend to be quite similar to each other) and minimizing between-category similarity (birds tend to be dissimilar to fish). Rosch et al. showed that basic-level categories are preferred by adults in naming objects, are learned first by children, are associated with the fastest categorization reaction times, and have a number of other properties that indicate their special conceptual status.

Turning Points 1 and 2 are not unrelated. To be sure, the Collins and Quillian model, as initially presented, would not predict typicality effects (but see Collins & Loftus, 1975), and it wasn't obvious that it contained anything that would predict the importance of basic-level categories. Nonetheless, these conceptual breakthroughs led to an enormous amount of research premised on the notion that concepts are linked in memory by meaningful pathways, so that memory in effect groups concepts according to their similarity in meaning (see Anderson & Bower, 1973; and Norman & Rumelhart, 1975, for theories and research in this tradition, and Goldstone & Son, Chapter 10, for current theories of similarity).

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Fragmentation of Semantics and Memory

Prior to about 1980, most researchers in this field saw themselves as investigating “semantic memory”—the way that long-term memory organizes meaningful information. Around 1980, the term itself became passé, at least for this same group of researchers, and the field regrouped under the banner of “Categories and Concepts” (the title of Smith & Medin’s 1981 synthesis of research in this area). At the time, these researchers may well have seen this change as a purely nominal one, but we suspect it reflected a retreat from the claim that semantic-memory research had much to say about either semantics or memory. How did this change come about?

Memory Organization

Initial support for a Quillian-type memory organization came from Quillian’s own collaboration with Allan Collins (Collins & Quillian, 1969), which we mentioned earlier. Related evidence also came from experiments on lexical priming: Retrieving the meaning of a word made it easier to retrieve the meaning of semantically related words (e.g., Meyer & Schvaneveldt, 1971). In these lexical decision tasks, participants viewed a single string of letters on each trial and decided, under reaction time instructions, whether the string was a word (e.g., “daisy”) or a nonword (“rais”). The key result was that participants were faster to identify a string as a word if it followed a semantically related item than an unrelated one. For example, reaction time for “daisy” was faster if on the preceding trial the participant had seen “tulip” than if he or she had seen “steel.” This priming effect is consistent with the hypothesis that activation from one concept spreads through memory to semantically related ones.

Later findings suggested, however, that the relation between word meaning and memory organization was less straightforward. For example, the typicality findings (see

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Turning Point 2) suggested that time to verify sentences of the form *An X is a Y* (e.g., “A finch is a bird”) might be a function of the overlap in the information that participants knew about the meaning of *X* and *Y*, rather than the length of the pathway between these concepts. The greater the information overlap—for example, the greater the number of properties that the referents of *X* and *Y* shared—the faster the time to confirm a true sentence and the slower the time to disconfirm a false one. For example, if you know a lot of common information about finches and birds but only a little common information about ostriches and birds, you should be faster to confirm the sentence “A finch is a bird” than “An ostrich is a bird.” Investigators proposed several theories along these lines that made minimal commitments to the way memory organized its mental concepts (McCloskey & Glucksberg, 1979; Smith, Shoben, & Rips, 1974; Tversky, 1977). Rosch’s (1978) theory likewise studiously avoided a stand on memory structure.

Evidence from priming in lexical decision tasks also appeared ambiguous. Although priming occurs between associatively related words (e.g., “bread” and “butter”), it is not so clear that there is priming between semantically linked words in the absence of such associations. It is controversial whether, for example, there is any automatic activation between “glove” and “hat,” despite their joint membership in the clothing category (see Balota, 1994, for a discussion). If memory is organized on a specifically semantic basis—on the basis of word meanings—then there should be activation between semantically related words even in the absence of other sorts of associations. A meta-analysis by Lucas (2000) turned up a small effect of this type, but as Lucas notes, it is difficult to tell whether the semantically related pairs in these experiments are truly free of associations.

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The idea that memory organization mimics semantic organization is an attractive one, and memory researchers attempted to modify the original Quillian approach to bring it into line with the results we have just reviewed (e.g., Collins & Loftus, 1975). The data from the sentence verification and lexical decision experiments, however, raised doubts about these theories. Later in this chapter we will consider whether newer techniques can give us a better handle on the structure of memory, but for now let us turn to the other half of the memory = meaning equation.

Semantics

Specifying the meaning of individual words is one of the goals of semantics, but only one. Semantics must also account for the meaning of phrases, sentences, and longer units of language. One problem in using a theory like Quillian's as a semantic theory is how to extend its core idea—that the meaning of a word is the coordinates of a node in memory structure—to explain how people understand meaningful phrases and sentences. Of course, Quillian's theory and its successors can tell us how we understand sentences that correspond to preexisting memory pathways. We have already seen how the model can explain our ability to confirm sentences like "A daisy is a flower." But what about sentences that do not correspond to preexisting connections, sentences like "Fred placed a daisy in a lunchbox"?

The standard approach to sentence meaning in linguistics is to think of the meaning of sentences as built from the meaning of the words that compose them, guided by the sentence's grammar (e.g., Chierchia & McConnell-Ginet, 1990). We can understand sentences that we have never heard or read before, and since there are an enormous number of such novel sentences, we cannot learn their meaning as single chunks. It therefore seems quite likely that we compute the meaning of these new sentences. But if word meaning is the position of a

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node in a network, it is hard to see how this position could combine with other positions to produce sentence meanings. What is the process that could take the relative network positions for FRED, PLACE, DAISY, IN, and LUNCHBOX and turn them into a meaning for “Fred placed a daisy in a lunchbox”?

If you like the notion of word meaning as relative position, then one possible solution to the problem of sentence meaning is to connect these positions with further pathways. Since we already have an array of memory nodes and pathways at our disposal, why not add a few more in order to encode the meaning of a new sentence? Perhaps the meaning of “Fred placed a daisy in the lunchbox” is given by a new set of pathways that interconnect the nodes for FRED, PLACE, DAISY, and so on, in a configuration corresponding to the sentence’s structure. This is the route that Quillian and his successors took (e.g., Anderson & Bower, 1973; Norman & Rumelhart, 1975; Quillian, 1969), but it comes at a high price. Adding new connections changes the overall network configuration and thereby alters the meaning of the constituent terms. (Remember: meaning is supposed to be *relative* position.) But it is far from obvious that encoding incidental facts alters word meaning. It seems unlikely, for example, that learning the sentence about Fred changes the meaning of “daisy.” Moreover, because meaning is a function of the entire network, the same incidental sentences change the meaning of all words. Learning about Fred’s daisy-placing shifts the meaning of seemingly unrelated words like “hippopotamus” if only a bit.

Related questions apply to other psychological theories of meaning in the semantic-memory tradition. To handle the typicality results mentioned earlier, some investigators proposed that the mental representation of a category like daisies consists of a prototype for that category—for example, a description of a good example of a daisy (e.g., Hampton, 1979;

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McCloskey & Glucksberg, 1979). The meaning of “daisy” in these prototype theories would thus include default characteristics, such as growing in gardens, that apply to most, but not all, daisies. We will discuss prototype theories in more detail soon, but the point for now is that prototype representations for individual words are difficult to combine to obtain a meaning for phrases that contain them. One potential way to combine prototypes—fuzzy set theory (Zadeh, 1965)—proved vulnerable to a range of counterexamples (Osherson & Smith, 1981, 1982). In general, the prototypes of constituent concepts can differ from the prototypes of their combinations in unpredictable ways (Fodor, 1994). The prototype of BIRDS THAT ARE PETS (perhaps a parakeet-like bird) may differ from the prototypes of both BIRDS and PETS (see Storms, de Boeck, van Mechelen, & Ruts, 1998, for related evidence). So if word meanings are prototypes, it is hard to see how the meaning of phrases could be a compositional function of the meaning of their parts.

Other early theories proposed that category representations consist of descriptions of exemplars of the category in question. For example, the mental representation of DAISY would include descriptions of specific daisies that an individual had encoded (e.g., Hintzman, 1986; Medin & Schaffer, 1978; Nosofsky, 1986). However, these theories have semantic difficulties of their own (see Rips, 1995). For example, if, by chance, the only Nebraskans you have met are chiropractors and the only chiropractors you have met are Nebraskans, then exemplar models appear to mispredict that “Nebraskan” and “chiropractor” will be synonyms for you.

To recap briefly, we have found that experimental research on concepts and categories was largely unable to confirm that global memory organization (as in Quillian’s semantic memory) conferred word meaning. In addition, neither the global theories that initiated this

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

research nor the local prototype or exemplar theories that this research produced were able to provide insight into the basic semantic problem of how we understand the meaning of novel sentences. This left semantic-memory theory in the unenviable position of being unable to explain either semantics or memory.

Functions and Findings

Current research in this field still focuses on categorization and communication, but without the benefit of a framework that gives a unified explanation for the functions that concepts play in categorizing, reasoning, learning, language understanding, and memory organization. In this section, we survey the state of the art, and in the following one, we consider the possibility of reuniting some of these roles.

Category Learning and Inference

One nice aspect of Rosch and Mervis's (1975) studies of typicality effects is that they used both natural language categories and artificially created categories. Finding typicality effects with natural (real-world) categories shows that the phenomenon is of broad interest; finding these same effects with artificial categories provides systematic control for potentially confounding variables (e.g., exemplar frequency) in a way that cannot be done for lexical concepts. This general strategy linking the natural to the artificial has often been followed over the past few decades. Although researchers using artificial categories have sometimes been guilty of treating these categories as ends in themselves, there are enough parallels between results with artificial and natural categories that each area of research informs the other (see Medin & Coley, 1998, for a review).

Prototype Versus Exemplar Models

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

One idea compatible with Rosch's family-resemblance hypothesis is the *prototype view*. It proposes that people learn the characteristic features (or central tendency) of categories and use them to represent the category (e.g., Reed, 1972). This abstract prototype need not correspond to any experienced example. According to this theory, categorization depends on similarity to the prototypes. For example, to decide whether some animal is a bird or a mammal, a person would compare the (representation of) that animal to both the bird and the mammal prototypes and assign it to the category whose prototype it most resembled. The prototype view accounts for typicality effects in a straightforward manner. Good examples have many characteristic properties of their category and have few characteristics in common with the prototypes of contrasting categories.

