Comprehending Complex Concepts

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Recent theories of concepts have raised the issue of how people combine simple concepts (like engine and repair) to form complex concepts (like engine repair). This article approaches this issue by asking how people comprehend modified noun phrases of this sort. One explanation of how complex concepts are understood (the feature weighting model) provides a simple mechanism in which the primary feature of the modifying concept is made more salient in the modified concept. Another explanation focuses on how world knowledge directs the combination process. The two explanations are compared in their ability to account for the interpretation of various kinds of noun phrases. Two experiments are reported which evaluate the feature weighting model's predictions for adjective-noun phrases. These contrasts suggest that the combination process does require reference to world knowledge. The consequences of accepting such an account are discussed.

The issue of complex concepts has become an important one in the psychology of concepts. Although theories of concepts may make similar predictions about the structure of simple concepts (e.g., Hintzman & Ludlam, 1980), they may not be equally facile at explaining how concepts are combined to form new, more complex concepts. Thus, an account of complex concepts may be crucial for evaluating the many theories of concepts now extant (see Smith & Medin, 1981).

The creation of complex concepts is a fascinating example of a high level cognitive process that people can perform very quickly. People are likely to create novel noun-noun phrases in their conversations, and listeners are adept at understanding them (E. Clark, Gelman, & Lane, 1985; H. Clark, 1983; Downing, 1977). In fact, Clark, et al. (1985) found that children as young as 3 years old could understand noun compounds as well as create novel compounds like lion door and apple car to describe objects that they had never seen before (see also Nelson, 1976, p. 23). The ability to understand a novel phrase like United States Senate Michigan bean soup (an example by

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Terry Winograd; see Cohen & Murphy, 1984) testifies to the richness of our conceptual processes and is an ability that poses a challenge for cognitive science to explain.

The definition of complex concept (itself a complex concept) is by no means easy. One can simply say that a complex concept is one that is built out of more primitive concepts, but this definition is far too generous. For example, many theories hold that simple concepts are represented as lists of features or as schemata of some kind (e.g., Rosch & Mervis, 1975; Rumelhart, 1980). Yet, each feature or slot of a schema could itself be considered a concept, so even a seemingly simple concept such as dog or chair might be counted as complex by this definition.

It would be best to establish an operational definition for complex concepts that does not depend on a particular theory of how simple concepts are represented. A rule of thumb that seems to be used in the literature goes as follows: 1. a concept is "simple" if it can be represented as a single lexical item; 2. a concept that requires more than one lexeme is "complex;" 3. Unless its linguistic expression is lexicalized (i.e., idiomatic). So, dog and apartment seem to be simple concepts, whereas apartment dog seems to be complex. The qualifier in the third part of the rule serves to rule out idiomatic phrases like dog house, which has the conventional meaning “house that a dog sleeps in,” and therefore may no longer be a truly complex concept. Note that this is only an operational definition; vocabulary is probably a good sign of conceptual simplicity, but it is by no means infallible. However, it seems more productive to proceed by considering the clearest cases of complex and simple concepts rather than to attempt a more precise but more contentious definition. Furthermore, a similar criterion has proved useful in related investigations (Berlin, Breedlove, & Raven, 1973).

One reason that the psychology of concepts may be central to cognitive science is that concepts are closely related to word meanings, perhaps forming the basis for word meanings (E. Clark, 1983). Thus, understanding the structure of concepts may help us to understand word meaning and language comprehension. This article will focus on how theories of complex concepts explain processes of understanding noun phrases like apartment dog or old door. There are two reasons for focusing on the interpretations of such phrases. One is that the interpretation of noun phrases is obviously an important part of language comprehension, as it forms the basis for much linguistic reference. The other is that the question “how do people combine concepts X and Y” is not a well-specified question. It is only in the context of some task that it takes on clear meaning. For example, how do people combine concepts of bird and house? They could combine them in various ways: take the intersection of the sets of birds and houses, take the union, try to find common or distinctive features, look for associations between
the two, and so on. In different situations, any one of these could be appropriate. This article, then, will focus on the more limited question of how people interpret phrases like *house bird*, which may have a more tractable answer.

The understanding of noun phrases in discourse has at least two separate components. One is the assignment of an interpretation or "meaning" to the phrase. For example, a reader might interpret *house bird* to mean a certain kind of winged animal that lives indoors as a pet. The next component is the assignment of a discourse referent to the phrase. That is, the reader might recognize an utterance of *house bird* to refer to Tweety, a bird that was already mentioned in the discourse (Clark & Marshall, 1981). Under other circumstances, a reader could understand this phrase to introduce a new character into the discourse (Murphy, 1984; Webber, 1979). This article addresses only the first component, the semantic interpretation of the phrase. To this end, I typically consider the understanding of noun phrases in isolated contexts to avoid any contamination by discourse referents. Research on definite reference has typically taken the interpretation of the noun phrase for granted and focused on the assignment of reference; this article simply takes the opposite tack. In real discourse, however, there is probably mutual influence between these components (Johnson-Laird, 1981), and future work on realistic discourse understanding will have to take this into account.

The rest of this article, then, investigates whether theories of complex concepts can provide an adequate account of the interpretation of simple noun modification. Its primary goal is to present data and examples that any theory of the comprehension of complex concepts would have to explain. Its secondary goal is to attempt to use these data to evaluate some specific theories. The next section presents the theories of complex concepts. The following sections present linguistic evidence and two empirical demonstrations that bear on these theories. The final section relates these results to other issues in cognitive science.

**ACCOUNTS OF COMPLEX CONCEPTS**

Perhaps the first account of complex concepts was an extensional one (Osherson & Smith, 1981; Zadeh, 1965): the complex concept $XY$ was analyzed as the intersection of the sets corresponding to $X$ and $Y$. This model, which was inspired by formal logic, has two fatal drawbacks. First, it is very difficult to interpret it as a psychological theory at all. Even if all pet fish fall into the intersection of pets and fish, this does not tell us what people do with their concepts *pet* and *fish* in order to create a new concept. Presumably, people do not have sets of pets and fish in their heads, and therefore they cannot perform set intersection. More likely, they have *intensions* in the
form of mental representations or rules that allow them to pick out the exemplars of a concept. Thus, any extensional explanation must also supply an intensional explanation of some kind in order to be a psychological model. But the set intersection model does not. Second, the extensional model does not account for non-intersective concepts. For example, complex concepts like apartment dog or typewriter table are not intersective: They do not correspond to the set of apartments-and-dogs or the set of typewriters-and-tables. Although it is difficult to estimate such things, it seems likely that the majority of complex concepts are not intersective (see Cohen & Murphy, 1984, for further discussion, and Downing, 1977; or Levi, 1978, for evidence).

Another model is the concept specialization model. In this view, and contrary to the extensional view, complex concepts are seen as having an asymmetric structure. The last concept in the compound (e.g., dog in apartment dog) is the "head" concept and the earlier concept acts by modifying it. Thus, the concepts apartment dog and dog apartment are not at all the same, although the same two sets are involved in both: one is a kind of dog, and the other is a kind of apartment. More specifically, this theory takes simple concepts to be representable as schemata (Rumelhart, 1980), which are structured lists of slots and fillers. Table 1 shows a simplified schema for dog. The slots define quite generally what properties dogs can have, and the fillers specify more exactly what their characteristics are. The concept specialization theory suggests that the modifying concept acts by filling a slot in the head concept's schema. So, in apartment dog, the concept apartment would be likely to be a HABITAT, and it would replace all the other fillers in the HABITAT slot (see Table 1). Thus, the concept dog has been specialized, in that its habitat has been described more specifically. This account is derived from a number of language understanding systems that attempt to understand such phrases (Brachman, 1979; Finin, 1980).

Cohen and Murphy (1984) proposed that, with appropriate elaboration, concept specialization could provide an adequate explanation of complex

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Simplified Schema for the Concept dog.</th>
</tr>
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<tbody>
<tr>
<td>NAME:</td>
<td>&quot;dog&quot;</td>
</tr>
<tr>
<td>BODY PARTS:</td>
<td>LEGS: 4, 3</td>
</tr>
<tr>
<td></td>
<td>HEAD: 1</td>
</tr>
<tr>
<td></td>
<td>HAIR</td>
</tr>
<tr>
<td></td>
<td>EYES: 2</td>
</tr>
<tr>
<td></td>
<td>COLOR: brown, white, black...</td>
</tr>
<tr>
<td></td>
<td>(etc.)</td>
</tr>
<tr>
<td>HABITAT:</td>
<td>home, streets</td>
</tr>
<tr>
<td>FUNCTIONS:</td>
<td>best friend, guard home</td>
</tr>
<tr>
<td>BEHAVIORS:</td>
<td>bark, bite, eat, sleep, chase cats,...</td>
</tr>
</tbody>
</table>
concept formation. (Henceforth, I take "concept specialization" to refer to the specialization process plus the elaboration.) They argued that forming complex concepts was a heavily knowledge-dependent operation. It isn't possible to form the complete concept if one knows only the two concepts involved; instead, one must have access to a very large data base—one's world knowledge—that can influence the process. This knowledge affects the process in two ways: First, outside knowledge must often be consulted in order to decide which slot is the appropriate one to specialize. For example, one had to realize that it was more likely that a dog inhabits an apartment than that it looks like an apartment or that it bites apartments, etc. As computational linguists have discovered, it is by no means easy to ensure that a program modeling this task will choose the correct slot to specialize (Finin, 1980). Yet, people easily access the relevant knowledge in order to specialize the proper slot.

