The Role of Structural Alignment in Conceptual Combination

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Abstract

Many researchers have suggested that understanding novel noun phrases involves a process of conceptual combination in which people determine how two or more concepts fit together to form a new concept. One important way that people combine concepts is by property mapping, which involves asserting that a property of one concept is true of the other concept as in, "box that is striped" for "skunk box." An experiment investigated the hypothesis that property mapping occurs by structural alignment in which mental representations are aligned or put into correspondence. The result of this process is primarily a set of matching elements (called *commonalities*) and a set of mismatching elements *related to* the commonalities (called *alignable differences*). The experiment compared property mapping definitions to the alignable differences listed by subjects in a comparison task which is known to involved structural alignment. Consistent with the hypothesis, there was a strong correspondence between property mapping definitions and alignable differences compared to another strategy in conceptual combination not thought to involve structural alignment (slot filling).

Introduction

A popular view in cognitive science is that the interpretation of novel noun phrases is largely a process of conceptual combination (e.g., Medin & Shoben, 1988; Murphy, 1988; Smith, Osherson, Rips, & Keane, 1988; Thagard, 1984; Wisniewski & Gentner, 1991). According to this view, words are represented in the conceptual system as schemata or frames. A frame or schema is a knowledge structure or concept that represents a stereotypical situation or object (Minsky, 1975; Rumelhart, 1980). Frames consist of slots and fillers which can be viewed as dimensions of the situation or object along with their typical values. For example, a frame for "box" might include the slots "color," "shape," and "made-of" with the typical values "brown," "square," and "cardboard," respectively.

Understanding a novel phrase such as "skunk box" involves combining the concepts "skunk" and "box" in some way. According to a number of theorists, concepts are combined by slot filling (e.g., Cohen & Murphy, 1984; Murphy, 1988; Smith, Osherson, Rips, & Keane, 1988; Wisniewski, 1993). Using this strategy, a noun-noun phrase is interpreted by filling one of the slots of the head noun with the modifier noun. For example, to interpret "skunk box," one would fill a slot in the head noun "box" (e.g., a slot like "contains") with the modifier noun "skunk." So, "skunk box" might be interpreted as "a box that contains skunks." Slot filling amounts to asserting that some relation holds between the objects named by the modifier and head nouns. This view of conceptual combination was influenced by early AI models (Brachman, 1978; Finin, 1980) which also use slot filling as their primary mechanism for interpreting noun phrases.

Recent work by Wisniewski and Gentner (1991, 1993) suggests a second important way that concepts are combined to understand novel noun phrases. In this strategy, called property mapping, people assert that some property that is true of the modifier noun is also true of the head noun. For example, a possible interpretation of "skunk squirrel" is "squirrel that is striped" or "squirrel that smells bad." Here, a property that is true of skunks (i.e., that they are striped or that they smell bad) is being asserted of the head noun "squirrel." This way of combining concepts contrasts with slot filling, in that a relation is not being asserted between the objects named by the modifier and head nouns (as in "box that contains skunks"). Rather, a property of the the modifier noun is being asserted of the head noun.

Importantly, Wisniewski and Gentner (1991, 1993) hypothesized that property mapping may involve the same process used by people in making similarity judgments, called structural alignment (Markman & Gentner, in press-a, in press-b). This

paper investigates that hypothesis. First, we describe the role of structural alignment in similarity judgments. Then we present a study that examined whether structural alignment could be involved in the interpretation of novel noun phrases by property mapping.

Similarity as Structural Alignment

Recent work examining the nature of similarity suggests that similarity judgments involve structural alignment (Markman & Gentner, in press-a, in press-b). The structural alignment process is similar to the structure mapping assumed to be involved in analogy (Gentner, 1983, 1989). According to the structural alignment view, items are represented as hierarchical structures constructed from *objects*, *attributes* (i.e. predicates that describe objects), and *relations* (i.e., predicates that relate two or more arguments). The similarity between two items is determined by aligning or putting into correspondence these parts of their structures (see Falkenhainer, Forbus, & Gentner, 1989, for details of a processing model of structural alignment). The result of this alignment process is a set of matching elements (called *commonalities*), a set of mismatching elements *related to* the commonalities (called *alignable differences*) and a set of mismatching elements *unrelated* to the commonalities (called *nonalignable differences*). For example, consider the pair car/motorcycle. The fact that both have *wheels* would be a commonality of this pair. Further, the fact that cars have *four* wheels, whereas motorcycles have *two* wheels would be an alignable difference (related to the commonality of having *wheels*). In contrast, the fact that cars have *seatbelts*, whereas motorcycles have nothing corresponding to *seatbelts* would be a nonalignable difference.