Early research appeared to provide striking confirmation of the idea of prototype abstraction. Using random dot patterns as the prototypes, Posner and Keele (1968, 1970) produced a category from each prototype. The instances in a category were "distortions" of the prototype, generated by moving constituent dots varying distances from their original positions. Posner and Keele first trained participants to classify examples that they created by distorting the prototypes. Then they gave a transfer test in which they presented both the old patterns and new low or high distortions that had not appeared during training. In addition, the prototypes, which the participants had never seen, were presented during transfer. Participants had to categorize these transfer patterns; but unlike the training procedure, the transfer test gave participants no feedback about the correctness of their responses. The tests either immediately followed training or appeared after a 1-week delay.

Posner and Keele (1970) found that correct classification of the new patterns decreased as distortion (distance from a category prototype) increased. This is the standard

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typicality effect. The most striking result was that a delay differentially affected categorization of prototypic versus old training patterns. Specifically, correct categorization of old patterns decreased over time to a reliably greater extent than performance on prototypes. In the immediate test, participants classified old patterns more accurately than prototypes; but in the delayed test, accuracy on old patterns and prototypes was about the same. This differential forgetting is compatible with the idea that training leaves participants with representations of both training examples and abstracted prototypes, but that memory for examples fades more rapidly than memory for prototypes. The Posner and Keele results were quickly replicated by others and constituted fairly compelling evidence for the prototype view.

But this proved to be the beginning of the story rather than the end. Other researchers (e.g., Brooks, 1978; Medin & Schaeffer, 1978) put forth an *exemplar view* of categorization. Their idea was that memory for old exemplars by itself could account for transfer patterns without the need for positing memory for prototypes. On this view, new examples are classified by assessing their similarity to stored examples and assigning the new example to the category that has the most similar examples. For instance, some unfamiliar bird (e.g., a heron) might be correctly categorized as a bird not because it is similar to a bird prototype, but rather because it is similar to flamingos, storks, and other shore birds.

In general, similarity to prototypes and similarity to stored examples will tend to be highly correlated (Estes, 1986). Nonetheless, for some category structures and for some specific exemplar and prototype models, it is possible to develop differential predictions. Medin and Schaffer (1978), for example, pitted number of typical features against high similarity to particular training examples and found that categorization was more strongly influenced by the latter. A prototype model would make the opposite prediction.

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Another contrast between exemplar and prototype models revolves around sensitivity to within-category correlations (Medin, Altom, Edelson, & Freko, 1982). A prototype representation captures what is on average true of a category but is insensitive to within-category feature distributions. For example, a bird prototype could not represent the impression that small birds are more likely to sing than large birds (unless one had separate prototypes for large and small birds). Medin et al. (1982) found that people are sensitive to within-category correlations (see also Malt & Smith, 1984, for corresponding results with natural object categories). Exemplar theorists were also able to show that exemplar models could readily predict other effects that originally appeared to support prototype theories—differential forgetting of prototypes versus training examples, and prototypes being categorized as accurately or more accurately than training examples. In short, early skirmishes strongly favored exemplar models over prototype models. Parsimony suggested no need to posit prototypes if stored instances could do the job. Since the early 1980s, there have been a number of trends and developments in research and theory with artificially constructed categories, and we will be able to give only the briefest of summaries here.

New Models

There are now more contending models for categorizing artificial stimuli, and the early models have been extensively elaborated. For example, researchers have generalized the original Medin and Schaffer (1978) exemplar model to handle continuous dimensions (Nosofsky, 1986), to address the time course of categorization (Lamberts, 1995; Nosofsky & Palmeri, 1997a; Palmeri, 1997), to generate probability estimates in inference tasks (Juslin & Persson, 2002), and to embed it in a neural network (Kruschke, 1992).

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Three new kinds of classification theories have been added to the discussion: rational approaches, decision-bound models, and neural network models. Anderson (1990, 1991) proposed that an effective approach to modeling cognition in general and categorization in particular is to analyze the information available to a person in the situation of interest and then to determine abstractly what an effective, if not optimal, strategy might be (see Chater & Oaksford, Chapter 2; Griffiths et al., Chapter 3). This approach has led to some new sorts of experimental evidence (e.g., Anderson & Fincham, 1996; Clapper & Bower, 2002) and pointed researchers more in the direction of the inference function of categories. Interestingly, the Medin and Schaffer exemplar model corresponds to a special case of the rational model, and Nosofsky (1991) has discussed the issue of whether the rational model adds significant explanatory power. However, there is also some evidence undermining the rational model's predictions concerning inference (e.g., Malt, Ross, & Murphy, 1995; Murphy & Ross, 1994; Palmeri, 1999; Ross & Murphy, 1996).

Decision-bound models (e.g. Ashby & Maddox, 1993; Maddox & Ashby, 1993) draw their inspiration from psychophysics and signal detection theory. Their primary claim is that category learning consists of developing decision bounds around the category that will allow people to categorize examples successfully. The closer an item is to the decision bound, the harder it should be to categorize. This framework offers a new perspective on categorization in that it may lead investigators to ask questions such as: How do the decision bounds that humans adopt compare with what is optimal? What kinds of decision functions are easy or hard to acquire? Researchers have also directed efforts to distinguish decision-bound and exemplar models (e.g., Maddox & Ashby, 1998; Maddox, 1999; McKinley & Nosofsky, 1995; Nosofsky & Palmeri, 1997b; Nosofsky, 1998). One possible difficulty with decision-

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

bound models is that they contain no obvious mechanism by which stimulus familiarity can affect performance, contrary to empirical evidence that it does (Verguts, Storms, & Tuerlinckx, 2003).

Neural network or connectionist models are the third type of new model on the scene (see Knapp & Anderson, 1984, and Kruschke, 1992, for examples; and Doumas & Hummel, Chapter 5, for further discussion of connectionism). It may be a mistake to think of connectionist models as comprising a single category, as they take many forms depending on assumptions about hidden units, attentional processes, recurrence, and the like. There is one sense in which neural network models with hidden units may represent a clear advance on prototype models: They can form prototypes in a bottom-up manner that reflects within-category structure (e.g., Love, Medin, & Gureckis, 2004). That is, if a category comprises two distinct clusters of examples, network models can create a separate hidden unit for each chunk (e.g., large birds versus small birds) and thereby show sensitivity to within-category correlations.

Mixed Models and Multiple Categorization Systems

A common response to hearing about various models of categorization is to suggest that all the models may be capturing important aspects of categorization and that research should determine in which contexts one strategy versus another is likely to dominate. One challenge to this divide-and-conquer program is that the predictions of alternative models tend to be highly correlated and separating them is far from trivial. Nonetheless, there is both empirical research (e.g., Johansen & Palmeri, 2002; Nosofsky, Clark, & Shin, 1989; Reagher & Brooks, 1993) and theoretical modeling that support the idea that mixed models of categorization are useful and perhaps necessary. Current efforts combine rules and examples (e.g., Erickson &

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Kruschke, 1998; Nosofsky, Palmeri, & McKinley, 1994), as well as rules and decision bounds (Ashby, Alfonso-Reese, Turken, & Waldron, 1998). Some models also combine exemplars and prototypes (e.g., Homa, Sterling, & Trepel, 1981; Minda & Smith, 2001; Smith, Murray, & Minda, 1997; Smith & Minda, 1998, 2000), but it remains controversial whether the addition of prototypes is needed (e.g., Busemeyer, Dewey, & Medin, 1984; Nosofsky & Johansen, 2000; Nosofsky & Zaki, 2002; Stanton, Nosofsky, & Zaki, 2002).

The upsurge of cognitive neuroscience (see Morrison & Knowlton, Chapter 6) has reinforced the interest in multiple memory systems. One intriguing line of research by Knowlton, Squire, and associates (Knowlton, Mangels & Squire, 1996; Knowlton & Squire, 1993; Squire & Knowlton, 1995), favoring multiple categorization systems, involves a dissociation between categorization and recognition. Knowlton and Squire (1993) used the Posner and Keele dot pattern stimuli to test amnesic and matched control patients on either categorization learning and transfer or on a new-old recognition task (involving five previously studied patterns versus five new patterns). The amnesiacs performed very poorly on the recognition task but were not reliably different from control participants on the categorization task. Knowlton and Squire took this as evidence for a two-system model, one based on explicit memory for examples and one based on an implicit system (possibly prototype abstraction). Reed, Squire, Patalano, Smith, and Jonides (1999) used the same “prototype extraction” task to compare amnesic patients and controls, but instead of dot patterns Reed et al. employed a set of artificial animals that varied on 10 salient features. Unlike the dot patterns, which are quite abstract and difficult to describe, the features of the artificial animals were easy to verbalize. The results, however, were the same: The amnesiacs performed worse than controls on an explicit-memory test, but they were not reliably different

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

from controls on the categorization task. So implicit category learning is not reserved for what cannot be articulated. On this view, amnesiacs have lost access to the explicit system but can perform the classification task using their intact implicit memory.

These results have provoked a number of counterarguments to the hypothesis that categorization and recognition involve two different memory systems. First, investigators have raised questions about the details of the procedures in the prototype-extraction studies. Specifically, Palmeri and Flanery (1999) suggested that some learning may have occurred during the transfer tests (not during training), and this learning did not depend on the storage of exemplars. In support of the claim that learning during transfer occurs in the prototype extraction, Palmeri and Flanery showed that undergraduates who had never been exposed to training exemplars (the students thought that they were being shown patterns subliminally) performed above chance on transfer tests. Bozoki, Grossman, and Smith (2006) did a similar study, but their subjects included amnesiacs in addition to normals, and they used artificial animals rather than dot patterns. Bozoki et al. again found that learning occurred even when no training exemplars occurred—for amnesiacs as well as controls!—but even more learning occurred when exemplars were presented. These results suggest that something is indeed being learned implicitly—namely, whatever it is that both amnesiacs and controls get from training exemplars. But the two studies under scrutiny differ in too many ways—kinds of materials and subjects—to draw firm conclusions.

Perhaps the most important argument against the Knowlton and Squire evidence for implicit category learning came from Nosofsky and Zaki (1998). They showed that a single-system (exemplar) model could account for both the categorization and recognition data from both the amnesiacs and controls, by assuming that: (1) the exemplar-based memory of

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

amnesiacs was impaired but not absent; and (2) the categorization task was less cognitively demanding than the recognition task. A recent review of this literature (Smith, 2008) notes that the Nosofsky-Zaki analysis has never been refuted by patient data (and not for lack of trying).