The second reason for consulting outside knowledge is to elaborate or "clean up" the concept in order to make it more coherent and complete. After specializing the appropriate slot, people may go through an additional stage in which the complex concept is augmented and refined. For example, people are not limited to saying that an apartment dog is simply a dog that lives in an apartment—they can fill in a large amount of information based on their knowledge of dogs, apartments and how the two interact. An apartment dog might be smaller, quieter and better behaved than a house dog or farm dog, for instance. A farm dog, on the other hand, would be expected to be larger, less friendly, perhaps dirtier, and may even have special skills such as rounding up sheep. Thus, in creating these complex concepts, people may not be satisfied to simply specialize the schema. They may add to and refine the concepts by referring to their knowledge of the world. Evidence for this claim is provided below.

The final theory of complex concepts I will consider here was proposed by Smith and Osherson (1984; Smith, Osherson, Rips, & Keane, 1988). Hampton (1988) proposes a model with some similar characteristics—see the General Discussion. Their feature weighting approach was designed primarily to explain how adjective-noun concepts are formed.¹ In this model also, concepts are defined as schemata. Although noun concepts are typically quite complex, involving a number of different characteristics (slots and fillers), adjective concepts are thought to generally be much simpler, often specified by a single feature. For example, the adjectives red, long, round and happy could be specified by a value on a single dimension.

¹Smith et al. (1988) call their model, "A Selective Modification Model." However, since both of the theories under consideration involve modifying schemata in some way (and most models of complex concepts involve noun modification), this name is not very distinctive. With apologies to Smith et al., I have chosen a more descriptive name, which reflects the specific processes that their theory proposes.
On this view, when an adjective-noun concept is created, people simply reweight the adjective's primary feature (or features, if there are more than one) in the noun concept. (If the adjective's feature is not already on the noun, it can be added to it.) Thus, the concept *table* may have no particular color associated with it. *Red table*, however, refers to the same thing as *table*, but with an added color feature, which is given a high weight in the concept. Also, redness is more important to the concept *red apple* than it is to *apple*, even though redness is already typical of *apple*. By reweighting the relevant feature, the model captures this strong intuition. Smith and Osherson provided experimental evidence for the model's ability to explain typicality judgments involving adjective-noun concepts. (In fact, their model involves two kinds of reweighting: one within a schema slot—e.g., to pick out *red* among the colors—and one across all slots—e.g., to give the COLOR dimension greater salience. In general, I will treat these two weightings as if they were one.)

The primary difference between the feature weighting account and the concept specialization theory is that the former does not refer to any information outside the two concepts being combined. That is, the feature weighting model does not require outside knowledge to modify the noun (because the adjective itself specifies the feature to be reweighted), and it has nothing analogous to the elaboration process of the specialization account. Also, the feature weighting account depends on the assumption of each adjective having a similar effect with each noun it modifies. For example, the modification that *red* performs on *table* is the same as the modification it performs on *shirt, sky* or *apple*, since it is *red*'s features that control the process. Because the specialization model depends on a best-fit relation between the particular adjective and noun, the adjective can have different effects with different nouns (since the nouns will have different slots and will be associated with different sources of information), as discussed below.

I have only briefly outlined these three approaches to complex concepts. The extensional view has already been rejected as not providing a psychological explanation and as not accounting for non-intersective concepts. The strengths and weaknesses of the other two views are probably already apparent. The concept specialization model seems particularly strong in explaining the richness of conceptual representations. That is, by referring to the rich base of world knowledge people can use in constructing new concepts, the model can explain the many details that people can supply in their interpretations of noun phrases that they have never heard before. The same point is the main weakness of the model: The means by which people access their knowledge of the world is not completely specified. Thus, the model may never be as explicit as the others.

The feature weighting model has essentially the converse problems and strengths. It is clearly a well-specified mechanism: It refers only to the nor-
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mal features of the concept (which can be operationally derived via the methods of Rosch & Mervis, 1975, or Smith, Rips, & Shoben, 1974), and those features are processed by simple, predictable operations. Thus, it lacks the drawbacks of the elaboration process. The weakness of the model is its restricted range. Although it may be accurate for adjective-noun phrases, I will argue later that it works easily only for certain adjective-noun phrases, and not for noun-noun compounds like apartment dog. (To be fair to Smith et al., 1988, it must be pointed out that I am focusing on whether their model can be extended beyond the range of phenomena that they attempt to account for. This is largely a function of my emphasis on the comprehension of noun phrases vs. their emphasis on object typicality.)

One way to relate these two models is to think of the feature weighting model as a simpler version or subset of the specialization model. That is, the specialization model is very similar in the way it deals with simple features, but it adds another layer of conceptual operations—the elaboration based on world knowledge. In fact, in order for the specialization model to be successful, it will have to adopt some of the assumptions of the feature weighting theory, in order to explain the data of Smith and Osherson (1984) and Smith et al. (1988). The conflict between the two models boils down to the question of whether these additional operations are necessary. In order to evaluate this question, the next section presents linguistic evidence relevant to how the two views explain noun modification.3

LINGUISTIC EVIDENCE

Much of the work on complex concepts has used methods traditional in the psychology of concepts, such as typicality ratings, attribute listings, and categorization judgments. But there is also relevant work in linguistics and psycholinguistics, which analyzes the forms of noun modification in order to identify the syntactic or semantic rules involved. This work has implications for theories of comprehending complex concepts, and this section attempts to connect these two endeavors.

Adjective-noun concepts like red apple are the simplest forms of complex concepts. On the feature weighting account, the adjective contains a salient feature that directs the reweighting process. No world knowledge or complicated processing is required. The concept specialization model also finds this case the easiest one to implement, because the adjective's meaning gen-

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3 I use the term “noun modification” to refer to simple examples of modified noun phrases, namely adjective-noun and noun-noun phrases. English allows more complex noun modification, such as relative clauses and compounded prenominal modification (like the example of United States Senate Michigan bean soup cited earlier). These more complex modifications often require more syntactic analysis than the simpler examples that are the focus of this paper, and they will not be considered here (but see Hampton, 1987).
erally picks out the slot of the schema that must be modified. For example, *red apple* clearly modifies the COLOR slot of *apple*, because *red* is a color. According to this view, adjective-noun modification is merely a simple sub-species of the general concept specialization process. If these adjective-noun concepts were the only kind of complex concept, one could plausibly argue that the knowledge-dependent processes that are part of the concept specialization account are unnecessary. After all, how much world knowledge do we need in order to modify the concept *apple* with the concept *red*? (This question is partially answered in the experiments.)

Unfortunately, adjective-noun concepts like *red apple* do not exhaust the universe of adjective modification: There are other kinds of adjectives that do not fit the feature weighting analysis, in particular, nonpredicating adjectives (Bolinger, 1967; Levi, 1978). Nonpredicating adjectives are those that can be used as modifiers in a noun phrase, but that cannot appear as predicates (or, if they can appear as predicates, they do not carry the same meaning as when they appear prenominally). For example, the adjectives *musical, lunar, corporate,* and *rural* are (sometimes) nonpredicating. Compare (1) and (2), from Levi (1978):

(1) a musical clock
   a lunar rock
   a corporate lawyer
   a rural policeman

(2) *The clock is musical.
*The rock is lunar.
*The lawyer is corporate.
?The policeman is rural.

This property of appearing only prenominally (before the noun) establishes these as nonpredicating adjectives. The interesting thing about these adjectives for our purposes is that none of them can be defined by a primary feature or dimension that is then reweighted in the noun concept. For example, *corporate lawyer* refers to a lawyer who works for a corporation. However, "working for a corporation" is not the sole or primary feature of *corporate*. Compare, for example, *corporate stationery, corporate account, corporate car, corporate building,* and *corporate donor.* Although all somehow involve a corporation, each usage of *corporate* specifies a different relationship between the head noun and a corporation. That is, *corporate* does not modify the same slot in each concept.

