Psychonomic Bulletin & Review
1996, 3 (2), 227–230

Structural alignment in similarity and difference judgments

ARTHUR B. MARKMAN
Columbia University, New York, New York

Similarity is a central construct in models of cognitive processing, and as such has been the focus of psychological inquiry. This work has revealed that similarity and difference judgments are not always inverses. One explanation for this effect is that similarity judgments focus on matching relations between the items, while difference judgments focus on the mismatching attributes. A second explanation is that both similarity and difference judgments involve a process of structural alignment, and that they use the output of this process differently. These views are contrasted by using the one-shot mapping technique that places attribute similarity and relational similarity in competition. The results suggest that similarity and difference judgments both involve structural alignment.

Similarity is a central aspect of many cognitive models. Theories of inference posit that a subject's confidence in a conclusion is based partly on the similarity of the conclusion to the premises (Osherson, Smith, Wilkie, Lopez, & Shafir, 1990). Models of automaticity propose that actions are performed quickly when there are similar instances in memory (Logan, 1988). Even theories of learning state that the degree of transfer between tasks is dependent on their similarity (Singley & Anderson, 1989; Thorndike & Woodworth, 1901). Because of its centrality, similarity has become a focal area of study in psychology.

One intriguing finding is that judgments of similarity and judgments of difference are not always mirror images. Tversky (1977) demonstrated that when more is known about one object than about another, people may view the first object both as more similar to *and* more different from the second object. This finding was extended by Medin, Goldstone, and Gentner (1990), who found that subjects presented with triads like the one in Figure 1 selected the same item (B) both as being more similar to *and* more different from T than A. In this case, figures T and B share the *relation* that all of the shapes in the configuration have the same shading, while A does not share that relation. On this basis, B is judged to be more similar to T than is A. Furthermore, the shading of all of the objects in B differs from that of the objects in T, while the shading of only two of the objects in A differ from that of the objects in T. Thus, B has more object *attribute* differences with T than with A. For this reason, B is also considered more different from T than is A.

Medin et al. (1990) present two possible explanations for this phenomenon. One suggestion is that these data can be explained by assuming that features encoding attributes and features encoding relations are treated separately (see also Goldstone, Medin, & Gentner, 1991). They suggest that the sets of attributes of each scene are compared and the sets of relations of each scene are compared. They further posit that greater weight is given to relations than to attributes during similarity comparisons, but that greater weight is given to attributes than to relations during difference judgments. Thus, for the triad in Figure 1, subjects find T-B most similar because it has more relational matches than T-A and most different because it has more attribute mismatches than T-A.

As a second possibility, Medin, Goldstone, and Gentner (1990) point out that the distinction between attributes and relations is compatible with the view that similarity comparisons involve structural alignment rather than simple feature matches (Gentner, 1983, 1989; Gentner & Markman, 1994; Goldstone, 1994; Markman & Gentner, 1993a, 1993b; Medin, Goldstone, & Gentner, 1993). On this view, rather than simply being collections of features, representations encode the connections between attributes, objects, and relations explicitly. Similarity comparisons involve finding corresponding and mismatching elements in structured representations. The output of this comparison process can then be used in different ways for judgments of similarity and difference (or to serve other cognitive processes that involve comparisons). On this view, both similarity and difference judgments are products of the same comparison process.

Structural alignment is derived from the process of structure mapping that has been proposed in models of analogical reasoning (Gentner, 1983, 1989; Holyoak & Thagard, 1995). Just as analogies are based on matching relations between two items (e.g., the solar system is like an atom because there is something revolving around something else in each one), it is assumed that structural alignment focuses similarity comparisons on matching

The author would like to thank Dedre Gentner, Reid Hastie, Gordon Logan, Doug Medin, Ed Wisniewski, and one anonymous reviewer, for helpful comments on an earlier draft, and Mutsumi Imai and Phil Wolff, for comments and discussions during the evolution of this project. Thanks are also extended to Scott Stevens for solid checking. Please direct all correspondence to A. B. Markman, Department of Psychology, Columbia University, 406 Schermerhorn Hall, New York, NY 10027 (e-mail: markman@psych.columbia.edu).

relations between the items being compared. This prediction was supported in a series of studies using the *one-shot mapping* paradigm (Markman & Gentner, 1993b). In these studies, pairs of scenes were created in which objects that were perceptually similar played different relational roles in each scene (i.e., the objects were cross-mapped; Gentner & Toupin, 1986). For example, in Figure 2, the robots are perceptually similar, but the robot is repairing the car in one scene and is being repaired by the man in the other scene.