But there is another kind of data that is relevant here, which turns out to have more diagnostic power—neuroimaging evidence from experiments in which normal subjects perform both prototype-extraction and recognition tasks. Reber, Stark, and Squire (1998a, b) had subjects perform these tasks while having their brains scanned by functional magnetic resonance imaging (fMRI). The recognition task resulted in increased activations in numerous brain areas, including the hippocampus, the very area that is damaged in the amnesiac patients that we have been discussing and that is routinely activated in neuroimaging studies of explicit memory (e.g., Wagner, Bunde, & Bader, 2004). However, none of these areas were activated in the categorization task. Even more striking, an area in visual cortex known to be involved in early visual processing was *activated* in recognition but *deactivated* in categorization. Reber, Gitelman, Parrish, and Mesulam (2003) have observed the same kind of dissociation in another neuroimaging experiment. These results argue quite strongly for a distinction between explicit and implicit category learning.

But what is the nature of the “category” acquired when learning is implicit? The neuroimaging findings suggest an answer. The deactivations observed in occipital cortex are similar to those reported in studies of visual priming (e.g., Buckner, 2000). The latter deactivations are attributed to increased efficiency in processing the perceptual features of the items. This same process could play a role in prototype extraction. The training items are highly similar to one another (else they would not form a category) and thus have numerous

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

features in common. These common features occur frequently during the training phase—else the features would not be “common”—and consequently subjects become increasingly proficient in processing them. If we assume subjects experience a feeling of greater perceptual fluency with items that are processed efficiently, then subjects could use this feeling as a guide to categorization during the transfer phase—the greater the fluency, the more likely the item is a member of the category (Smith, 2008).

So fluency alone can support categorization, but are we really talking about “concepts” here? At the outset, we noted that one of the only things that cognitive scientists agree on concerning concepts is that they are mental representations. Feelings of fluency are not representations of categories (they are more like sensations), so what we have here is categorization without concepts. And perceptual fluency alone may not be able to support the functions that we attributed to concepts early on. Can perceptual fluency support inductive inferences? For example, if one learns a category of artificial animals via perceptual fluency and then learns that some of the instances have an additional feature, will one generalize this feature to other instances? And it seems clear that categories acquired by perceptual fluency will not be available for communication, as it is a hallmark of material learned implicitly that it cannot be verbalized.

The debate is far from resolved, and there are strong advocates both for and against the multiple systems view (e.g., Filoteo, Maddox, & Davis, 2001; Maddox, 2002; Nosofsky & Johansen, 2000; Palmeri & Flanery, 2002; Reber et al., 1998a, b). It is safe to predict that this issue will receive continuing attention.

Inference Learning

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Recently investigators have begun to worry about extending the scope of category learning studies by looking at inference. Often we categorize some entity in order to help us accomplish some function or goal. Ross (1997, 1999, 2000) has shown that the category representations people develop in laboratory studies depend on use and that use affects later categorization. In other words, models of categorization ignore inference and use at their peril. Other work suggests that having a cohesive category structure is more important for inference learning than it is for classification (Yamauchi & Markman, 1998, 2000a, 2000b; Yamauchi, Love, & Markman, 2002; for modeling implications see Love, Markman, & Yamauchi, 2000; Love et al., 2004). More generally, this work raises the possibility that diagnostic rules based on superficial features, which appear so prominently in pure categorization tasks, may not be especially relevant for contexts involving multiple functions or more meaningful stimuli (e.g., Markman & Makin, 1998; Wisniewski & Medin, 1994).

Feature Learning

The final topic on our “must mention” list for work with artificial categories is feature learning. It is a common assumption in both models of object recognition and category learning that the basic units of analysis or features remain unchanged during learning. There is increasing evidence and supporting computational modeling indicating that this assumption is incorrect. Learning may increase or decrease the distinctiveness of features and may even create new features (see Goldstone, 1998, 2003; Goldstone & Stevyers, 2001; Goldstone, Lippa, & Shrifin, 2001; Schyns & Rodet, 1997; Schyns, Goldstone, & Thibaut, 1998).

Feature learning has important implications for our understanding of the role of similarity in categorization. It is intuitively compelling to think of similarity as a causal factor supporting categorization—things belong to the same category because they are similar. But

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

this may have things backward. Even standard models of categorization assume that learners selectively attend to features that are diagnostic, and the work on feature learning suggests that learners may create new features that help partition examples into categories. In that sense, similarity (in the sense of overlap in features) is the byproduct, not the cause, of category learning. We will take up this point again in discussing the theory of categorization later in this review.

Features of Natural Categories and Cognitive Neuroscience

In the research reviewed thus far, the features (1) have not been subdivided into types and (2) have been assumed to be abstract symbols. Both of these assumptions have been challenged by the foray of cognitive neuroscience into the study of natural concepts, a movement that began in the mid-1980s but still remains somewhat separate from the mainstream of behavioral studies on categories and concepts. In what follows, we try to convey the gist of this research by focusing on studies dealing with Points (1) and (2) mentioned earlier. This work includes both neuropsychological studies of neurological patients with categorization deficits and neuroimaging studies of normals (typically college students) who answer questions about categories and their properties while having their brains scanned.

Neuropsychological Studies of Categorization

The seminal article in this line of research was a 1984 paper by Warrington and Shallice that analyzed the categorization abilities of patients with “visual agnosia,” an inability to categorize visual objects even though perceptual abilities remain intact. Such patients often have lesions in the bottom or ventral portion of temporal cortex. It had been known for some time that such patients may show greater deficits with some categories than others.

Warrington and Shallice (1984) thoroughly documented such “category-specific” deficits in

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

four patients, showing that patients could have normal levels of categorization accuracy on some categories while being drastically impaired on others. For example in a task in which subjects simply had to match pictures to category-names, Patient JBR achieved 98% accuracy on categories of nonliving things (obviously normal), but only 67% on categories of animals (obviously impaired). Other patients showed a similar pattern. However, in some tasks there were exceptions to the living versus nonliving distinction, such as musical instruments, which clustered with living things, whereas body parts clustered with the nonliving categories.

To handle these exceptions, Warrington and Shallice (1984) shifted their analysis from the level of categories to that of features. They noted that the impaired categories tended to be those characterized by perceptual features, while the less impaired, or intact, categories tended to be characterized by functional features (where “functional” is used very broadly). This led to the “perceptual-functional” hypothesis of category deficits: Brain damage can selectively affect sensory/perceptual regions or regions more involved in the use of artifacts (e.g., motor areas), and the first type of damage will hurt the categorization of living things while the second will mainly affect categories of nonliving things like tools. The hypothesis is extremely influential in neurological and neuroimaging studies, and it makes clear the importance of distinguishing features with regard to what they refer to—perceptual versus functional properties of objects.

If problems with perceptual features are what underlie patients’ problems in dealing with animal categories, one would expect that, when asked about the features of a category (e.g., “Does a canary have a beak?”) these patients should have more problems with questions about perceptual than nonperceptual features of the same category. This prediction has been confirmed numerous times (e.g., Thompson-Schill, D’Esposito, Aguirre, & Farah, 1997). The

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

difference between perceptual and functional features seems to be a key distinction about the nature of concepts that has been relatively ignored in the mainstream literature on normal categorization.

This perceptual-functional distinction lies at the heart of a number of computational models of categorization that have been applied to the results of the neuropsychological studies. Farah and McClelland (1991) developed a model in which conceptual knowledge about objects is divided into perceptual and functional components, and the ratio of perceptual-to-functional features for living things is much greater than that for nonliving things. They then selectively degraded either perceptual or functional features and showed that this “lesioned” model provided a good account of patients’ performance on simple categorization tasks. Subsequent models have become increasingly more sophisticated. Thus, in Rogers and McClelland’s (2004) model, the features are not built into the model by the modeler, but rather are based on normal subjects’ verbal descriptions and drawings of these objects. These empirically obtained features reveal not only the perceptual-functional distinction but also a further distinction based on whether color is a feature, which is critical in distinguishing animals from plants (fruits/vegetables), both of which are living things. When the different kinds of features are “lesioned,” the model’s performance on a variety of simple categorization tasks matches that of various patients to a striking degree.

Neuroimaging Studies

The first neuroimaging studies of natural concepts appeared in the mid-1990s. Martin, Haxby, Lalonde, Wiggs, and Ungerleider (1995) imaged peoples’ brains while they performed a simple property-verification task (e.g., “Is a banana yellow?”). Unsurprisingly they found increased activation in left-hemisphere language areas (located in the ventral part of the

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

frontal cortex and the medial part of the temporal cortex). In addition, though, there was a notable increase in activation in the ventral region of temporal cortex, which is the region responsible for object recognition. Even though only semantic processing was called for, object-processing seemed to be involved as well. Even more striking, the activation at issue was close to the subregion that underlies the perception of the property. For example, when answering verbal questions about the color of an object, there was an activation in the general area concerned with perceiving the color of objects.

Subsequent studies replicated the critical finding that perceptual questions activate perceptual areas—what has come to be called “modality specificity” (e.g., Chao & Martin, 1999; Kellenbach, Brett, & Patterson, 2001). Indeed, some studies showed activation in perceptual areas even when language areas were not activated (Kan, Barasalou, Solomon, Minor, & Thompson-Schill, 2003). The neuroimaging evidence for modality specificity gets even more detailed, as some property-verifications studies have varied the kind of perceptual property queried—color versus size, for example—and shown that color questions activate color areas, whereas size questions activate areas in parietal cortex known to be involved in the perception of space. Interestingly, though the brain areas being activated are clearly perceptual ones, subjects in these experiments rarely if ever report experiencing visual imagery. The conclusion that has repeatedly been drawn from these studies is that knowledge about perceptual properties, which had been thought to be represented in a completely amodal fashion, is in fact partially represented in a modality-specific way (Thompson-Schill, 2001). Object concepts are claimed to be “perceptually embodied.” Furthermore, since the different perceptual modalities are processed in differed brain regions, “perceptual-conceptual

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

knowledge” must be represented by a distributed network of brain regions. There is no Bird area in the brain.