Let's consider these examples in more detail, since the analysis may not be obvious at first. One possible interpretation of these adjectives is that they do have a common core of meaning, but that it is a vague one. Perhaps, then, *corporate X* means "X that has something to do with a corporation." This could save the feature weighting analysis by allowing us to reweight or
to add a rather general feature like "related-to-corporation" on the noun. Levi (1978, p. 84) argues strongly against such interpretations (see also H. Clark, 1983; Downing, 1977). Levi points out that people do in fact make more specific interpretations than such vague ones; for example, they understand corporate stationery to be the stationery actually used by a corporation—with its logo—not just stationery that is somehow related to corporations (which might include all stationery, after all). We may further notice that most readers would rule out many interpretations that fall under the vague meaning. For example, corporate stationery does not usually include stationery that is sent to a corporation; corporate donors does include a donor who consults a corporation. Yet, both of these examples would be admitted by the "X that is related to a corporation" interpretation. These counterexamples suggest that the vague reading does not correspond to people's normal interpretations. Also, one might question why speakers would attempt to communicate such vague propositions. Saying Bill's a corporate lawyer would be very uninformative if it only meant "a lawyer that has something to do with a corporation." In most cases such modified nouns are intended to mean something more informative, and they are understood in this way as well.

Another approach to this problem is to suggest that each nonpredicating adjective may have a well-specified subset of interpretations that speakers know. For example, corporate might include three or four such meanings, such as "X works for a corporation," "X is owned by a corporation," and "X is used by a corporation for its business." Unfortunately, it is hard to see how all such meanings could be specified in advance (H. Clark, 1983; Kay & Zimmer, 1976). It is a well known property of noun modification that it is productive, that novel modifications can be created and understood (Clark et al., 1985; Downing, 1977). For example, one could construct the (relatively) novel phrase corporate clothing to mean "clothing worn by people who work for a corporation (in the upper ranks)." It seems unlikely that corporate has a prespecified meaning relating to what corporation employees wear. The comprehensibility of such novel adjective-noun combinations poses a problem for any view that tries to specify in the lexicon how an adjective will modify all nouns. This property will arise again when noun-noun compounds are discussed.

In summary, nonpredicating adjectives pose problems for feature weighting approaches, namely, that these adjectives don't always provide the same feature to be reweighted or added. Although some aspects of the adjective seem constant across contexts, others vary widely. Why do nonpredicating adjectives in particular have this property? Levi (1978) argues that nonpredicating adjectives are not simple adjectives at all, but are derived from nouns. That is, corporate is derived from the noun corporation, and it therefore provides the same problems of interpretation as noun-noun phrases
such as corporation lawyer. However, as the examples in (1) show, these are common, perfectly normal adjectives. The feature weighting account was devised to account for "regular" adjectives that have a single dominant dimension, and it is difficult to extend it to more conceptually complex adjectives.

So, the crucial characteristic of nonpredicating adjectives that causes difficulty for the feature weighting view is probably their conceptual complexity rather than the syntactic characteristic that defines these adjectives. If nonpredicating adjectives are derived from nouns, then they are probably more complex than unidimensional, predicating adjectives. Consider the adjective French, for example. Although it is predicating (the dress is French), it is clearly related to the noun France. Like the nonpredicating adjectives considered above, French could modify a noun in many different ways, by specifying the location, place of origin, or geographical, geological, political, gastronomic, or social features of the noun. The specialization model, which assumes that choosing the slot for the modifier to fill is a knowledge dependent process, can accommodate such complex adjectives that have different effects in different contexts.

Noun-noun concepts present a challenge for any theory of complex concepts. The problem with such concepts is that the modifying noun has no single feature that dominates the rest. Accordingly, a relatively simple noun like ocean can have many different effects when used as a modifier: ocean road, ocean cruise, ocean plate, ocean view, ocean wave, ocean bird, ocean boat, ocean book, and so on. Each use of ocean does, of course, involve the ocean in some way. Yet, as with nonpredicating adjectives, knowing this is not sufficient to understand the complex concept. One does not understand ocean road merely to be a "road that has something to do with the ocean." For example, a highway connecting the Atlantic and Pacific oceans (going straight across the USA) would generally not be considered an ocean road.

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3 Quirk, Greenbaum, Leech, and Svartvik (1972, sections 13.48–13.50) and Bolinger (1967) discuss other kinds of nonpredicating adjectives. For example, mere, pure, utter and sheer can only be used prenominally (*this misundersfunding is mere) but are not derived from nouns. Instead, these authors suggest that they are derived from adjectival intensifiers (i.e., adverbs) like merely and utterly. These adjectives are not strictly relevant to this discussion, because they do not specify category terms (there is no category of utter things or mereness). They function more like discourse markers.

4 Traditional analyses have distinguished two kinds of noun-noun combinations. In compounds, like birdbath, the two nouns form a new word. In nominal phrases like hot dog man or railroad transportation, the two nouns do not form a new word, but only a subconstituent of a noun phrase (Levi, 1978). Often, the two are said to be distinguishable on the basis of stress patterns (Gleitman & Gleitman, 1970; Lees, 1960). Other authors (e.g., Downing, 1977) have found this distinction to be rather blurred. I will typically ignore this distinction, calling all noun-noun pairs "phrases," since the issues discussed seem to apply to both varieties: In one case, the listener must interpret a new word, and in the other, a new phrase.
The full interpretation of the concept involves spelling out the relation of
the two nouns more fully, for example, "a road next to the ocean," "a
cruise on the ocean," "a dinner consisting of seafood," and so on. If the
feature weighting account were roughly correct for noun-noun phrases, we
would be able to identify one or two features of ocean that get highlighted
in each case. (In one particularly interesting version, related to Hampton's
1987 work on conjunctive concepts, the defining features of the modifying
noun would always be made salient.) In fact, noun-noun phrases are quite
different from (predicating) adjective-noun phrases. In adjective modifica-
tion, the main properties of the adjective are carried over onto the noun.
For example, empty means "contentless" or "unfilled," and an empty bowl
is a bowl with nothing in it. Similarly, red refers to a certain color, and a red
bowl is a bowl with that color. This pattern is very consistent with the feature
weighting account. Noun modifiers act quite differently, however: The most
salient properties of oceans (wetness, largeness, saltiness, being composed
of water) are not usually carried over at all when ocean is used as a modifier
(e.g., ocean books are not wet, large, salty, or made of water). Thus, the
feature weighting account seems fundamentally unsuited to explaining noun-
noun concepts. As Downing (1977, p. 837) put it, "The semantic weight of
these forms is not merely the sum of the meanings of the two elements con-
catenated in surface structure; it is up to the hearer to discover the missing
link."

The concept specialization account, on the other hand, treats noun modi-
fiers the same as it does adjective modifiers. That is, comprehenders are
said to attempt to place ocean (or another noun) into the best fitting slot in
the head noun's schema. It explains which slot is chosen by its appeal to
world knowledge. People realize that birds cannot be made of water, that
they don't live in the ocean, and that they aren't part of the ocean, but that
birds can live near or frequent the ocean. Thus, ocean bird can mean "bird
that lives near the ocean" but not "bird that is part of the ocean," and so
forth. Although noun-noun concepts can have an indefinite number of mean-
ings in principle (H. Clark, 1983; Downing, 1977; Kay & Zimmer, 1976),
people are often able to use their world knowledge (coupled with discourse
context, if there is one) to agree upon a single likely interpretation. The slot-
finding process is more difficult for noun-noun than for adjective-noun
concepts, since noun concepts are more complex, with no single primary
feature, and therefore could possibly modify many slots. This requires the
comprehender to consider more alternative interpretations before arriving
at the best one. Nonetheless, adjective-noun and noun-noun concepts are
constructed through the same processes in this view. This parsimony is a
point in favor of the concept specialization view.

In fact, the use of world knowledge is probably much more extensive
than that required for picking the best-fitting slot. I have already referred to
the use of outside knowledge to elaborate or "fix up" the complex concept. One source of this knowledge is what Hampton (1988) calls extensional feedback, which reflects our knowledge of actual objects in the world (Cohen & Murphy, 1984). Thus, once an initial interpretation of apartment dog is constructed, people may recall actual dogs they have met and use these memories to modify the concept. It is through this process that they add attributes like "yappy and neurotic" to the normal dog attributes. Extensional feedback is an important source of conceptual elaboration and detail. This elaboration would be necessary in understanding attributions like, "I hate that Rover—he's a real apartment dog."

To summarize the argument so far, various kinds of modified nouns have been considered. Linguistic analyses (H. Clark, 1983; Downing, 1977; Kay & Zimmer, 1976; Levi, 1978) and new examples have been cited to show that modifying nouns is a complex process, and that a single modifier may have varying effects depending on the following noun. Two proposals about complex concepts have been discussed, the feature weighting proposal and the concept specialization proposal. The feature weighting account is simple and elegant, but, I have argued, it cannot be extended beyond a limited class of adjective-noun concepts, because it cannot handle the flexibility of other kinds of modifiers. The concept specialization account can be extended to nonpredicating adjective-noun and noun-noun concepts, but it has the drawback of referring to world knowledge in a rather unconstrained fashion.