Markman and Gentner (in press-b) provided evidence for this view by asking subjects to list the commonalities or differences of word pairs that varied in their similarity. Subjects listed many commonalities for similar pairs and few commonalities for dissimilar pairs. Further, subjects listed more alignable differences for pairs with many commonalities than for pairs with few commonalities, suggesting that commonalities and alignable differences are related. That is, finding the commonalities between two objects leads people to find their (alignable) differences. So, in the car/motorcycle example described above, finding the commonality *has wheels* leads to the difference *two wheels* versus *four wheels*.

On this view of similarity, the comparison process focuses subjects on matching information and mismatching information that is *connected to* the matching information. Thus, commonalities and alignable differences are conceptually related and of paramount importance in similarity judgments. Nonalignable differences are assumed to be less important, since they are rarely listed.

The core assertion of this paper is that the strategy of property mapping involves structurally aligning the modifier and head nouns. The interpretation of a noun-noun phrase is then based on an alignable difference. So, people might interpret a phrase like "car motorcycle" as "a motorcycle with four wheels" (instead of two). However, they should not interpret "car motorcycle" as "motorcycle with seatbelts," since that interpretation is based on a nonalignable difference.

An Experiment

As a test of the hypothesis that structural alignment is involved in property mapping, we will compare the results of a task that clearly involves structural alignment to property mapping in conceptual combination. The structural alignment results will be taken from the commonality and difference listing study described above (Markman & Gentner, in press-b). For comparison with these data, we asked people to interpret noun-noun phrases involving the nouns used in that study. Table 1 lists these noun pairs. As in previous studies, subjects should define these phrases by using either a property mapping or a slot filling strategy (Wisniewski & Gentner, 1993).

If property mapping involves structural alignment, then property mapping definitions for the noun-noun phrases should consist of properties corresponding to the alignable differences mentioned in the commonality and difference listing study. Futhermore, just as subjects in the commonality and listing task rarely mentioned nonalignable differences, property mapping definitions should not consist of properties corresponding to nonlignable differences In contrast, we should not see this pattern of results for slot filling definitions. As Wisniewski and Gentner (1993) suggested, slot filling does not involve structural alignment. Rather, it involves finding a relation between the two objects named by the nouns instead of aligning their representations and mapping properties over from the modifier noun to the head noun.

The study also contrasted conceptual combination with noun phrases consisting of pairs of similar nouns to those consisting of dissimilar pairs. Wisniewski and Gentner (1993) found that noun phrases with similar modifier and head nouns (e.g., "mouse squirrel") were overwhelmingly interpreted by property mapping compared to ones in wich the modifier and head nouns were dissimilar (e.g., "radish squirrel"). The notion of structural alignment can

explain this finding in at least two ways. First, it should be easier to align more similar representations, since they have more commonalities. Second, because alignable differences are related to commonalities between objects, then aligning similar nouns should lead to more alignable differences and hence more property mapping.

Method

Subjects in the conceptual combination study were 32 undergraduates from Northwestern University. They received course credit in Introductory Psychology for their participation. Subjects in the commonality and difference listing task were 44 students from the University of Illinois. Subjects in the similarity rating task were 40 undergraduates at the University of Illinois. The commonality and difference listing task and similarity rating task are described in detail by Markman and Gentner (in press-b).

Items were sixteen pairs of words (taken from Markman & Gentner, in press-b) which ranged in similarity from 1.30 to 7.75 (on a scale from 1 (low) to 9 (high)) with a mean of 3.62. These pairs were arranged to form noun-noun phrases and are shown in Table 1. A second stimulus set was created by reversing the order of the words in the first stimulus set. Four word pairs were placed on each page. Below each pair was a difficulty scale ranging from 1 (very easy to come up with a meaning) to 7 (very hard to come up with a meaning).