Modality specificity cannot be the whole story, however. There are longstanding arguments against the idea that object concepts are purely perceptual (summarized in Miller & Johnson-Laird, 1976). For example, why do people who are congenitally blind seem to share the same concepts as the sighted? It is even possible to question whether the modality-specific activations found in the aforementioned studies actually play an important role in categorization and property verification (e.g., Mahon & Caramazza, 2008). Specifically, the knowledge that is used to answer simple questions about object categories may be represented amodally (symbolically), as has routinely been assumed in the semantic-memory literature, but these representations may be closely linked to modality-specific ones, which may be used for purposes of recognizing objects and generating visual images. If so, activation of the relevant amodal representation may lead to the concurrent activation of the associated modality-specific representation. The apparent evidence for modality specificity is essentially a spread of activation from the amodal areas that do the real neural work. At this point, however, there is little independent evidence in favor of the spreading activation account, so modality specificity cannot be dismissed.

Reasoning

As we noted earlier, one of the central functions of categorization is to support reasoning. Having categorized some entity as a bird, one may predict with reasonable confidence that it builds a nest, sings, and can fly, though none of these inferences is certain. In addition, between-category relations may guide reasoning. For example, from the knowledge that robins have some enzyme in their blood one is likely to be more confident that the enzyme is

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

in sparrows than in raccoons. The basis for this confidence may be that robins are more similar to sparrows than to raccoons, or that robins and sparrows are more likely to share relevant biological mechanisms than robins and raccoons. We will not review this literature here, but see Heit (2000), Kemp and Tenenbaum (2009), and Rips (2001, 2011) for detailed treatments.

Summary

Due to space limitations, we have glossed a lot of research and skipped numerous other relevant studies. The distinction between artificially created and natural categories is itself artificial, at least in the sense that it has no clear definition or marker. When we take up the idea that concepts may be organized in terms of theories, we will return to some laboratory studies that illustrate this fuzzy boundary. For the moment, however, we shift attention to the more language-like functions of concepts.

Language Functions

Most investigators in the concepts-and-categories area continue to assume that, in addition to their role in recognition and category learning, concepts also play a role in understanding language and in thinking discursively about things. In addition to determining, for example, which perceptual patterns signal the appearance of a daisy, the DAISY concept also contributes to the meaning of sentences like our earlier example, “Fred placed a daisy in a lunchbox.” We noted that early psychological research on concepts ran into problems in explaining the meaning of linguistic units larger than single words. Most early theories posited representations, such as networks, exemplars, or prototypes, that did not combine easily and thus complicated the problem of sentence meaning. Even if we reject the idea that sentence meanings are compositional functions of word meaning, we still need a theory of

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

sentence meanings, and no obvious contenders are in sight. In this section, we return to the role that concepts play in language to see whether new experiments and theories have clarified this relationship.

Concepts as Positions in Memory Structures

One difficulty with the older semantic-memory view of word meaning is that memory seems to change with experience from one person to another, while meaning must be more or less constant. The sentences that you have encoded about daisies may differ drastically from those that we have encoded, because your conversation, reading habits, and other verbal give-and-take can diverge in important ways from ours. If meaning depends on memory for these sentences, then your meaning for “daisy” should likewise differ from ours. This observation raises the question of how you could possibly understand the sentences in this chapter in the way we intend or how you could meaningfully disagree with us about some common topic (see Fodor, 1994).

Two people—say, Calvin and Martha—might be able to maintain mutual intelligibility as long as their conceptual networks are not too different. It is partly an empirical question how much their networks can vary while still allowing Calvin’s concepts to map correctly into Martha’s. To investigate this issue, Goldstone and Rogosky (2002) carried out some simulations that try to recover such a mapping. The simulations modeled Calvin’s conceptual system as the distance between each pair of his concepts (e.g., the distance between DOG and CAT in Calvin’s system might be one unit, while the distance between DOG and DAISY might be six units). Martha’s conceptual system was represented in the same way (i.e., by exactly the same interconcept distances), except for random noise that Goldstone and Rogosky added to each distance to simulate the effect of disparate beliefs. A constraint-

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

satisfaction algorithm then applied to Calvin's and Martha's systems that attempted to recover the original correspondence between the concepts—to map Calvin's DOG to Martha's DOG, Calvin's DAISY to Martha's DAISY, and so on. The results of the stimulations show that with 15 concepts in each system (the maximum number considered and the case in which the model performed best) and with no noise added to Martha's system, the algorithm was always able to find the correct correspondence. When the simulation added to each dimension of the interconcept distance in Martha a small random increment (drawn from a normal distribution with mean 0 and standard deviation equal to .004 times the maximum distance), the algorithm recovered the correspondence about 63% of the time. When the standard deviation increased to .006 times the maximum distance, the algorithm succeeded about 15% of the time (Goldstone & Rogosky, 2002, Figure 2).

What should one make of the Goldstone and Rogosky results? Correspondences may be recovered for small amounts of noise, but performance dropped off dramatically for larger amounts of noise. Foes of the meaning-as-relative-position theory might claim that the poor performance under the 0.6% noise proves their contention. Advocates would point to the successful part of the simulations and note that its ability to detect correct correspondences usually improved as the number of points increased (although there are some nonmonotonicities in the simulation results that qualify this finding). Clearly, this is only the beginning of the empirical side of the debate. For example, the differences between Martha and Calvin are likely to be not only random but also systematic, as in the case where Martha grew up on a farm and Calvin was a city kid.

Concept Combination

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Let us now consider attempts to tackle head-on the problem of how word-level concepts combine to produce the meanings of larger linguistic units. There is relatively little research in this tradition on entire sentences (see Conrad & Rips, 1986; Rips, Smith, & Shoben, 1978), but there has been a fairly steady research stream devoted to noun phrases, including adjective-noun (“edible flowers”), noun-noun (“food flowers”), and noun-relative-clause combinations (“flowers that are foods”). We will call the noun or adjective parts of these phrases *components* and distinguish the main or *head noun* (“flowers” in each of our examples) from the adjective or noun *modifier* (“edible” or “food”). The aim of the research in question is to describe how people understand these phrases and, in particular, how the typicality of an instance in these combinations depends on the typicality of the same instance in the components. How does the typicality of a marigold in the category of edible flowers depend on the typicality of marigolds in the categories of edible things and flowers? As we have already noticed, this relationship is far from straightforward (parakeets are superbly typical as pet birds but less typical pets and even less typical birds). For reviews of work on this problem, see Hampton (1997), Murphy (2002), Rips (1995), and Wisniewski (1997).

Research on the typicality structure of combinations has turned up interesting phenomena. These same phenomena, however, pose some serious challenges to the idea that people can predict the typicality of a combination from the typicality of its components. This difficulty is instructive, in part because all psychological theories of concept combination posit complex, structured representations, and they depict concept combination either as rearranging (or augmenting) the structure of the head noun by means of the modifier (Franks, 1995; Murphy, 1988; Smith, Osherson, Rips, & Keane, 1988) or as fitting both head and modifier into a larger relational complex (Gagné & Shoben, 1997). Table 11.1 summarizes the

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

assumptions of these theories. Earlier models (at the top of the table) differ from later ones mainly in terms of the complexity of the combination process. Smith et al. (1988), for example, aimed at explaining simple adjective-noun combinations (e.g., “white vegetable”) that, roughly speaking, refer to the intersection of the sets denoted by modifier and head (white vegetables are approximately the intersection of white things and vegetables). In this theory, combination occurs when the modifier changes the value of an attribute in the head noun (changing the value of the color attribute in VEGETABLE to WHITE) and boosts the importance of this attribute in the overall representation. Later theories attempted to account for nonintersective combinations (e.g., “criminal lawyers,” who are often not both criminals and lawyers). These combinations call for more complicated adjustments, for example, determining a relation that links the modifier and head (a criminal lawyer is a lawyer whose clients are in for criminal charges) or extracting a value from the modifier that can then be assigned to the head (e.g., a panther lawyer might be one who is especially vicious or tenacious).

<Insert Table 11.1 about here>

One reason for difficulty in providing a theory for concept combination is that many of the combinations that investigators have studied are familiar or, at least, have familiar referents. Some people have experience with edible flowers, for example, and know that they include nasturtiums, are sometimes used in salads, are often brightly colored, are peppery-tasting, and so on. We learn many of these properties by direct or indirect observation (by what Hampton, 1987, calls “extensional feedback”), and they are sometimes impossible to learn simply by knowing the meaning of “edible” and “flower.” Because these properties can affect the typicality of potential instances, the typicality of these familiar combinations won’t

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be a function of the typicality of their components. This means that if we are going to be able to predict typicality in a compositional way, we will have to factor out the contribution of these directly acquired properties. Rips (1995) refers to this filtering as the “No Peeking Principle”—no peeking at the referents of the combination. Of course, you might be able to predict typicality if you already know the relevant real-world facts in addition to knowing the meaning of the component concepts. The issue about understanding phrases, however, is how we are able to interpret an unlimited number of new ones. For this purpose, people need some procedure for computing new meanings from old ones that is not restricted by the limited set of facts they happened to have learned (e.g., through idiosyncratic encounters with edible flowers).

Another reason why it is hard to explain concept combination is that some of the combinations used in this research may be compounds or lexicalized phrases (e.g., “White House” [accent on “White”] = the residence of the President) rather than modifier-head constructions (e.g., “white house” [accent on “house”] = a house whose color is white). Compounds are often idiomatic; their meaning is not an obvious function of their parts (see Gleitman & Gleitman’s, 1970, distinction between phrasal and compound constructions; and Partee, 1995).

There is a deeper reason, however, for the difficulty in predicting compound typicality from component typicality. Even if we adhere to the No Peeking Principle, and even if we stick to clear modifier-head constructions, the typicality of a combination can depend on “emergent” properties that are not part of the representation of either component (Hastie, Schroeder, & Weber, 1990; Kunda, Miller, & Claire, 1990; Medin & Shoben, 1988; Murphy, 1988). For example, you may never have encountered, or even thought about, a smoky apple

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

(so extensional feedback does not inform your conception of the noun phrase), but nevertheless it is plausible to suppose that smoky apples are not good tasting. Having a bad taste, however, is not a usual property of (and is not likely to be stored as part of a concept for) either apples or smoky things; on the contrary, many apples and smoky things (e.g., smoked meats, cheeses, and fish) are quite good tasting. If you agree with our assessment that smoky apples are likely to be bad tasting, that is probably because you imagine a way in which apples could become smoky (being caught in a kitchen fire, perhaps) and you infer that under these circumstances the apple would not be good to eat. The upshot is that the properties of a combination can depend on complex inductive or explanatory inferences (Johnson & Keil, 2000; Kunda et al., 1990). If these properties affect the typicality of an instance with respect to the combination, then models of this phenomenon will not be simple. No current theory provides an adequate and general account of these processes.