Given the choice of these positions, one might wish to split the difference in order to get the best of both worlds—use the simpler feature weighting account for any adjective-noun pairs that are appropriate for it, and use the concept specialization method for noun-noun concepts and the leftover adjectives. This way, one might have a simple account of some of the concepts, leaving the more elaborate specialization process only for the difficult cases.

To help settle this question, two experiments were conducted to investigate the properties of predicating adjective-noun concepts. These experiments attempted to demonstrate that forming an adjective-noun concept can require the access of world knowledge that the concept specialization view includes. If true, this entails that the feature weighting view (Smith & Osherson, 1984; Smith et al., 1988) is not fully sufficient even for predicating adjective-noun concepts. (However, as remarked earlier, any complete theory of complex concepts will probably have to include this theory's assumptions as one of its parts.) The logic here is one of an existence proof: The experiments attempt to demonstrate that complex concepts have features that could not have been derived from their component parts. If so, then they must have been derived from knowledge outside of the concepts per se. It should be emphasized that these experiments merely attempt to demonstrate the existence of these counterexamples, rather than to provide a full account of how people form complex concepts. Thus, they use methods suitable for a demonstration rather than for an on-line processing study.
This first step will help in deciding whether a theory involving elaborate, knowledge-dependent processing is necessary.

EXPERIMENT 1

The Smith and Osherson (1984) feature weighting model is very clear about where the features come from in an adjective-noun concept: Most of them were already in the head concept, and one or two may have been transferred from the adjective concept. So, the concept round table contains many features from table (e.g., has legs, has a flat top, is made of wood) and one feature that is emphasized because of round (has a round shape). Forming this concept does not involve episodic memories about tables or knowledge about activities in which tables are involved. Thus, an important question about the formation of complex concepts is whether it is a closed operation, that is, whether the complex concept is constructed only from the elements of its components. As described earlier, the specialization model proposes that complex concepts are elaborated by outside knowledge, and so it claims that complex concept formation is not a closed operation.

If complex concepts derive from a closed operation, then if a feature is not found in either the adjective or the noun concept, it should not be found in the complex concept. Of course, it is not always easy to decide whether a feature is really "in" a concept or not: Some features are quite typical, whereas others appear in a small subset of the members (Rosch & Mervis, 1975). Therefore, it is necessary to state the prediction in a slightly more complicated way: If a feature is atypical of both the adjective and noun concept, then it should not be typical of the complex concept. Hampton (1987) tested a similar hypothesis for conjunctive concepts like bird that is also a pet. (This way of stating the constraint may be reminiscent of Zadeh's 1965 min rule, which has been roundly criticized—see Cohen & Murphy, 1984; Osherson & Smith, 1981; Zadeh, 1981. The min rule says that an object's typicality in the concept $XY$ is equal to the lesser of its typicality values for $X$ and $Y$. However, the min rule applies to objects and their typicality in categories. The prediction just described applies instead to features of people's concepts, and the problems observed for the min rule do not necessarily apply here.) The proponents of the feature weighting view (Smith & Osherson, 1984; Smith et al., 1988) don't attempt to model feature-category typicality judgments, so the predictions claimed for them here are based on my understanding of their model rather than being their own predictions. In general, however, it is hard to see how a feature could be highly weighted in the adjective-noun concept if it were not salient in either the adjective or noun concepts.

Tversky and Hemenway (1984) and others have noted that subjects list features of categories based on rules of cooperative conversation. That is, they list features that seem to them relevant in the context, omitting irrele-
vant features that they also know. For example, subjects might list "has wings" for the category of birds, but not for the category of barn swallow, because having wings does not differentiate barn swallows from other birds. For our purposes, this phenomenon causes a problem: inconsistency in listing a feature could arise from subjects' attempts to be cooperative rather than from the feature's absence from a concept. The experiment avoided this problem by asking subjects to rate features that were given to them. Thus, continuing the analogy, subjects didn't have to decide whether it was relevant to mention "has wings," but only whether birds or barnswallows typically have wings. As Tversky and Hemenway note, such judgments seem to avoid the problems inherent in a production task.

The first two columns of Table 2 present a list of complex concepts and potential properties of those concepts. Nine of the concepts were taken from Smith and Osherson's Experiment 1 (1984); more were added in order to generalize the study. (Three of Smith and Osherson's items were omitted because the adjectives seemed to be too domain dependent. That is, the modifiers husked, laced and sedan—which is not really an adjective—are typically used with one or two particular nouns. Since these adjectives' meaning may not be completely independent of the noun, it was questionable as to whether they formed complex concepts.) All of the adjectives used were "nondiagnostic"; that is, they were neither particularly typical nor atypical.

The properties were chosen in order to demonstrate that adjective-noun modification is not a closed operation. They were properties that seem to be true of the complex concept but much less true of the individual concepts, thereby posing counterexamples to the feature weighting account. The experiment, then, attempted to verify these counterexamples by questioning naive subjects.

Method

Subjects. Subjects were 59 Brown University undergraduates and summer students, who were paid for participating.

Materials. The items consisted of 18 adjective-noun concepts, each with a possible attribute. The items were tested in two separate groups. (This difference, which did not have any apparent impact on the results, will be ignored in the Results and Discussion sections. The second set of items was added to increase the number of total items, including a replacement of an item that contained an error in the first set.) For one set of 15 items, subjects rated each feature's typicality of either the noun, the adjective or the adjective-noun concept. There were 36 total subjects in this rating set; thus, each property-concept pair received 12 ratings. Three forms were used to present these items, the forms differing in which of the three judgments was made about an item. The order of items was randomly determined once and then
TABLE 2
Complex Concepts and Properties Used in Experiment 1

<table>
<thead>
<tr>
<th>Concept</th>
<th>Property</th>
<th>Most Typical Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smelly trucks</td>
<td>emits lots of black smoke</td>
<td>Noun</td>
</tr>
<tr>
<td>Sliced apples</td>
<td>is cooked in a pie</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Casual shirts</td>
<td>is pulled over your head</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Small couches</td>
<td>seats only 2 people</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Split canteloupes</td>
<td>on a plate</td>
<td>Noun</td>
</tr>
<tr>
<td>Uncaged canaries</td>
<td>lives in South America</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Round tables</td>
<td>used at a conference</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Standing ostriches</td>
<td>calm</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Unshelled peas</td>
<td>long</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Yellow jackets</td>
<td>worn by fishermen</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Green bicycles</td>
<td>painted green</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Convertible drills</td>
<td>can be used as a screwdriver</td>
<td>Noun</td>
</tr>
<tr>
<td>Overturned chairs</td>
<td>is on a table</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Short pants</td>
<td>exposes knees</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Ancient saws</td>
<td>rusty</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Russian novels</td>
<td>(originally) written in Russian</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Empty stores</td>
<td>lose money</td>
<td>Complex concept</td>
</tr>
<tr>
<td>Dirty bowls</td>
<td>sticky</td>
<td>Complex concept</td>
</tr>
</tbody>
</table>

This entry tells whether subjects judged the indicated property to be most typical of the adjective, noun, or complex concept.

kept constant across the forms. For the second set of four items, 23 different subjects made typicality judgments of all of the components of each complex concept. These items were embedded in a larger typicality questionnaire (from an unrelated experiment), and so there was little likelihood of interference among the related items.

Procedure. Subjects were given standard typicality-rating instructions (see Rosch, 1975). They were asked to rate how typical each feature was of its listed category and were given for examples “barks” as a typical feature of dog and “green” as atypical of cow. They were instructed to base their judgments on the category as a whole rather than a few examples. The ratings were on a 1 to 7 scale, where 1 meant “very typical” and 7 meant “not at all typical.” The scale was printed at the top of the page.

Results and Discussion
According to the analysis presented above, the feature weighting theory predicts that the typicality of a feature in the complex concept should be about the same as that of its most typical component concept. For example, the feature “is eaten” should be no more typical in red apple than it is in the more typical of apple or red. However, Table 2 shows that the feature tested was most typical of the adjective-noun concept for 15 of the 18 items—far
more than would be expected by chance ($p < .001$ by a sign test). To pick some salient examples, subjects said that green bicycles are very likely to have been painted green, whereas bicycles or green things in general are not particularly likely to have been painted green. Similarly, empty stores are more likely to lose money than stores or empty things in general. And unshelled peas (one of Smith and Osherson's examples) are more likely to be long than unshelled things or peas in general. These trends were just as strong for the items taken from Smith and Osherson (1984) as for the other items: The feature violated the typicality constraint for 8 of the 9 such items.