In the simple one-shot mapping paradigm, the experimenter points to the cross-mapped object in one scene (e.g., the robot) and asks the subject to point to the object in the other scene that goes with that object. The neutral phrase "goes with" is used to avoid suggesting which correspondence is most appropriate. In this task, subjects frequently select the perceptually similar object in the other scene (e.g., the other robot). In the critical experimental manipulation, subjects were asked to rate the similarity of the scenes and then were asked to make the one-shot mapping. In this *similarity-first* condition, subjects were much more likely to make a relational mapping (e.g., to map the robot to the man, because both are fixing something) than they were without the similarity rating or with an artistic merit rating condition that did not involve comparison (Markman & Gentner, 1993b). This finding was taken as support for the proposal that similarity involves structural alignment.

A simple extension to this methodology can be used to distinguish between the two explanations for the observation that similarity and difference judgments are not always inverses. In particular, a *difference-first* condition can be run in the one-shot mapping task that is analogous to the similarity-first condition, except that subjects perform a difference rating on the items rather than a similarity rating.

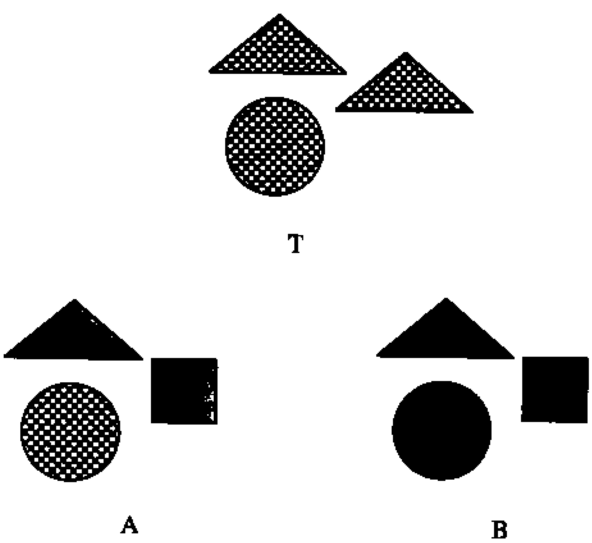

Figure 1. Sample triad like those used by Medin et al. (1990) (T = target).

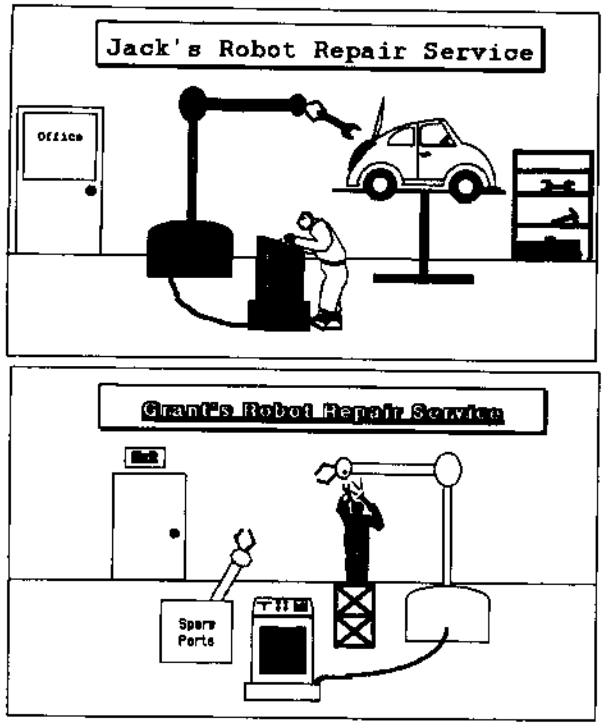

Figure 2. Sample stimulus pair used in Experiment 1 depicting a causal scene with a cross-mapped object.