Inferential Versus Atomistic Concepts

Research on the typicality structure of noun phrases is of interest for what it can tell us about people's inference and problem-solving skills. But because these processes can be quite complex—drawing on general knowledge and inductive reasoning to produce emergent information—we cannot predict noun phrase typicality in other than a limited range of cases. By themselves, emergent properties do not rule out the possibility of a model that explains how people derive the meaning of a noun phrase from the meaning of its components. Compositionality does not require that all aspects of the noun phrase's meaning are literally parts of the components' meanings. It is sufficient to find some computable function from the components to the composite that is simple enough to account for people's understanding (see Partee, 1995, for a discussion of types of composition). The trouble is that if noun phrases'

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

meanings require theory construction and problem solving, such a process is unlikely to explain the ease and speed with which we usually understand them in ongoing speech.

We have only considered the role of schemas or prototypes in concept combination, but many of the same difficulties with semantic composition affect other contemporary theories, such as latent semantic analysis (Landauer & Dumais, 1997), which take a global approach to meaning. Latent semantic analysis takes as input a table of the frequencies with which words appear in specific contexts. In one application, for example, the items comprise about 60,000 word types taken from 30,000 encyclopedia entries, and the table indicates the frequency with which each word appears in each entry. The analysis then applies a technique similar to factor analysis to derive an approximately 300-dimensional space in which each word appears as a point and in which words that tend to co-occur in context occupy neighboring regions in the space. Because this technique finds a best fit to a large corpus of data, it is sensitive to indirect connections between words that inform their meaning. However, the theory has no clear way to derive the meaning of novel sentences. Although latent semantic analysis could represent a sentence as the average position of its component words, this would not allow it to capture the difference between, say, *The financier dazzled the movie star* versus *The movie star dazzled the financier*, which depend on sentence structure as well as word meaning. In addition, the theory uses the distance between two words in semantic space to represent the relation between them; so the theory has trouble with semantic relations that, unlike distances, are asymmetric. It is unclear, for example, how it could cope with the fact that *father* implies *parent* but *parent* does not imply *father*.

On the one hand, online sentence understanding is a rapid, reliable process. On the other, the meaning of even simple adjective-noun phrases seems to require heady inductive

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

inferences. Perhaps we should distinguish, then, between the *interpretation* of a phrase or sentence and its *comprehension* (Burge, 1999). On this view, comprehension gives us a more or less immediate understanding of novel phrases, based primarily on the word meaning of the components and syntactic/semantic structure. Interpretation, by contrast, is a potentially open-ended process, relying on the result of comprehension plus inference and general knowledge. As we have just noticed, it is hard, if not impossible, to compute the typicality structure of composites. So if we want something readily computable in order to account for comprehension, we have to look to something simpler than typicality structures (and the networks, prototypes, schemas, or theories that underlie them). One possibility (Fodor, 1994, 1998) is to consider a representation in which word meanings are mental units not much different from the words themselves, and whose semantic values derive from (unrepresented) causal connections to their referents.

The comprehension/interpretation distinction that we just proposed may be more of a continuum than a dichotomy. Background knowledge about the component concepts may come in gradually as part of sentence interpretation, with more atomistic components becoming available early in the process, simple typicality information arriving later, and inference-intensive information still later. Researchers usually study sentence understanding, classification, and inference with different methodologies. Reaction time, for example, is often a dependent measure for sentence understanding and classification, but rarely for interpretation tasks, which employ off-line choice and think-aloud methods (more on interpretation tasks in upcoming sections). Different methodologies make it hard to generalize about the way in which knowledge informs sentence understanding. However, some evidence exists that typicality information, in particular, can impact simple language generation tasks.

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

In early work, Rosch (1975) asked one group of subjects to produce sentences containing names of categories like “bird” and “weapon.” The result was often items like “Twenty or so birds often perch on the telephone wires outside my window and twitter in the morning.” Rosch substituted for the category name in these sentences either the name of a typical member of the category (“sparrow”) or an atypical member (“turkey”). An independent group of subjects then judged how natural or peculiar the resulting sentences were, and they gave higher naturalness ratings to the sentences with typical instances (“Twenty or so robins often perch on the telephone wires . . .”) than sentences with atypical instances (“Twenty or so turkeys often perch on the telephone wires . . .”). Typicality therefore seems to inform simple sentence production.

Returning to concept combination, we might be able to salvage some of the models in Table 11.1 if we view the models as describing a particular stage of the comprehension process. Theories like Smith et al.’s (1988) Selective Modification Model, for example, might give the right account of concept combination for a stage that is not too early (so some typicality information can enter the picture) and not too late (so higher level inferences do not have time to override typicality).

Generic Noun Phrases

Even if we abandon typicality structures as accounts of comprehension, however, it does not follow that these structures are useless in explaining all linguistic phenomena. Recent research on two fronts seems to us to hold promise for interactions between psychological and linguistic theories. First, there are special constructions in English that, roughly speaking, describe default characteristics of members of a category. For example, “Lions have manes” means (approximately) that having a mane is a characteristic property of lions. Bare plural

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

noun phrases (i.e., plurals with no preceding determiners) are one way to convey such a meaning as we have just seen, but indefinite singular sentences (“A lion has a mane”) and definite singular sentences (“The lion—*Panthera leo*—has a mane”) can also convey the same idea in some of their senses. These generic sentences seem to have normative content. Unlike “Most lions have manes,” generic sentences seem to hold despite the existence of numerous exceptions; “Lions have manes” seems to be true despite the fact that most lions (e.g., female and immature lions) do not have manes (see Krifka et al., 1995, for an introduction to generic sentences, and Leslie, 2008, for one recent account). There is an obvious relation between the truth or acceptability of generic sentences and the typicality structure of categories, since the typical properties of a category are those that appear in true generic sentences. Of course, as Krifka et al. note, this may simply be substituting one puzzle (the truth conditions of generic sentences) for another (the nature of typical properties), but this may be one place where linguistic and cognitive theories might provide mutual insight. Research by Susan Gelman and her colleagues (see Gelman, 2003, for a thorough review) suggests that generic sentences are a frequent way for caregivers to convey category information to children. Four-year-olds differentiate sentences with bare plurals (“Lions have manes”) from those explicitly quantified by “all” or “some” in comprehension, production, and inference tasks (Gelman, Star, & Flukes, 2002; Hollander, Gelman, & Star, 2002). It would be of interest to know, however, exactly what meaning children and adults attach to generic sentences.

Polysemy

A second place to look for linguistic-cognitive synergy is in an account of the meanings of polysemous words. Linguists (e.g., Lyons, 1977) traditionally distinguish homonyms like “mold,” which have multiple unrelated meanings (e.g., a form into which liquids are poured

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

vs. a fungus) from polysemous terms like “line” that have multiple related meanings (e.g., a geometric line vs. a fishing line vs. a line of people, etc.). What makes polysemous terms interesting to psychologists in this area is that the relations among their meanings often possess a kind of typicality structure of their own. This is the typicality of the senses of the expression rather than the typicality of the referents of the expression, making it a kind of higher level typicality phenomenon. Figure 11.2 illustrates such a structure for the polysemous verb “crawl,” as analyzed by Fillmore and Atkins (2000). A rectangle in the figure represents each sense or use and includes both a brief label indicating its distinctive property and an example from British corpuses. According to Fillmore and Atkins, the central meanings for *crawl* have to do with people or creatures moving close to the ground (these uses appear in rectangles with darker outlines in the figure). But there are many peripheral uses, for example, time moving slowly (“The hours seemed to crawl by”) and creatures teeming about (“The picnic supplies crawled with ants”). The central meanings are presumably the original ones, with the peripheral meanings derived from these by a historical chaining process. Malt, Sloman, Gennari, Shi, and Wang (1999) have observed similar instances of chaining in people’s naming of artifacts, such as bottles and bowls, and it is possible that the gerrymandered naming patterns reflect the polysemy of the terms (e.g., “bottle”) rather than different uses of the same meaning. As Figure 11.2 shows, it is far from easy to distinguish different related meanings (polysemy) from different uses of the same meaning (contextual variation) and from different unrelated meanings (homonymy).

<Insert Figure 11.2 about here>

Some research has attacked the issue of whether people store each of the separate senses of a polysemous term (Klein & Murphy, 2002) or store only the core meaning, deriving

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

the remaining senses as needed for comprehension (Caramazza & Grober, 1976; Franks, 1995). Conflicting evidence in this respect may be due to the fact that some relations between senses seem relatively productive and derivable (*regular* polysemy, such as the relationship between terms for animals and their food products, e.g., the animal meaning of “lamb” and its menu meaning), while other senses seem ad hoc (e.g., the relation between “crawl” = *moving close to the ground* and “crawl” = *teeming with people* in Fig. 11.2). Multiple mechanisms are likely to be at work here.

Summary

We do not mean to suggest that the only linguistic applications of psychologists’ “concepts” are in dealing with interpretation, generic phrases, and polysemy. Far from it. There are many areas, especially in developmental psycholinguistics, that hold the promise of fruitful interactions but that we cannot review here. Nor are we suggesting that investigators in this area give up the attempt to study the use of concepts in immediate comprehension. But concepts for comprehension seem to have different properties from the concepts that figure in the other functions we have discussed, and researchers need to direct more attention to the interface between them.

Theories, Modules, and Psychometaphysics

We have seen, so far, some downward pressure on cognitive theories to portray human concepts as mental entities that are as simple and streamlined as possible. This pressure comes not only from the usual goal of parsimony but also from the role that concepts play in immediate language comprehension. But there is also a great deal of upward pressure, pressure to include general knowledge about a category as part of its representation. For example, the presence of emergent properties in concept combinations suggests that people

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

use background knowledge in interpreting these phrases. Similarly, people may bring background knowledge and theories to bear in classifying things, even when they know a decision rule for the category. Consider psychodiagnostic classification. Although *DSM-IV* (the official diagnostic manual of the American Psychological Association) is atheoretical and organized in terms of rules, there is clear evidence that clinicians develop theories of disorders and, contra *DSM-IV*, weight causally central symptoms more than causally peripheral symptoms (e.g., Kim & Ahn, 2002a). The same holds for laypeople (e.g. Furnham, 1995; Kim & Ahn, 2002b).