Of course, perhaps these violations are only trivial differences in typicality and do not really violate the assumption of noun modification as a closed operation. The mean ratings may dispel this concern: The average typicality ratings were 5.0 for the adjective concepts, 4.7 for the noun concepts, and 3.4 for the adjective-noun concepts. The features were significantly more typical of the complex concepts than they were of the noun concepts ($t(17) = 6.10, p < .001$) or the adjective concepts ($t(17) = 3.92, p < .005$). The crucial question, however, is whether, for each item, the feature was more typical of the complex concept than of both component concepts simultaneously. In fact, the typicality rating for the adjective-noun concept was .89 lower on average than the lowest of the other two scores, $t(17) = 3.60, p < .01$. This difference, then, is more than would be expected by chance. In the most extreme violation of the closed operation assumption (short pants), the feature was 3.2 rating units more typical in the adjective-noun phrase.

The statistics here are useful in eliminating the possibility that this finding is due to random variation, but they may be misleading as to the hypothesis being evaluated. I am not trying to demonstrate that features are usually more typical of adjective-noun concepts than of their component parts. Rather, the experiment is meant to show that concept elaboration creates cases in which the features of an adjective-noun concept cannot be predicted by its component concepts alone. An example may be useful here—take empty store. Most stores probably do not lose money (otherwise they would close), so lose money is only moderately typical of stores in general. Empty things in general do not lose money, since most empty things have no money to lose. However, empty stores generally do lose money. How did we draw this conclusion? First, we had to realize that empty stores means in particular that no customers are in the store (rather than merely empty of all people or of all things), already demonstrating an interaction of the adjective and noun. Then, our knowledge of economics and of how stores work allows us to infer that a store with no customers is taking in no money, yet since the store is probably expending money, it is losing money overall. The feature weighting model is at a loss here: since lose money is not a salient part of the concept empty, the adjective could not have picked out that feature to reweight. As the concept specialization approach empha-
sizes, there is an interaction between the modifier and head concept (formed through world knowledge), even in these predicating adjective-noun concepts. That is, we can’t predict the adjective’s exact effect unless we know which noun is being modified.

Medin and Shoben (1988) recently presented a demonstration similar to this one (as well as other interesting data). They asked subjects to rate the typicality of objects in simple and modified concepts. For example, they asked subjects to rate wooden spoons and metal spoons as examples of spoon, large spoon, and small spoon. They chose the adjectives so that they were apparently unrelated to the difference between the objects (e.g., the concept large does not include information about whether an object is wooden or metal). Nonetheless, they found that the typicality ranking of the objects was different in the different categories: Wooden spoons were the more typical in large spoon and metal spoons were the more typical in small spoon. They explain this reversal by subjects’ use of feature correlations and extensional feedback. As they note, this kind of result is not consistent with a pure feature weighting model.

There are two objections that one could make to the demonstration presented here. First, one could object to the nature of the features used. The features were chosen to demonstrate the interactive nature of complex concepts (which does not by itself make them inappropriate), but perhaps they do not reflect “real” or “natural” features that people use in everyday life. This objection is hard to answer, since it is unclear how to verify that any feature is used in everyday life. Most of them can be said to be easily inferable features that could be used in normal conversation or observation. For example, the knowledge about empty stores could be accessed in the following passage. “Walking along Main Street, Bruce was struck by the number of empty stores. Most of them would be closing soon; he thought.” In order to understand this passage, one must realize that empty stores lose money (the probed feature), and that this leads to their closing. But perhaps losing money is directly cued by the adjective empty. If so, then the noun could be changed and the passage would still make sense: “Walking along Main Street, Bruce was struck by the number of empty boxes. Most of them would be closing soon, he thought.” Clearly, this version is peculiar. Similarly, using the same noun but a different adjective gives a strange result: “Walking along Main Street, Bruce was struck by the number of busy stores. Most of them would be closing soon, he thought.” Although not as bizarre as the preceding example, this one has little coherence, in that Bruce’s conclusion has no support. Similar examples for each concept from this experiment are presented in the Appendix. Readers may see for themselves that most adjective-noun pairings cause the activation of the tested attribute, and that changing either the adjective or noun does not support the attribute, causing a loss of coherence or comprehensibility in the example. Thus, by
this criterion, the features appear to be "natural," in that they can support inferences.

A second objection that is similar to the first is that these features represent a very small number of the features in a complex concept, and not the most important features at that. If people were to construct their own complex concepts, such features might never come into play. Thus, although they may be true counterexamples to the feature weighting account, they are merely exceptions to the generally correct rule. The next demonstration will address both of these objections by using a less constrained task.

**EXPERIMENT 2**

Although the first experiment gave a number of counterexamples to the view of complex concepts as a closed operation (a property of the feature weighting view), it could be criticized as being somehow unnatural or including only the exceptions. The second experiment was a much more freeform investigation of how adjectives might modify nouns. As such, it is methodologically less precise than the previous experiment, but it is also less constrained by the experimenter's ability to construct counterexamples and by the typicality rating task.

The second experiment examined a second possible characteristic of complex concept formation; whether the modifying adjective has a similar effect in most contexts, the Principle of Consistent Modification. Although I argued earlier that nonpredicating adjectives and noun modifiers don't follow this principle, this has yet to be shown for simpler, predicating adjectives, though semanticists have suggested that most adjectives are very context dependent (Cruse, 1986).² In this experiment, subjects were shown 100 adjective-noun phrases and were asked to "define" them. These phrases were constructed by generating all possible combinations of 10 very common adjectives and 10 nouns. The experiment investigated whether each adjective affects the same feature in the context of each noun, or whether the interaction of adjective and noun predominates. That is, under the feature weighting account, adjectives should typically be like red: red table, red wall, red sky, red glass, and so forth, all contain the same modification—each one can be defined as an "X that is colored red." However, if these adjectives evoked different modifications with different nouns, then the feature weighting account would be shown to be inadequate. (Actually, Halff, Ortony, & Anderson, 1976, have shown that the amount of redness indicated by phrases like red fire and red light can vary substantially. That

² "It appears to be a property of predicative terms such as verbs and adjectives that their meanings are context-dependent to a much greater extent than those of nouns; their meanings are, in fact, dependent in various ways on those of closely associated nouns" (Cruse, 1986, p. 152).
is, even for apparently absolute adjectives—see Katz, 1972—one's knowledge of the noun concept may affect the interpretation. The current experiment explores more radical context dependence.)

Although it is somewhat arbitrary to use all the combinations of 10 adjectives and 10 nouns, this method removes most elements of choice on the part of the experimenter. Most previous research on complex concepts (including the previous experiment) can be criticized for possibly choosing particularly favorable noun phrases. This will not be possible here. Also, since complex concept formation is said to be a creative, productive process, any unusual combinations found in the stimuli should not pose any problems for subjects.

Method

Subjects. Subjects were three Brown University graduate students or recent graduates, none of whom was studying cognitive psychology or related fields. They were paid for participating in the experiment.

Materials. Ten adjectives and ten nouns were selected from the 35 most frequent adjectives and nouns in Francis and Kucera's (1982) word count. Originally, it had been hoped to simply use the ten most frequent in each class, but this turned out to be impossible. First of all, some of the most frequent words were very similar, coming from the same semantic field (e.g., good, great; long, small, big, larger, little; year, day). Second, not all of the nouns were category terms, or at least were vague enough to pose problems (e.g., way, thing, time). Third, many of the words marked as adjectives did not refer to enduring attributes but rather to momentary distinctions necessary to fix reference in discourse (e.g., such, own, possible, different). It seemed best to exclude these as well.

The final list of adjectives was new, good, long, social, important, white, human, political, early and open. The nouns were year, people, world, life, hand, house, problem, word, eye and city. All 100 adjective-noun combinations were created and printed on a booklet in 10 blocks of 10, such that each noun and adjective occurred once per block. (The blocks were not perceptibly divided, however.)

Procedure. Subjects read a page of written instructions that described the purpose of the research as investigating how people understand compound noun phrases. They were further told, "Your task is to write a definition of each noun phrase. Try not to be circular; that is, try not to simply repeat the noun phrase. For sore throat, don't just say 'a throat that is sore.' Try to be more informative. For example, you might say 'a throat that is swollen and painful.' It is the particular combination of noun and adjective that I'm interested in here, so you don't have to define the individual words—
just say what they mean together. For example, you wouldn’t have to define sore and throat separately; instead, say what kind of thing a sore throat is.’’

“You may think that some of these noun phrases have no meaning. Even so, write a definition for each one, using your best guess. However, for the ones that you think have no real meaning, also put a large X to the left of the noun phrase.’’ This last instruction was included to discover any anomalous adjective-noun pairs that might arise from combining all the nouns and adjectives.