Subjects were given a booklet and told that they would see a number of novel noun phrases. They were asked to pretend that they had just heard each phrase in a conversation and to write down a description of its most plausible, likely meaning. Subjects were also instructed to rate how difficult it was to come up with a meaning, using the 7-point scale provided.

Scoring took place in two phases. First, each definition was scored as either property mapping, slot filling or 'other'. A definition was considered to be property mapping if the subject asserted one or more properties of one item as being true of the other item (e.g., 'a two-wheeled car' for the phrase "motorcycle car"). A definition was labelled slot filling if the subject asserted a relation between the two objects named by the nouns (e.g., 'a motorcycle that is attached to a car' for the phrase "car motorcycle"). Any other definition was counted as 'other'. The definitions were scored by both authors together in a series of sessions, and all differences in scoring were resolved by discussion.

After scoring all of the definitions, they were compared to the differences listed by subjects in the study by Markman and Gentner (in press-b). For each definition, we counted the number of times that aspects of objects mentioned in the definition were listed as alignable differences or nonalignable differences by subjects in the commonality and difference listing task. Again, this scoring was done by both authors together, and differences in scoring were resolved by discussion.

Table 1: Noun-noun phrases used in the study

Similar pairs	Dissimilar pairs
bluebird robin	bench salamander
car motorcycle	cabinet helicopter
class game	debt selfishness
daffodil oak	hang-gliding fear
desk sofa	maple toad
idea moral	overseeing table
promise moral	sparrow discussion
talking writing	striding vacation

Results

Overall, 509 definitions were examined (3 items were left blank by subjects). Of these, 158 (31.0%) were scored as property mapping, 208 (40.9%) were scored as slot filling. Of the remaining definitions, 83 (18.5%) used an alternate strategy and were labelled 'other'. The last 60 definitions (11.8%) used a slot filling or property mapping strategy, but significantly transformed the mapped property so that it was hard to compare them to the commonality and difference listings.

To examine the prediction that property mapping definitions involve structural alignment, we examined the properties and their correspdondence to those listed by subjects in the difference listing task. Consistent with this claim, 78% of the property mapping definitions included properties that were listed as alignable differences. In contrast, only 3% of the property mapping definitions were related to nonalignable differences. The remaining 18% of definitions contained properties not mentioned by any subjects in the difference listing task.

For the slot filling definitions, a radically different pattern of results was obtained. Only 2% of the slot filling interpretations involved properties that were listed as alignable differences. A further 16% involved properties that were listed as nonalignable differences. The remaining 82% of the definitions were based on properties not mentioned in the difference listing task.

To assess the relationship between rated similarity and type of definition, correlations between rated similarity of a pair and the number of property mapping and slot filling definitions for that pair were calculated. As expected, there was a positive

correlation between rated similarity and number of property mapping definitions for a pair, $r(30)=0.50$, $p<.05$. In contrast, there was a negative correlation between rated similarity and number of slot filling definitions, although the correlation did not achieve significance, $r(30)=-0.24$, $p>.10$.

Discussion

The results provide suggestive evidence that structural alignment is involved in property mapping. The results of the structural alignment process, as reflected in the alignable differences listed by subjects, were more likely to appear in property mapping definitions than in slot filling definitions. These results also replicate the findings of Wisniewski and Gentner (1993), who demonstrated that property mapping was more common for similar pairs than for dissimilar pairs.

The results of the current study only show a correlation between the output of a structural alignment process and that of property mapping. Followup work we are now doing provides a more rigorous test of the connection between structural alignment and property mapping. In one study, some subjects are being asked to rate the similarity of the nouns in a phrase and then define the phrase. Making similarity judgments should cause subjects to perform structural alignment on the nouns' representations. Having already performed a structural alignment, it should be easier to for subjects to define these phrases by property mapping, relative to a control group that does not make similarity judgments.

The findings also have implications for models of conceptual combination. Typically, these models have assumed that noun phrases are interpreted by a slot filling strategy. Our results provide evidence indicating that a second strategy, property mapping, may involve a process of structural alignment. Therefore, this work may represent an important step in developing a more complete model of conceptual combination.

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