In this section we examine the consequences of expanding the notion of a concept to include theoretical information about a category. In the case of the natural categories, this information is likely to be causal (see Buehner & Cheng, Chapter 12), since people probably view physical causes as shaping and maintaining these categories. For artifacts, the relevant information may be the intentions of the person creating the object (e.g., Bloom, 1996). The issues we raise here concern the content and packaging of these causal beliefs.

The first of these issues focuses on people's beliefs about the locus of these causal forces—what we called “psychometaphysics.” At one extreme, people may believe that each natural category is associated with a single source, concentrated within a category instance, that controls the nature of that instance. The source could determine, among other things, the instance's typical properties, its category membership, and perhaps even the conditions under which it comes into and goes out of existence. Alternatively, people may believe that the relevant causal forces are more like a swarm—not necessarily internal to an instance, nor necessarily emanating from a unitary spot—but shaping the category in aggregate fashion.

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

The second issue has to do with the cognitive divisions that separate beliefs about different sorts of categories. People surely think that the causes that help shape daisies differ in type from those that shape teapots. Lay theories about flowers and other living things include at least crude information about specifically biological properties, whereas lay theories of teapots and other artifacts touch instead on intended and actual functions. But how deep do these divisions go? On the one hand, beliefs about these domains could be modular (relatively clustered, relatively isolated), innate, universal, and local to specific brain regions. On the other, they may be free-floating, learned, culturally specific, and distributed across cortical space. This issue is important to us because it ultimately affects whether we can patch up the “semantic memory” marriage.

Essentialism and Sortalism

Psychological Essentialism

What is the nature of people’s beliefs about the causes of natural kinds? One hypothesis is that people think there is something internal to each member of the kind—an essence—that is responsible for its existence, category membership, typical properties, and other important characteristics (e.g., Atran, 1998; Gelman & Hirschfeld, 1999; Medin & Ortony, 1989). Of course, it is unlikely that people think that all categories of natural objects have a corresponding essence. There is probably no essence of pets, for example, that determines an animal’s pet status. But for basic-level categories, such as dogs or gold or daisies, it is tempting to think that something in the instance determines crucial aspects of its identity. Investigators who have accepted this hypothesis are quick to point out that the theory applies to people’s beliefs and not to the natural kinds themselves. Many biologists and philosophers of science agree that essentialism will not account for the properties and variations that real

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

species display, in part because the very notion of species is not coherent (e.g., Ghiselin, 1981; Hull, 1999). Chemical kinds (e.g., gold) may conform much more closely to essentialist doctrine (see Sober, 1980). Nevertheless, expert opinion is no bar to laypersons' essentialist views on this topic. In addition, psychological essentialists have argued that people probably do not have a fully fleshed out explanation of what the essence is. What they have, on this hypothesis, is an IOU for a theory: a belief that there must be *something* that plays the role of essence, even though they cannot supply a description of it (Medin & Ortony, 1989).

Belief in a hypothetical, minimally described essence may not seem like the sort of thing that could do important cognitive work, but psychological essentialists have pointed out a number of advantages that essences might afford, especially to children. The principle advantage may be induction potential. Medin (1989) suggested that essentialism is poor metaphysics but good epistemology in that it may lead people to expect that members of a kind will share numerous, unknown properties—an assumption that is sometimes correct. In short, essences have a motivational role to play in getting people to investigate kinds' deeper characteristics. Essences also explain why category instances seem to run true to type—for example, why the offspring of pigs grow up to be pigs rather than cows. They also explain the normative character of kinds (e.g., their ability to support inductive arguments and their ability to withstand exceptions and superficial changes), as well as people's tendency to view terms for kinds as well defined.

Evidence for essentialism tends to be indirect. There are results that show that children and adults do in fact hold the sorts of beliefs that essences can explain. By the time they reach first or second grade, children know that animals whose insides have been removed are no longer animals, that baby pigs raised by cows grow up to be pigs rather than cows (Gelman &

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Wellman, 1991), and that cosmetic surgery does not alter basic-level category membership

(Keil, 1989). Research on adults also shows that “deeper” causes—those that themselves have few causes but many effects—tend to be more important in classifying than shallower causes (Ahn, 1998; Sloman, Love, & Ahn, 1998; but see Rehder, 2009).

However, results like these are evidence for essence only if there are no better explanations for the same results, and it seems at least conceivable that children and adults make room for multiple types and sources of causes that are not yoked to an essence. According to Strevens (2000), for example, although people’s reasoning and classifying suggest that causal laws govern natural kinds, it may be these laws alone, rather than a unifying essence, that are responsible for the findings. According to essentialists, people think there is something (an essence) that is directly or indirectly responsible for the typical properties of a natural kind. According to Strevens’ minimalist alternative, people think that for each typical property there is something that causes it, and that something may vary for different properties.

Essentialists counter that both children and adults assume a causal structure consistent with essence (see Gelman & Frazier, Chapter 26; also see Braisby, Franks, & Hampton, 1996; Diesendruck & Gelman, 1999; Kalish, 1995, 2002, for debate on this issue). One strong piece of evidence for essentialism is that participants who have successfully learned artificial, family-resemblance categories (i.e., those in which category members have no single feature in common) nevertheless believe that each category contained a common, defining property (Brooks & Wood, as cited by Ahn et al., 2001). Other studies with artificial “natural” kinds have directly compared essentialist and nonessentialist structures but have yielded mixed

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

results (e.g., Rehder & Hastie, 2001). It is possible that explicit training overrides people's natural tendency to think in terms of a common cause.

In the absence of more direct evidence for essence, the essentialist-minimalist debate is likely to continue (see Ahn et al., 2001; Sloman & Malt, 2003; and Strevens, 2001, for the latest salvos in this dispute). Indeed, the authors of this chapter are not in full agreement. Medin finds minimalism too unconstrained, whereas Rips opines that essentialism suffers from the opposite problem. Adding a predisposition toward parsimony to the minimalist view seems like a constructive move, but such a move would shift minimalism considerably closer to essentialism. Ultimately the issue boils down to determining to what extent causal understandings are biased toward the assumption of a unique, central cause for a category's usual properties.

Sortalism

According to some versions of essentialism, an object's essence determines not only which category it belongs to but also the object's very identity. According to this view, it is by virtue of knowing that Fido is a dog that you know (in principle) how to identify Fido over time, how to distinguish Fido from other surrounding objects, and how to determine when Fido came into existence and when he will go out of it. In particular, if Fido happens to lose his dog essence, then Fido not only ceases to be a dog, he ceases to exist entirely. As we noted in discussing essentialism, not all categories provide these identity conditions. Being a pet, for example, does not lend identity to Fido, since he may continue to survive in the wild as a non-pet. According to one influential view (Wiggins, 1980), the critical identity-lending category is the one that answers the question *What is it?* for an object; and since basic-level categories are sometimes defined in just this way, basic-level categories are the presumed source of the

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

principles of identity. (Theories of this type usually assume that identity conditions are associated with just one category for each object, since multiple identity conditions lead to contradictions; see Wiggins, 1980). Contemporary British philosophy tends to refer to such categories as *sortals*, and we will adopt this terminology here.

Sortalism plays an important role in current developmental psychology because developmentalists have used children's mastery of principles of identity to decide whether these children possess the associated concept. Xu and Carey (1996) staged for infants a scene in which (e.g.) a toy duck appears from one side of an opaque screen and then returns behind it. A toy truck next emerges from the other side of the screen and then returns to its hidden position. Infants habituate after a number of encores of this performance, at which time the screen is removed to reveal both the duck and truck (the scene that adults expect) or just one of the objects (duck or truck). Xu and Carey reported that younger infants (e.g., 10-month-olds) exhibit no more surprise at seeing one object than at seeing two, while older infants (and adults) show more surprise at the one-object tableau. Xu and Carey also showed in control experiments that younger and older infants perform identically if they see a preview of the two starring objects together before the start of the performance. The investigators infer that the younger infants lack the concepts DUCK and TRUCK, since they are unable to use a principle of identity for these concepts to discern that a duck cannot turn into a truck while behind the screen. Xu and Carey's experiments have sparked a controversy about whether the experimental conditions are simple enough to allow babies to demonstrate their grip on object identity (see Wilcox & Baillargeon, 1998; Xu, 2003), but for present purposes what is important is the assumption that infants' inability to reidentify objects over temporal gaps implies lack of the relevant concepts.

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Sortal theories impose strong constraints on some versions of essentialism. We noted that one of essentialism's strong points is its ability to explain some of the normative properties of concepts, for example, the role concepts play in inductive inferences. However, sortalism places some restrictions on this ability. Members of sortal categories cannot lose their essence without losing their existence, even in counterfactual circumstances. This means that if we are faced with a premise like *Suppose dogs can bite through wire . . .*, we cannot reason about this supposition by assuming that the essence of dogs has changed in such a way as to make dogs stronger. A dog with changed essence is not a superdog, according to sortalism, but rather has ceased to exist (see Rips, 2001). For the same reason, it is impossible to believe without contradiction both that basic-level categories are sortals and that objects can shift from one basic-level category to another.

These consequences of sortalism may be reasonable ones, but it is worth considering the possibility that sortalism—however well it fares as a metaphysical outlook—incorrectly describes people's views about object identity. Although objects typically do not survive a leap from one basic-level category to another, it may not be impossible for them to do so. Blok, Newman, and Rips (2005) and Liittschwager (1995) gave participants scenarios that described novel transformations that sometimes altered the basic-level category. In both studies, participants were more likely to agree that the transformed object was identical to the original if the transformational distance was small. But these judgments could not always be predicted by basic-level membership.

Results from these sci-fi scenarios should be treated cautiously, but they suggest that people think individual objects have an integrity that does not necessarily depend on their basic-level category. Although this idea may be flawed metaphysics, it is not unreasonable as

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

psychometaphysics. People may think that individuals exist as the result of local causal forces, forces that are only loosely tethered to basic-level kinds. As long as these forces continue to support the individual's coherence, that individual can exist even if it finds itself in a new basic-level category. Of course, not all essentialists buy into this link between sortalism and essentialism. For example, people might believe that individuals have both a category essence *and* a set of historical and other characteristics that make it unique. Gutheil and Rosengren (1996) hypothesize that objects have two difference essences, one for membership and another for identity. Just how individual identity and kind identity play out under these scenarios could then be highly variable.