Subjects defined all 100 items. They took the booklet home and performed the task at their leisure. They were asked to take frequent breaks in order to maintain their attention while defining these phrases.

Scoring Procedure. First, each subject’s list of definitions was transcribed and edited so that only the adjective definition remained. For example, one subject’s definition of good people, was “people or families that have sound ethical values.” The adjective meaning “that have sound ethical values” was recorded. All of the subject’s definitions for each adjective were collected together. Next, two raters examined these adjective meanings to judge whether a single feature was being made salient in each case. (The raters were the author and another psychologist specializing in psycholinguistics. The latter rater was blind to the particular hypothesis being tested, but the nature of the task would clearly reveal the general topic being investigated to any rater.) The raters judged the number of “different meanings” or features that each adjective took on in the 10 noun contexts. These judgments were performed separately for each subject’s definitions, so that the results reflect individual people’s concepts rather than group agreement or disagreement.

Results and Discussion
The results showed that each adjective took on many different meanings, depending on which noun it modified. Table 3 illustrates this phenomenon with two examples of a subject’s complete definitions of an adjective. Although there might be disagreement over how many “meanings” are expressed by the adjective in each case, there can be no doubt that very different features are being made salient. For example, long, an apparently simple spatial-temporal adjective, can mean not only of great length, but also “seeming to pass slowly,” “expressed in complete sentences,” and “towards the future.” In some cases, the central meaning of the adjective was simply elaborated (e.g., a long word has many letters or syllables), but in other cases, a totally new meaning was introduced (e.g., an open problem was said to have many solutions—clearly not part of the core meaning of open).

The number of different adjective “meanings” counted by the two raters were consistent with these observations. The mean number of meanings for each adjective is shown in Table 4. They range from a high of 8.3 out of 10
(for open) to a low of 4 (for important). On the average, the adjectives transferred 6.95 different meanings in the 10 noun contexts. These figures are not meant to be taken as literal estimates of how many meanings each adjective has, but rather as demonstrating that different adjective-noun combinations

| TABLE 3                                                                                       |
|                                                                                              |
| Examples of the "Meanings" of Two Adjectives from Experiment 2                                |
|                                                                                              |
| One subject's meanings for the adjective long.                                              |
| (year) seeming to pass slowly                                                                |
| (people) *tall                                                                               |
| (world) *covering a great distance                                                           |
| (life) lasting for years                                                                     |
| (hand) expressed in complete sentences and without abbreviations                            |
| (house) with large dimensions, especially in one direction                                  |
| (problem) whose solution takes a long time                                                   |
| (word) with many syllables                                                                   |
| (eye) *towards the future                                                                    |
| (city) *with large dimensions in one direction                                               |
|                                                                                              |
| One subject's meanings for the adjective open.                                              |
| (year) flexible; in which plans are made                                                      |
| (people) revealing of thoughts, opinions, feelings                                           |
| (world) *full of opportunities and choices                                                   |
| (life) having no secrets, hiding nothing                                                     |
| (hand) dealt face up                                                                         |
| (house) a period of time when people can drop by to visit                                    |
| (problem) having many solutions                                                              |
| (word) having more than one interpretation                                                   |
| (eye) alert; keenly aware                                                                    |
| (city) *lively, welcoming visitors, and transients                                           |
|                                                                                              |
| Note: The word in parentheses shows the noun that evoked that definition.                    |
| * These items were marked by the subject as having "no real meaning," but see text.           |

<p>| TABLE 4                                                                                       |
|                                                                                              |
| Number of Different Meanings For Each Adjective from Experiment 2                             |
|                                                                                              |</p>
<table>
<thead>
<tr>
<th>Adjective</th>
<th>Mean Number of Meanings</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>5</td>
<td>9</td>
<td>5.5</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>8.5</td>
<td>9</td>
<td>9</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>Long</td>
<td>8</td>
<td>6.5</td>
<td>8.5</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td>7</td>
<td>8.5</td>
<td>7.5</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>Important</td>
<td>3.5</td>
<td>2.5</td>
<td>6</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>7.5</td>
<td>8.5</td>
<td>8</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Human</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>Political</td>
<td>5</td>
<td>7.5</td>
<td>5</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>5</td>
<td>6.5</td>
<td>9.5</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.95</td>
</tr>
</tbody>
</table>
evoke different meanings or features of the adjective. It seems clear that each adjective does not take on a single primary meaning, as it would if each adjective had a consistent effect.

It is important to know whether the raters agreed in counting the number of adjective meanings being transferred: perhaps one rater consistently counted near 10 meanings whereas the other counted only 2 or 3. In fact, the correlation between the number of meanings they listed for each subject’s adjective definitions was a moderate sized .62. However, the size of this measure is limited by the small range. (For two-thirds of the pairs of meaning counts, the two judges gave counts that were identical or separated by only one.) Perhaps more important is the fact that the two raters detected nearly identical numbers of different meanings overall: the raters detected means of 6.93 and 6.97 meanings per adjective. So, they agreed very well in the total numbers of adjective features.

Interestingly, some of the noun meanings also changed with context. When preceded by different adjectives, ambiguous nouns could take on different senses. For example, hand took on the meanings: side (left or right), assistance, handwriting, assistant, card hand, or anatomical hand—all for one subject! However, not all cases of meaning change were due to true polysemy—in some cases, different aspects of the noun were emphasized (see Anderson & Ortony, 1975). For example, for one subject, word was interpreted as a word of the language, an exchange or phrase, advice or comfort, warning and a speech or lecture. Similarly, the word house was interpreted as a home, household, or building. For these cases, the adjective may help to specify some more specific meaning of the noun, rather than picking out one of two or more unrelated meanings.

We did not count the different noun meanings, but six of the ten words seemed to have such differences consistently (world, life, hand, house, word, and eye). The existence of such differences would also seem to question the sufficiency of the feature weighting account. The difference between the simple and complex concept is supposed to be based on the salience weighting of a small number of features on the noun. It is difficult to see what small set of features could turn the concept hand to mean a card hand from its primary meaning of a body part. Similarly, the change in meaning from a lexical item to advice or a speech seems hard to describe by adding a feature or two. Clearly, some kind of ambiguity resolution is occurring here, as will be discussed later. Although the concept specialization account did not predict these changes in noun meanings, they seem analogous to the use of world knowledge to find the correct slot—in this case, knowledge is being used to select the most coherent noun meaning.

The analysis so far has ignored the marks subjects made in order to indicate that a word had no “real meaning.” These judgments were highly erratic: some subjects used the X often to indicate any unusual construc-
tion, whereas others used it seldom, though not always when we expected. For example, one subject said that there was no real meaning to the phrases white house, important house, long hand, human eye, good hand, long problem, white city, and others, even though they have very clear, non-metaphorical meanings. Table 3 shows that one subject marked the expressions long people and long city even though people and cities could easily be said to be long. Yet the same subject did not mark long problem, even though problems themselves (as opposed to their descriptions or solution times) have no literal length. In retrospect, this poor performance seems quite normal for untrained subjects who are asked to perform a metalinguistic task. For example, people are notoriously variable in their judgments of sentence grammaticality (Carden, 1976; Newmeyer, 1983, chapter 2). Such a task is similar to what we posed for our subjects, who were essentially asked to make semantic anomaly judgments: It is difficult for naive subjects to distinguish the merely bizarre (e.g., purple cow) from the actually anomalous (e.g., purple hope).

In spite of these problems, we rescored subjects’ responses, eliminating any items they marked as having “no meaning.” Presumably, such items posed some kind of problem for the subject. Each subject had an average of 7.46 nouns not marked with an X, and there were now 5.34 different meanings counted per adjective, or 72%. This figure is nearly identical to the 70% found in the original analysis. So, even when the pairs marked as troublesome are eliminated, the Principle of Consistent Modification receives little support.

Empirical Conclusions
The main goal of this article is to bring to light important facts about the interpretation of modified nouns. It would be useful, then, to summarize these findings before addressing the question of how to construct a theory to account for them.

The linguistic evidence included an examination of a number of adjective-noun and noun-noun phrases to see whether they all followed relatively simple patterns of modification. The following conclusions were supported. First, modifiers in general do not have the same effect on all the nouns they modify. There may be some core of meaning that is preserved across contexts (e.g., corporate donor and corporate stationery both involve corporations), but there is also considerable variation in exactly how the modifier interacts with the head concept. Another conclusion was that the primary features of the modifier do not always carry over to the complex concept. For example, although a long table does have the properties of long, a corporate lawyer lacks most of the properties of corporations, and an apartment dog lacks most of the properties of apartments. A final conclusion was that both of these characteristics were more true for modifiers that were
themselves conceptually complex (nonpredicting adjectives and noun modifiers).