The account that similarity and difference judgments involve greater attention to relations and attributes, respectively, predicts that subjects in the similarity-first condition should make many relational responses (e.g., matching the robot arm and the man), because similarity comparisons are assumed to focus on relations. Subjects in the difference-first condition should make many object responses (e.g., matching the robot arm and the robot arm), because difference judgments are assumed to focus on attributes. In contrast, structural alignment predicts that subjects in both the similarity-first and difference-first conditions should make many relational responses, because both judgments are based on the output of a relational alignment. The baseline level of relational responding can be assessed by asking a third group to do the one-shot mapping task after viewing all of the picture pairs and rating their artistic merit. This kind of judgment is not expected to involve a relational alignment of the scenes, and should not lead to many relational responses.

EXPERIMENT

Method

Subjects. Subjects in this study were 75 undergraduates at Northwestern University. They received course credit for their participation. Three subjects were dropped from the study, 2 because of experimenter error and 1 for failing to follow instructions, leaving 72 subjects (24/condition).

Materials. Eight pairs of scenes were drawn using a computer drawing package. Each pair depicted a different action (e.g., repairing, giving, towing). In addition, each pair had a single cross-mapping, operationalized as a perceptually similar object that played a different role in the relational structure of each scene. The pairs were placed one above the other on sheets of paper. Four different booklets were constructed with the set of stimuli. In the *one-shot mapping* booklet, an arrow was placed over the cross-mapped object in one scene. The instructions for this booklet asked subjects to indicate the object in the bottom scene that "goes with" the object in the top scene with the arrow pointing to it. Following Markman and Gentner (1993b), the neutral phrase "goes with" was used to avoid biasing subjects toward either the object or the relational response. Subjects could make their responses by drawing a line between the objects they placed in correspondence or by circling an object in the bottom scene.

Three rating booklets were also constructed using these pairs. In these booklets, a scale ranging from 1 (*low*) to 9 (*high*) was placed at the bottom of the page, and subjects were asked to circle their rating with a pencil. In the *similarity* booklet, subjects were asked to rate the similarity between the scenes. In the *difference* booklet, subjects were asked to rate the difference between the scenes. In the *artistry* booklet, subjects were told that each pair of pictures was drawn by the same person, though different pairs may have been drawn by different people. They were told that we were interested in human aesthetic preferences, and that they were to rate the artistic merit of the pictures, assuming the pictures were representative of the person's artistic skill. A single random order for the pages of the booklets was determined and then rotated completely to balance sequence effects.

Design. There were three levels of mapping condition (similarity first, difference first, and artistry first). This factor was run between subjects.

Procedure. Subjects in the similarity-first condition received the similarity booklet, followed by the one-shot mapping booklet. Subjects in the difference-first condition received the difference booklet, followed by the one-shot mapping booklet. Subjects in the artistry-first condition received the artistry booklet followed by the one-shot mapping booklet. The ratings tasks all took approximately 5 min to complete, and the entire task lasted for about 10 min.

Results and Discussion

As expected, subjects made a significantly higher proportion of relational mappings in both the similarity-first condition ($M = 0.69$) and the difference-first condition ($M = 0.65$) than in the artistry-first condition ($M = 0.39$) [$F(2,69) = 7.79$, $MS_e = 6.17$, $p < .005$]. Post hoc tests revealed that both the similarity-first and difference-first conditions differed significantly from the artistry-first condition ($p < .05$, Tukey's HSD). The similarity-first and difference-first conditions did not differ significantly. An item analysis supports this pattern, as more relational responses were made to all eight items in the similarity-first and difference-first conditions than in the artistry-first condition. Furthermore, more relational responses were made to items in the similarity-first condition than in the difference-first condition for only 5/8 items. Finally, the similarity and difference ratings were inversely related in this study [$r(6) = -0.96$, $p < .001$].

Both similarity and difference judgments led to a higher level of relational responding in the one-shot mapping task than was observed in the control condition. This finding suggests that both judgments involve a process of structural alignment, although the output of this process is combined differently in each type of judgment. This proposal can be made more specific on the basis of research on structural alignment, which suggests that the output of the comparison process consists of *commonalities*, differences related to the commonalities (called *alignable difference*), and differences not related to the commonalities (called *nonalignable differences* (Gentner & Markman, 1994; Markman & Gentner, 1993a, 1996). For example, in the comparison of the scenes in Figure 2, the fact that both involve something repairing something else is a commonality. The fact that the robot is doing the repairs in one scene while a man is doing the repairs in the other scene is an alignable difference. Finally, the fact that there is a box in the bottom scene but not in the top scene is a nonalignable difference.