Domain Specificity

The notion of domain specificity has served to organize a great deal of research on conceptual development. For example, much of the work on essentialism has been conducted in the context of exploring children's naïve biology (see also Au, 1994; Carey, 1995; Gopnik & Wellman, 1994; Spelke, Phillips, & Woodward, 1995). Learning in a given domain may be guided by certain skeletal principles, constraints, and (possibly innate) assumptions about the world (see Gelman & Coley, 1990; Gelman, 2003; Keil, 1981; Kellman & Spelke, 1983; Markman, 1990; Spelke, 1990). Susan Carey's influential (1985) book presented a view of knowledge acquisition as built on framework theories that entail ontological commitments in the service of a causal understanding of real-world phenomena. Two domains can be distinguished from one another if they represent ontologically distinct entities and sets of phenomena and are embedded within different causal explanatory frameworks. These ontological commitments serve to organize knowledge into domains such as naïve physics (or mechanics), naïve psychology, or naïve biology (e.g., see Au, 1994; Carey, 1995; Gelman &

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Koenig, 2001; Gopnik & Wellman, 1994; Hatano & Inagaki, 1994; Keil, 1994; Spelke et al., 1995; Wellman & Gelman, 1992). In the following we will focus on one candidate domain, naïve biology.

Folk Biology and Universals

There is fairly strong evidence that all cultures partition local biodiversity into taxonomies whose basic level is that of the “generic species” (Atran, 1990; Berlin, Breedlove, & Raven, 1973). Generic species often correspond to scientific species (e.g., elm, wolf, and robin); however, for the large majority of perceptually salient organisms (see Hunn, 1999), such as vertebrates and flowering plants, a scientific genus frequently has only one locally occurring species (e.g., bear, oak). In addition to the spontaneous division of local flora and fauna into generic species, cultures seem to structure biological kinds into hierarchically organized groups, such as white oak/oak/tree. Folk-biological ranks vary little across cultures as a function of theories or belief systems (see Malt, 1994, for a review). For example, in studies with Native American and various U.S. and Lowland Maya groups, correlations between folk taxonomies and classical evolutionary taxonomies of the local fauna and flora average $r = .75$ at the generic-species level and about 0.5 with higher levels included (Atran, 1999; Bailenson et al., 2002; Medin et al., 2002). Much of the remaining variance owes to obvious perceptual biases (Itza’ Maya group bats with birds in the same life form) and local ecological concerns. Contrary to received notions about the history and cross-cultural basis for folk-biological classification, utility does *not* appear to drive folk taxonomies (cf. Berlin et al., 1973).

These folk taxonomies also appear to guide and constrain reasoning. For example, Coley, Medin, and Atran (1997) found that both Itza’ Maya and U.S. undergraduates privilege the generic-species level in inductive reasoning. That is, an inference from Swamp White Oak

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

to all White Oaks is little if any stronger than an inference from Swamp White Oak to all Oaks. Above the level of Oak, however, inductive confidence takes a sharp drop. In other words, people in both cultures treat the generic level (e.g., Oak) as maximizing induction potential. The results for undergraduates are surprising, since the original Rosch et al. (1976) basic-level studies had suggested that a more abstract level (e.g., TREE) acted as basic for undergraduates and should have been privileged in induction. That is, there is a discrepancy between results with undergraduates on basicness in naming, perceptual classification, and feature listing, on the one hand, and inductive inference, on the other. Coley et al. suggest that the reasoning task relies on expectations rather than knowledge, and that undergraduates may know very little about biological kinds (see also Wolff, Medin, & Pankratz, 1999). Medin and Atran (2004) caution against generalizing results on biological thought from undergraduates, since most have relatively little firsthand experience with nature.

Interdomain Differences

Carey (1985) argued that children initially understand biological concepts like ANIMAL in terms of folk psychology, treating animals as similar to people in having beliefs and desires. Others (e.g., Keil, 1989) argue that young children do have biologically specific theories, albeit more impoverished than those of adults. For example, Springer and Keil (1989) show that preschoolers think biological properties are more likely to be passed from parent to child than are social or psychological properties. They argue that this implies that the children have a biology-like inheritance theory.

The evidence concerning this issue is complex. (see, e.g., Au & Romo, 1996, 1999; Carey, 1991; Coley, 1995; Gelman, 2003; Hatano & Inagaki, 1996 Inagaki, 1997; Inagaki & Hatano, 1993, 1996, 2002; Johnson & Carey, 1998; Keil, 1995; Keil, Levin, Richman, &

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Gutheil, 1999; Rosengren, Gelman, Kalish, & McCormick, 1991; Springer & Keil, 1989, 1991). On one hand, Solomon, Johnson, Zaitchik, and Carey (1996) claim that preschoolers do not have a biological concept of inheritance, because they do not have an adult's understanding of the biological causal mechanism involved. On the other hand, there is growing cross-cultural evidence that 4- to 5-year-old children believe (like adults) that the identity of animals and plants follows that of their progenitors, regardless of the environment in which the progeny matures (e.g., progeny of cows raised with pigs, acorns planted with apple trees) (Atran et al., 2001; Gelman & Wellman, 1991; Sousa et al., 2002). Furthermore, it appears that Carey's (1985) results on psychology versus biology may only hold for urban children who have little intimate contact with nature (Atran et al., 2001; Ross et al., 2003). Altogether, the evidence suggests that 4- to 5-year-old children do have a distinct biology, though perhaps one without a detailed model of causal mechanisms (see Rozenbilt & Keil, 2002, for evidence that adults also have only a superficial understanding of mechanisms).

Domains and Brain Regions

While some cognitive scientists have argued strongly for the idea that different biological categories, such as animals, are represented in different regions of the brain, we saw earlier that the current evidence favors the hypothesis that these categories are represented in terms of their constituent features (the perceptual-functional hypothesis). There is, however, some evidence for different categories being represented in different brain regions, but the categories involved are not the familiar animals and tools, but rather faces and places.

Consider faces. Why should the category of faces get special treatment in the brain? Because faces are special in a number of ways. First, unlike most categories, faces do not seem to be perceived in terms of their constituent features; rather, the visual perception of a

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

face involves configurational processes not featural ones (e.g., Tanaka & Farah, 1993; Tanaka & Sengco, 1997). Second, the recognition of a face is substantially disrupted by inverting it, more so than with any other category of objects (Yin, 1969). And lastly, recognition of faces may be more critical to an infant's survival than recognition of just about any other class of objects—the first thing that an infant needs to know is who are its conspecifics, as they are the ones who will take care of the infant.

The neural basis of face recognition and face categorization again are located in the general region responsible for object recognition, the ventral temporal cortex. Within this broad region, faces activate a subregion called the fusiform face area, or FFA (so called because the subregion lies on the fusiform gyrus). The precise location of the FFA varies somewhat from person to person, but it is always in the fusiform gyrus of the temporal cortex (Kanwisher, McDermott, & Chun, 1997). Most important, viewing human faces will activate this subregion more than viewing any other object, including body parts (e.g., Kanwisher, 2000). Indeed, some studies show that the FFA activates to virtually every presentation of a face, but not at all to many other objects, such as letter strings, animal torsos, and the backs of human heads. Furthermore, activation in the FFA is less when viewing inverted than upright faces, which fits perfectly with the fact that inversion disrupts face recognition. That is, if increased activation in the FFA mediates successful face recognition, then unsuccessful face recognition should go with less activation in the FFA.

Some have argued that the special status of faces—the fact that this domain gets its own specialized chunk of brain—is really due to the fact that we spend so much time recognizing faces that we become experts at it, and it is really the expertise that is responsible for the brain specialization (e.g., Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999). There

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

is something to this point, as researchers have shown that the FFA is increasingly activated by a novel domain of objects as the subject becomes increasingly expert at discriminating among novel objects with a face-like structure (Gauthier, Anderson, Tarr, Skudlarski, & Gore, 1997). Still, neither such highly practiced objects nor even other kinds of faces, like the faces of dogs, will activate the FFA as much as human faces do (Kanwisher, 2000).

There is also evidence that another subregion of ventral temporal cortex is specialized for the domain of places: landscapes and layouts of buildings. The region is referred to as the “parahippocampal place area,” or PPA (as it is located on the parahippocampal gyrus). Viewing scenes of landscapes or buildings will activate the PPA more than will any other class of objects (Epstein, Harris, Stanley, & Kanwisher, 1999). Faces do not activate the PPA just as places do not activate the FFA. And activation of the place area seems sufficient for one to be able to categorize it as a place.

Will other domain-specific areas be found in the brain? There is suggestive evidence of a “word area” located in the occipital cortex of literate people (distinct from the face and place areas) (e.g., Polk & Farah, 2002). What is interesting about this domain-specific area is that it must be acquired through experience with reading. Like the face and place areas, the word area has been studied more in the context of object recognition than object categorization. So at this point in time, there may a limit to what these domain-specific categories can tell us about the implementation of concepts in the human brain.

Domains and Memory

The issue of domain specificity returns us to one of earlier themes: Does memory organization depend on meaning? We have seen that early research on semantic memory was problematic in this respect, since many of the findings that investigators used to support meaning-based

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

organization had alternative explanations. General-purpose decision processes could produce the same pattern of results, even if the information they operated on was haphazardly organized. Of course, in those olden days, semantic memory was supposed to be a hierarchically organized network like that in Figure 11.1; the network clustered concepts through shared superordinates and properties but was otherwise undifferentiated. Modularity and domain specificity offer a new interpretation of semantic-based memory structure—a partition of memory space into distinct theoretical domains. Can large-scale theories like these support memory organization in a more adequate fashion than homogeneous networks?