The experiments, therefore, examined simpler cases of predicating adjectives to see whether these conclusions could be generalized to the "easy" cases like *unshelled peas* and *short pants*. In one experiment, the counterexamples were cooked up with malice aforethought, but in the second experiment, subjects freely produced such counterexamples themselves. (Once again, it should be emphasized that these experiments were designed as existence proofs, to demonstrate that some complex concepts have these properties.) Both experiments suggest that adjective-noun concepts are constructed through some interactive process that involves knowledge of both concepts. Complex concepts had properties that were not properties of either component. Furthermore, the meaning of the adjective took on different senses when modifying different nouns, and the noun itself seemed to be changed by the preceding adjective. Clearly, the two concepts are not being processed independently (see also Medin & Shoben, 1988).

One objection to this sort of evidence is that it merely reflects ambiguity. For example, the reason that "loses money" is more typical of *empty stores* than of *empty* could be that *empty* is ambiguous between a number of meanings. One meaning might be dominant in the neutral case, but another could become dominant in the context of the noun *stores*, leading to different typicality rankings. For the second experiment, one could argue that the reason that *human* was found to have so many different meanings in context is that it has a number of separable senses in the lexicon. Thus, perhaps complex concepts don't follow the Principle of Consistent Modification, but the feature weighting model is still appropriate, because it applies only to the relevant word sense. So, when a subject read *human world*, she may have first selected the relevant sense of *human* ("inhabitated by people") and then followed the feature weighting process.

This alternative explanation has three problems associated with it. First, it may multiply word senses in a post hoc fashion, contrary to the law of parsimony in lexical semantics (see Cruse, 1986). Second, it assumes an ambiguity resolution device separate from the complex concept interpreter. But this is unnecessary, as part of ambiguity resolution for modified nouns would have to involve checking the words' senses for how well they fit the head noun, which is exactly the concept-formation process. That is, in order to understand *human world*, one must evaluate how well *human* fits the INHABITANTS slot on *world* versus other slots (PARTS, GEOLOGY, LOCATION, SIZE, etc.). This process is just what an ambiguity resolution device would have to do to select the appropriate meaning of *human*—try to match each sense of *human* with the slots of *world* and then choose the sense that provides the best fit. In short, if the concept specialization theory is accepted, we need not offer a separate ambiguity resolver for such phrases. Third, if our goal is to explain how people interpret modified nouns, then
ambiguity resolution will have to be part of the explanation. Although it would be easier if words like long had the same effect regardless of what they modify, natural language does not seem to work this way.

One final objection to the experiments is that they did not avoid certain well-known problematic adjectives. In particular, syncategorematic adjectives are those whose meanings depend radically on the noun they modify. The prototypical one is good—a good knife is not good in the same way that a good cook or a good table or a good book is. And, in fact, good itself was one of the stimuli used. Perhaps the results of the experiments simply conflate two classes of adjectives: those that are normal (following the feature weighting account), and those special exceptions that require knowledge of the noun in order to be interpreted.

One would be hard put to justify all the adjectives that produced these results as syncategorematic. New, long, social, political and open all produced many different meanings in different contexts, yet they do not have the same "empty" quality as good (see Katz, 1966, for an analysis). Instead, the adjectives new and long fall into the well-known class of relative adjectives (Rips & Turnbull, 1980). The decision of whether something is new depends crucially on the type of object in question: a week-old pie is hardly new, but a week-old car or house certainly is. So, even when the meaning of the adjective doesn’t change across a set of nouns, its exact interpretation (e.g., just how recent a new thing is, or the actual length of a long thing) can still vary, probably through extensional feedback.

Even if we accept the argument that the experiment has not eliminated especially troublesome adjectives, this might simply indicate that we were wrong about what constitutes a "normal" adjective. Certainly, relative adjectives form a large and very common class (Katz, 1972). More generally, Barsalou (1987) has argued that concepts are not nearly as stable as most theories have assumed. He provides evidence that the concept evoked by a word varies considerably across subjects, tasks, and contexts. Because conceptual information in memory is so richly interconnected, he suggests, all the information associated with a concept cannot (and probably should not) be retrieved every time the concept is used (see also Gerrig, 1986, for a related discussion). Instead, different information is retrieved under different conditions, producing instability in observed category structure. According to this view, context dependence is an integral part of conceptual structure rather than being something to avoid. Barsalou’s proposal is consistent with the linguistic analyses given above and with the results of Experiment 2, as well as being compatible with the concept specialization theory.

**GENERAL DISCUSSION**

In many ways, the problem of constructing complex concepts is an exemplary issue in cognitive science. One reason for this is that the problem has
required reference to work in a number of disciplines. The theories being compared come from psychology; many of the basic findings and phenomena were described by linguists; and the technique of concept specialization was suggested by artificial intelligence (Brachman, 1979; Finin, 1980). (Fodor, 1981, also ties the topic to basic issues in epistemology. However, his sense of *complex concept* is somewhat different from the one being used here. Unfortunately, space does not permit discussions of the epistemological issues.) Furthermore, this topic is also exemplary in the conflict between the two theories being compared, as will now be discussed.

Earlier in the article, the conflict between the concept weighting and feature weighting accounts was phrased this way: Since the feature transfer process could be described as a subset of the processes included in the concept specialization model, the primary question is whether the additional processes in the specialization account are necessary. I have argued that there is convincing empirical evidence favoring additional knowledge-based processes:

1. The experiments suggest that such processes are necessary even to explain adjective-noun concepts;
2. Feature weighting seems inadequate to explain combinations involving nonpredicating and other complex adjectives; and
3. World knowledge is almost certainly required for noun-noun concepts.

Although the empirical evidence seems to favor the concept specialization view, there are some drawbacks to adopting this theory. The specialization model is an example of what Abelson (1981) has called a "scruffy" theory, whereas the feature transfer model is a "neat" theory. The feature weighting model, as outlined by Smith and Osherson (1984), is a very elegant, simple model with little ambiguity or obscurity. The concept specialization model, on the other hand, is relatively unformed. It refers to people’s world knowledge in a rather unconstrained manner, saying that people may access this knowledge in order to find the best-fitting slot for the modifier and then to elaborate and specify the concept more fully. But exactly what knowledge is accessed, and how does it direct the combination process? So far, we are only beginning to answer these questions.

As Abelson (1981) points out, the neat-scruffy argument is one that can be found in many areas of cognitive science (and even far beyond, he argues). In general, neat theories are well-specified (usually formalized) theories with a few, well-defined input variables. Scruffy theories are more encompassing, allowing many sources of information and many processes to come into play. To take some recent examples, the "neat" view of language comprehension suggests that language can be largely understood based on formal rules of grammar. The "scruffy" view emphasizes listeners’ use of pragmatics and world knowledge in the domain of discourse. In theories of
reasoning, neat models that are based on logic, probability theory or formal heuristics (such as means-end analysis) may be contrasted with the scruffy use of "mental models," which are large and unwieldy packets of knowledge. Neat theories typically make very specific, accurate predictions within a narrow range of phenomena. Their scruffy counterparts typically attempt to handle a much wider range of phenomena but are less able to make exact predictions. The data presented in this paper, then, argue against the sufficiency of the neat feature weighting model by attempting to demonstrate its shortcomings even within its narrow range (adjective-noun combinations). Thus, it can be argued that the (scruffy) references to world knowledge and elaboration are necessary even within the rarified task of interpreting isolated adjective-noun phrases. However, this argument against the sufficiency of the feature weighting approach does not deny that it may be an important part of concept formation.

Recent studies by Hampton (1987) support the general conclusions drawn here. Hampton asked subjects to list features (or to rate their importance) for concepts like pets, birds, and pets that are also birds. For the six conjunctive concepts tested, subjects generated 14 features that appeared in the conjunctive concept but in neither component (cf. the present Experiment 1). Interestingly, there were also 20 features that appeared in both components but that did not appear in the conjunctive concept. Both of these cases would appear to pose problems for a feature weighting model. In other respects, however, the conjunctive concept was a predictable function of its conjuncts (consistent with the feature weighting view): There were very few cases in which an attribute that was "impossible" for a conjunct appeared in its conjunctive concept, or in which a necessary feature of a component was omitted from the conjunctive concept. However, this result may partly be a function of the explicitly conjunctive concepts Hampton used, like sports that are also games. For noun-noun phrases like apartment dog or doughnut box, the necessary features of the modifier do not always carry over into the complex concept.

Hampton concluded that whether a feature is included in a conjunctive concept is largely a function of its importance in the component concepts. But he also argued that conjunctive concepts are determined in part by coherence, the degree to which attributes can plausibly co-occur, and an analysis of feature importance ratings supported his hypothesis. Although justice cannot be done to his quantitative analysis here, Hampton's account can be seen to include a combination of formal rules and knowledge-based processing. The experiments presented here extend this analysis—with greater emphasis on the knowledge-based processing—to adjective-noun phrases.