This three-part output of comparison can explain how similarity and difference judgments on stimuli like those used by Medin et al. (1990) can fail to be inverses. For example, for the triad in Figure 1, subjects select B as both most similar and most different from the target. In similarity judgments, it is well established that commonalities get more weight than differences (Tversky, 1977). Furthermore, subjects generally find stimuli with relational commonalities to be more similar than stimuli with only attribute commonalities (Gentner, Rattermann, & Forbus, 1993; Goldstone et al., 1991; Markman & Gentner, 1993b). An examination of Figure 1 suggests that choice B shares a relation with the target that A does not, and hence B and T are considered most similar.

Difference judgments focus more on the differences between the items than do similarity judgments; in particular, previous research suggests that alignable differences are more salient than are nonalignable differences (Gentner & Markman, 1994; Markman & Gentner, 1996). One difference between choice A and the target is that the target has the relationship of "same shading," while choice A does not. Subjects probably treat this difference as a nonalignable difference (and hence give it little weight), because there is no reason to represent the absence of the "same shading" relationship in choice A.[1] Choices A and B also have attribute alignable differences with the target, although choice B has one more alignable difference than does A. This extra alignable difference leads choice B to be selected as most different from the target. Thus, the structural alignment view is able to account for why similarity and difference judgments are not always inverses by positing a single comparison process whose output is used in different ways for different judgments.

REFERENCES

GENTNER, D. (1983). Structure mapping: A theoretical framework for analogy. *Cognitive Science*, **7**, 155-170.

GENTNER, D. (1989). The mechanisms of analogical learning. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 199-241). Cambridge: Cambridge University Press.

GENTNER, D., & MARKMAN, A. B. (1994). Structural alignment in comparison: No difference without similarity. *Psychological Science*, **5**, 152-158.

GENTNER, D., RATTERMANN, M. J., & FORBUS, K. D. (1993). The roles of similarity in transfer: Separating retrievability from inferential soundness. *Cognitive Psychology*, **25**, 524-575.

GENTNER, D., & TOUPIN, C. (1986). Systematicity and surface similarity in the development of analogy. *Cognitive Science*, **10**, 277-300.

GOLDSTONE, R. L. (1994). Similarity, interactive activation and mapping. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **20**, 3-28.

Goldstone, R. L., Medin, D. L., & Gentner, D. (1991). Relational similarity and the non-independence of features in similarity judgments. *Cognitive Psychology*, **23**, 222-262.

Holyoak, K. J., & Thagard, P. (1995). *Mental leaps*. Cambridge, MA: MIT Press.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, **95**, 492-527.

Markman, A. B., & Gentner, D. (1993a). Splitting the differences: A structural alignment view of similarity. *Journal of Memory & Language*, **32**, 517-535.

Markman, A. B., & Gentner, D. (1993b). Structural alignment during similarity comparisons. *Cognitive Psychology*, **25**, 431-467.

Markman, A. B., & Gentner, D. (1996). Commonalities and differences in similarity comparisons. *Memory & Cognition*, **24**, 235-249.

Medin, D. L., Goldstone, R. L., & Gentner, D. (1990). Similarity involving attributes and relations: Judgments of similarity and differences are not inverses. *Psychological Science*, **1**, 64-69.

Medin, D. L., Goldstone, R. L., & Gentner, D. (1993). Respects for similarity. *Psychological Review*, **100**, 254-278.

Osherson, D. N., Smith, E. E., Wilkie, O., Lopez, A., & Shafir, E. (1990). Category based induction. *Psychological Review*, **97**, 185-200.

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill*. Cambridge, MA: Harvard University Press.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvements in one mental function upon the efficiency of other functions. *Psychological Review*, **8**, 247-261.

Tversky, A. (1977). Features of similarity. *Psychological Review*, **84**, 327-352.

NOTE

1. Previous work on structural alignment has generally assumed that the absence of properties (either attributes or relations) is not encoded explicitly in mental representations, since this would lead to a limitless set of properties contained in a representation. Particularly salient absent properties like the roof of a convertible car are the exception to this generalization. This point is discussed in greater detail by Markman and Gentner (1993b, 1996).

(Manuscript received July 17, 1995;
revision accepted for publication October 25, 1995.)