One difficulty in merging domain specificity with memory structure is that domain theories do not taxonomize categories; they taxonomize assumptions. What differentiates domains is the set of assumptions or warrants they make available for thinking and reasoning (see Toulmin, 1958, for one such theory), and this means that a particular category of objects usually falls in more than one domain. To put it another way, domain-specific theories are “stances” (Dennett, 1971) or “construals” (Keil, 1995) that overlap in their instances. Take the case of people. The naive psychology domain treats people as having beliefs and goals that lend themselves to predictions about actions (e.g., Leslie, 1987; Wellman, 1990). The naive physics domain treats people as having properties like mass and velocity that warrant predictions about support and motion (e.g., Clement, 1983; McCloskey, 1983). The naive law-school domain treats people as having properties, such as social rights and responsibilities, that lead to predictions about obedience or deviance (e.g., Fiddick, Cosmides, & Tooby, 2000). The naive biology domain (at least in the Western adult version) treats people as having properties like growth and self-animation that lead to expectations about behavior and development. In short, each ordinary category may belong to many domains.

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

If domains organize memory, then long-term memory will have to store a concept in each of the domains to which it is related. Such an approach makes some of the difficulties of the old semantic-memory theories yet more perplexing. Recall the issue of identifying the same concept across individuals, which we discussed earlier (see section on “Concepts as Positions in Memory Structure”). Memory modules have the same problem, but they add to it the dilemma of identifying concepts *within* individuals. How do you know that PEOPLE in your psychology module is the same concept as PEOPLE in your physics module and PEOPLE in your law-school module? Similarity is out (since the modules won’t organize them in the same way), spelling is out (both concepts might be tied to the word “people” in an internal dictionary, but then fungi and metal forms are both tied to the word “mold”), and interconnections are out (since they would defeat the idea that memory is organized by domain). We cannot treat the multiple PEOPLE concepts as independent either, since it is important to get back and forth between them. For example, the rights-and-responsibilities information about people in your law-school module has to get together with the goals-and-desires information about people in your psychology module in case you have to decide, together with your fellow jury members, whether the killing was a hate crime or was committed with malice aforethought.

It is reasonable to think that background theories provide premises or grounds for inferences about different topics, and it is also reasonable to think that these theories have their “proprietary concepts.” But if we take domain-specific modules as the basis for memory structure—as a new semantic memory—we have to worry about nonproprietary concepts, too. We have argued that there must be such concepts, since we can reason about the same thing with different theories. Multiple storage is a possibility, if you are willing to forego memory

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

economy and parsimony, and if you can solve the identifiability problem that we discussed in the previous paragraph. Otherwise, these domain-independent concepts have to inhabit a memory space of their own, and modules cannot be the whole story.

Summary

We seem to be arriving at a skeptical position with respect to the question of whether memory is semantically organized, but we need to be clear about what is and what is not in doubt.

What we doubt is that there is compelling evidence that long-term memory is structured in a way that mirrors lexical structure, as in the original semantic-memory models. We do not doubt that memory reflects meaningful relations among concepts, and it is extremely plausible that these relations depend to some extent on word meanings. For example, there may well be a relation in memory that links the concept TRUCKER with the concept BEER, and the existence of this link is probably due in part to the meaning of “trucker” and “beer.” What is not so clear is whether memory structure directly reflects the sort of relations that, in linguistic theory, organizes the meaning of words (where, e.g., “trucker” and “beer” are probably not closely connected). We note, too, that we have not touched (and we do not take sides on) two related issues, which are themselves subjects of controversy.

One of these residual issues is whether there is a split in memory between (a) general knowledge and (b) personally experienced information that is local to time and place.

Semantic memory (Tulving, 1972) or *generic memory* (Hintzman, 1978) is sometimes used as a synonym for general knowledge in this sense, and it is possible that memory is partitioned along the lines of this semantic/episodic difference, even though the semantic side is not organized by lexical content. The controversy in this case is how such a dual organization can handle learning of “semantic” information from “episodic” encounters (see Tulving, 1984,

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

and his critics in the same issue of *Behavioral and Brain Sciences* for the ins and outs of this debate).

The second issue that we are shirking is whether distributed brands of connectionist models can provide a basis for meaning-based memory. One reason for shirking is that distributed organization means that concepts like DAISY and CUP are *not* stored according to their lexical content. Instead, parts of the content of each concept are smeared across memory in overlapping fashion. It is possible, however, that at a subconcept level—at the level of features or hidden units—memory has a semantic dimension, and we must leave this question open.

Conclusions and Future Directions

Part of our charge was to make some projections about the future of research on concepts. We do not recommend a solemn attitude toward our predictions. But there are several trends that we have identified and, barring unforeseen circumstances (never a safe assumption), these trends should continue. One property our nominations share is that they uniformly broaden the scope of research on concepts. Here is our shortlist.

Sensitivity to Multiple Functions

The prototypical categorization experiment involves training undergraduates for about an hour and then giving transfer tests to assess what they have learned. This practice is becoming increasingly atypical, even among researchers studying artificially constructed categories in the lab. Recently researchers have studied functions other than categorization, as well as interactions across functions (see also Solomon et al., 1999).

Broader Applications of Empirical Generalizations and Computational Models

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

As a wider range of conceptual functions come under scrutiny, new generalizations emerge and computational models face new challenges (e.g., Yamauchi et al., 2002). Both developments set the stage for better bridging to other contexts and applications. This is perhaps most evident in the area of cognitive neuroscience where computational models have enriched studies of multiple categorization and memory systems (and vice versa). Norman, Brooks, Coblenz, and Babcock (1992) provide a nice example of extensions from laboratory studies to medical diagnosis in the domain of dermatology.

Greater Interactions Between Work on Concepts and Psycholinguistic Research

We have pressed the point that research on concepts has diverged from psycholinguistics because two different concepts of concepts seem to be in play in these fields. But it cannot be true that the concepts we use in online sentence understanding are unrelated to the concepts we employ in reasoning and categorizing. There is an opportunity for theorists and experimenters here to provide an account of the interface between these functions. To our knowledge, no one has tried to build a model that would integrate concept combination over its different stages, but it might be a worthwhile goal to do so. One possibility, for example, is to use sentence comprehension techniques to track the way that the lexical content of a word in speech or text is transformed in deeper processing (see Piñango, Zurif, & Jackendoff, 1999, for one effort in this direction). Another type of effort at integration is Wolff and Song's (2003) work on causal verbs and people's perception of cause, which contrasts predictions derived from cognitive linguistics with those from cognitive psychology.

Greater Diversity of Participant Populations

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

Although research with undergraduates at major Western universities will probably never go out of style (precedent and convenience are two powerful staying forces), we expect the recent increase to continue in the use of other populations. Work by Nisbett and his associates (e.g., Nisbett, Peng, Choi, & Norenzayan, 2001; Nisbett & Norenzayan, 2002) has called into question the idea that basic cognitive processes are universal, and categories and conceptual functions are basic cognitive functions. In much of the work by Atran, Medin, and their associates, undergraduates are the “odd group out” in the sense that their results deviate from those of other groups. In addition, cross-linguistic studies are often an effective research tool for addressing questions about the relationship between linguistic and conceptual development (e.g., Waxman, 1999).

More Psychometaphysics

An early critique of the “theory theory” is that it suffered from vagueness and imprecision. As we have seen in this review, however, this framework has led to more specific claims (e.g., Ahn’s causal status hypothesis) and the positions are clear enough to generate theoretical controversies (e.g., contrast Smith, Jones, & Landau, 1996, with Gelman, 2000; Booth & Waxman, 2002, 2003, with Smith, Jones, Yoshida, & Colunga, 2003; and Ahn, 1998, with Rehder & Kim, 2006 and Rehder, 2009). It is safe to predict even greater future interest in these questions.

All of the Above in Combination

Concepts and categories are shared by all the cognitive sciences, so there is very little room for researchers to stake out a single paradigm or subtopic and work in blissful isolation.

Although the idea of a semantic memory uniting memory structure, lexical organization, and categorization may have been illusory, this does not mean that progress will be fostered by

Rips, L. J., Smith, E. E., & Medin, D. L. (2012). Concepts and categories: Memory, meaning, and metaphysics. In K. Holyoak & R. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning*, pp 177-209. Submitted version.

ignoring the insights on concepts that these perspectives (and others) provide. We may see further fragmentation in the concepts of concepts, but it will still be necessary to explore the relations among them. Our only firm prediction is that the work we will find most exciting will be research that draws on multiple points of view.

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Table 11.1.

Some Theories of Concept Combination

Model	Domain	Representation of Head	Modification Process
		Noun	
Hampton	Noun-Noun and Noun-	Schemas (attribute-value	Modifier and head contribute

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(1987)	Relative-Clause NPs (conjunctive NPs, e.g., <i>sports that are also games</i>)	lists with attributes varying in importance)	values to combination on the basis of importance and centrality
Smith, Osherson, Rips, & Keane (1988)	Simple Adjective-Noun NPs (e.g., <i>red apple</i>)	Schemas (attribute-value lists with distributions of values and weighted attributes)	Adjective shifts value on relevant attribute in head and increases weight on relevant dimension.
Murphy (1988)	Adj-Noun and Noun-Noun NPs (esp. non-predicating NPs, e.g., <i>corporate lawyer</i>)	Schemas (lists of slots and fillers)	Modifier fills relevant slot; then representation is “cleaned up” on the basis of world knowledge.
Franks (1995)	Adj-Noun and Noun-Noun NPs (esp. privatives, e.g., <i>fake gun</i>)	Schemas (attribute-value structures with default values for some attributes)	Attribute-values of modifier and head are summed, with modifier potentially overriding or negating head values.
Gagné & Shoben (1997)	Noun-Noun NPs	Lexical representations containing distributions of relations in which nouns figure	Nouns are bound as arguments to relations (e.g., <i>flu virus</i> = virus causing flu).
Wisniewski (1997)	Noun-Noun NPs	Schemas (lists of slots and fillers, including roles in relevant events)	1. Modifier noun is bound to role in head noun (e.g., <i>truck soap</i> = soap for cleaning trucks). 2. Modifier value is reconstructed in head noun (e.g., <i>zebra clam</i> = clam with stripes). 3. Hybridization (e.g., <i>robin canary</i> = cross between robin and canary)

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Figure Captions

Figure 11.1 A semantic network after Collins and Quillian (1969).

Figure 11.2 The meaning of crawl: Why it is difficult to distinguish different related meanings (polysemy) from different uses of the same meaning (contextual variation) and from different unrelated meanings (homonymy). Adapted from Fillmore & Alking (2000) by permission of Oxford University Press.