One argument in favor of the concept specialization model is that the access of world knowledge that it promotes is not restricted to the task of
conceptual combination. Murphy and Medin (1985) argued at length that concept learning and typicality judgments are also dependent on people's theories about the world. That is, when making hypotheses about a new concept's meaning, people use their knowledge of what could be a sensible or likely concept. They wouldn't normally hypothesize that a kind of animal both lives under water and eats wheat, or that a tool has a pointy end and is used to smooth wallpaper, even when these hypotheses are empirically plausible. In fact, after directly learning some features of a concept, people may be able to infer other features from their world knowledge. Murphy and Wisniewski (in press) and Barrett and Murphy (1986) have demonstrated that adults and children (respectively) use their world knowledge to constrain their concept acquisition in this way. Researchers in children's concepts have recently begun to emphasize how learning a new concept depends on domain knowledge and the other concepts that children already know (e.g., Carey, 1982; E. Clark, 1983, 1987; Keil, in press). Also, the literature on how concepts change with expertise (Chi, Feltovich, & Glaser, 1981; Lesgold, 1984; Murphy & Wright, 1984) gives clear evidence of the interrelation of a domain's theories and concepts.

Studies of empirical semantics have also begun to take this view. Fillmore's (1982) theory of frame semantics proposes that word meanings can only be fully described in the context of a semantic frame, which combines world knowledge with a particular viewpoint. Simply knowing the "semantic features" of a word will now allow speakers to use the word properly. For example, in order to describe verbs of judging (criticize, blame, accuse, etc.), Fillmore had to refer to "a schematization of human judgment and behavior involving notions of worth, responsibility, judgment, and so on, such that one would want to say that nobody can really understand the meanings of the words in that domain who does not understand the social institutions or structures of experience which they presuppose" (Fillmore, 1982, p. 116). Thus, word meanings, like concepts, cannot be described in a vacuum. Another example related to complex concepts is the construction and interpretation of innovative words. Clark and Clark's (1979) analysis of innovative denominal verbs argues that people use their "generic theories" about objects in the world in order to understand these words.

Finally, it must be pointed out that any complete account of the comprehension of noun phrases will eventually have to come to terms with the issue of discourse context. Kay and Zimmer (1976) and H. Clark (1983) have argued that novel noun-noun concepts have an infinite number of possible interpretations, and that it is only in the context of a situated discourse that a listener can be sure of selecting the one intended meaning. Presumably, discourse context works by highlighting the relevant relation between the modifier and head noun, so that the listener knows which slot is likely to be specialized. For example, the attested phrase apple juice seat has no single
obvious interpretation out of context, but in its original utterance, it had one clear meaning. In that situation, it referred to the only seat at a table that had a glass of apple juice in front of it (Downing, 1977). Thus, to interpret noun phrases in actual speech, listeners must rely on the perceptible situation and their memory for the previous discourse (Clark & Marshall, 1981) in addition to the words' meanings and more general world knowledge. To make the point another way, the influence of discourse demonstrates that interpreting noun phrases could not be a closed operation.

This brief discussion should demonstrate that the knowledge-intensive processes proposed here are not merely post-hoc assumptions necessary to solve the particular problem of complex concepts. They are important to explaining language comprehension and concept learning and use in a variety of situations (Murphy & Medin, 1985; Rips, in press). Yet, there is still an argument against the concept specialization model: Its use of world knowledge is not spelled out to any degree. At this stage, the theory amounts to a list of ways in which world knowledge might be involved—in deciding which slot to fill and in elaboration through inference and extensional feedback.

The optimistic view of this situation is that we are still in the beginning stages of this investigation, and the answers to such questions will be forthcoming from a variety of attempts to explain knowledge representation and retrieval. Another view can be found in Jerry Fodor's book *The Modularity of Mind* (1983). Fodor argues that "central processes," which surely include most conceptual processes, are not susceptible to scientific explanation for just the reasons given above. A central process, in contrast to the more constrained *input systems*, may conceivably access any piece of knowledge that one has. For example, in learning about a new type of disease, one might form an analogy from a completely different conceptual domain, such as automobile mechanics, military strategy or sports. This property of *isotropy* leads Fodor to doubt whether central processes will ever receive an adequate explanation, which he states in "Fodor's First Law of the Nonexistence of Cognitive Science": "the more global (e.g., the more isotropic) a cognitive process is, the less anybody understands it" (p. 107).

Fodor's argument has two implications for the current discussion of complex concepts. First, it largely assumes what I have been arguing (and what the feature weighting account denies): that a simple, formal explanation will not be sufficient for complex concepts. Since complex concept formation is a good example of a central process, it will not be susceptible to explanations using simple stimulus-transformation rules, as input processes are.

This implication is separate from the second one, that we will never have an adequate explanation of complex concepts, because of their potential access to all world knowledge. Although the first may well be accurate, this does not completely justify the second. Certainly, if the psychology of con-
cepts requires considerable reference to a person’s world knowledge, it will be impossible to predict exactly what kind of complex concept that person will form. However, it does not follow that there are no generalities about or constraints on how people use this knowledge. To some degree, the goal of Artificial Intelligence is to discover and exploit those generalities (see Schank, Collins, & Hunter, 1986, for a relevant attempt). Furthermore, it is clear that speakers do construct modified noun phrases and that listeners do arrive at correct interpretations of them (Clark et al., 1985; Downing, 1977)—there must be some constraints on this process, or else such phrases would have no communicative value. Whether Fodor’s pessimism is well founded in this case cannot be decided until the hard work of attempting to create a complete theory of complex concepts has been carried out—and has succeeded or failed.

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REFERENCES


APPENDIX

Note. This appendix contains three examples for each complex concept tested in Experiment 1. As explained in the text, each one presents the modified noun phrase (e.g., *smelly truck*) in a neutral sentence. In order to be understood, the second sentence requires the inference of the property tested in the experiment. Presumably, if that property were not a normal or natural one, then the inference would not go through, and the second sentence would sound peculiar or incoherent. For comparison, two comparison phrases have been supplied: one with a changed noun and one with a changed adjective. If the inference were due solely to the adjective or noun, then the cor-
responding version should sound as normal and coherent as the original version does. In most cases, the examples sound normal for the original modified noun phrase but not for the other phrases. The few exceptions (according to my judgment) are marked with an asterisk. Note that these exceptions tend to correspond to the less successful cases shown in Table 2, in which the noun already contains the property.

*Mary walked behind a smelly truck. (cf. new truck, smelly man)
When she looked down, she found her pants covered with soot.

There were some sliced apples on the table. (cf. rotting apples, sliced roast beef)
"Who's making a pie?" Karin asked.

Bill put on a casual shirt. (cf. dress shirt, casual shoes)
Naturally, this messed up his hair again.

The living room held only a small couch. (cf. blue couch, small statue)
"Hey! There are three of us, you know," Sandy complained.

*The split cantaloupe was the only thing left in the kitchen. (cf. whole cantaloupe, split wood)
Mary picked up the plate and brought it into the dining room.

Little Billy watched the uncaged canaries. (cf. caged canaries, uncaged robins)
"Now, aren't you glad we came to Ecuador?" his mother asked.

Everyone sat around the round table. (cf. stone table, round window)
Lee looked at the table [window] and joked, "I call this meeting to order."

Arnold stared at the standing ostriches. (cf. running ostriches, standing trees)
They obviously weren't afraid of him.

Sammy gave some unshelled peas to his sister. (cf. cooked peas, unshelled walnuts)
"Don't do that! She could poke them in her eye," his mother said.

Tom looked at Suzi's yellow jacket. (cf. suede jacket, yellow socks)
"Are you a practicing to be a fisherman?" he asked.

Marvin admired the green bicycle. (cf. orange bicycle, green plant)
"Where did you get the green paint?" he asked the owner.

"This item is a convertible drill," the salesman said. (cf. ordinary drill, convertible table)
"It can also be used for driving screws."

Herb looked at the overturned chairs in the closed restaurant (cf. comfy chairs, overturned plants)
He picked one off a table to sit on.

Liz came to breakfast wearing short pants. (cf. long pants, short sleeves)
"Look at those sunburned knees," her brother teased.

The workshop was filled with ancient saws. (cf. new saw, ancient planks)
If she could get the rust off of them, they would be fine.
Sarah was uncomfortable studying Russian novels. (cf. English novels, Russian paintings)
She felt that they lost too much in translation.

Walking along Main Street, Bruce was struck by the number of empty stores.
(cf. busy stores, empty boxes)
Most of them would be closing soon, he thought.

The sink held only a dirty bowl. (cf. clean bowl, dirty boot)
That would be too sticky to use, Ellen felt.