Title
All Differences are not Created Equal: A Structural Alignment View of Similarity

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All differences are not created equal: A structural alignment view of similarity

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Abstract[1]

An emerging view in cognitive psychology is that the determination of similarity involves a comparison of structured representations. On this view, some differences are related to the commonalities of a pair (*alignable differences*) and others are unrelated to the commonalities of a pair (*nonalignable differences*). Previous evidence suggests that pairs of similar items have more commonalities and alignable differences than do pairs of dissimilar items. Structural alignment further predicts that alignable differences should be easier to find than nonalignable differences. Taken together, these assertions lead to the counterintuitive prediction that it should be easier to find differences for similar pairs than for dissimilar pairs. This prediction is tested in two studies in which subjects are asked to list differences for as many word pairs as possible in a short period of time. In both studies, more differences are listed for similar pairs than for dissimilar pairs. Further, similar and dissimilar pairs differ in the number of alignable differences listed for them, but not in the number of nonalignable differences listed for them. These studies provide additional support for the structural alignment view of similarity.

Introduction

Similarity is a central component of cognitive processing. Psychological theories of problem solving (e.g., Ross, 1989), categorization (e.g., Smith & Medin, 1981) and skill acquisition (e.g., Singley & Anderson, 1989) all give similarity a central explanatory role. Because of its importance, similarity itself has become an object of study.

The seminal work of Tversky (1977) formalized the insight that the similarity of a pair of objects increases with the commonalities of the items and decreases with the differences. Thus, determining the similarity of a pair first requires finding the commonalities and differences of the pair. A growing body of evidence suggests that this comparison is well characterized as a *structural alignment* of relational representations (Gentner & Markman, in press; Goldstone, Medin, & Gentner, 1991; Markman & Gentner, in press-a, in press-b; Medin, Goldstone, & Gentner, in press).

Structural Alignment in Similarity

According to the structural alignment view of similarity, object representations explicitly encode connections between elements of a representation. For example, the left-hand configuration in Figure 1 could be represented by the proposition **above**(circle,square). This representation clearly marks the connection between the *relation* (**above**) and its *arguments* (circle and square). In addition to relations, which link two or more elements, there are *entities*, which correspond to the objects in a domain, and *attributes*, which describe those objects.

Pairs of structured representations can be compared via a process of structural alignment akin to structure-mapping in analogy (Gentner, 1983, 1989). Structural alignment determines *structurally consistent* mappings by satisfying the constraints of *one-to-one mapping* and *parallel connectivity*. One-to-one mapping is satisfied when each element in one representation matches to at most one element in the other representation. Parallel connectivity is satisfied if each matching predicate also has matching arguments. A third constraint is *systematicity*, which

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suggests that deep connected matches should be preferred to isolated matches. This theory has been implemented in a symbolic system by Falkenhainer, Forbus and Gentner (1989), and in a localist connectionist network by Holyoak and Thagard (1989).

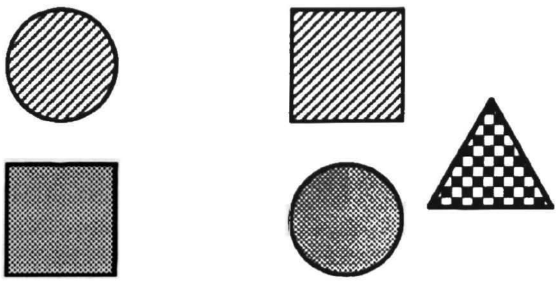

Figure 1. Sample configurations.

The output of this structural alignment process is a structurally consistent mapping. It is this mapping that is used to determine the *commonalities* and *differences* of the pair. Specifically, the matching elements are the commonalities of the pair. For example, if the items in Figure 1 are matched based on their configural positions, then the fact that there is one object **above** another in each configuration would be a commonality of the pair. On the structural alignment view, differences are split into (1) those differences connected to the matching information (called *alignable differences* (AD)) and (2) those differences not connected to the matching information (called *nonalignable differences* (NAD)). Continuing our example, the fact that the top object is a circle in the left-hand configuration and a square in the right-hand configuration is an alignable difference, because these items are only placed in correspondence due to the common relational role they play. In contrast, the triangle in the right-hand configuration is a nonalignable difference, because there is nothing that corresponds to it in the other configuration. See Markman and Gentner (1991, in press-a) for a more detailed explanation of this distinction.

On the structural alignment view, alignable and nonalignable differences have very different properties. Alignable differences are directly related to commonalities, and thus, pairs of items with many commonalities also have many alignable differences. In contrast, pairs with few commonalities have few alignable differences. Furthermore, alignable differences are conceptually related to the commonalities. Markman and Gentner (1991, in press-a) obtained evidence for these predictions by asking subjects to list commonalities and differences of word pairs.

The structural alignment view also suggests that similarity comparisons should focus on matching information. Thus, commonalities and alignable differences (which arise from the commonalities) should be favored by the comparison process. In contrast, nonalignable differences should play a less central role in similarity. Some evidence for this prediction was obtained by Markman and Gentner (1991, in press-a), who found that subjects listing the differences of word pairs generally listed more alignable differences than nonalignable differences.

One striking implication of this view is that we ought to be able to learn a lot about similarity by looking at differences. Indeed, the importance of alignable differences can be captured by the informal maxim "*No difference without similarity*" (Gentner & Markman, in press). On this view, the commonalities of a pair highlight the relevant differences of a pair. Thus, alignable differences should actually be easier to find than nonalignable differences. What follows from this claim is that it should be easier to find differences for similar pairs (which have many commonalities) than for dissimilar pairs (which have few commonalities). Put concretely, it should be easier to find a difference for the pair Hotel/Motel than for the pair Hotel/Grapefruit.

The prediction that differences are found more easily for similar pairs than for dissimilar pairs contrasts with what we might expect intuitively (or according to a simple featural model). For example, a glance at the schematic in Figure 2 suggests that it ought to be easier to find differences for dissimilar pairs than for similar pairs. We examined the ease of determining differences in two studies.

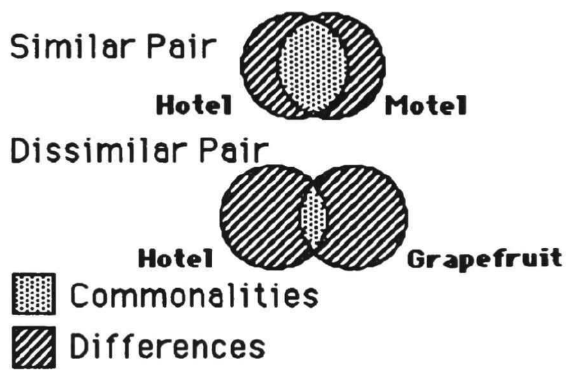

Figure 2. Sample feature sets.

Experiment 1

Both experiments used the same basic methodology. Subjects were given a sheet of paper with 40 word pairs on it and were asked to write down one difference for as many pairs as they could in five minutes. They were told that there was not enough time to list differences for every pair and they were encouraged to skip around the page and do the 'easiest' pairs first and then to do the 'hard' ones.

For the first experiment, two stimulus sets were generated from a single set of 80 words. The first set consisted of 20 pairs of words that we thought were highly similar, and 20 pairs that we thought were highly dissimilar. The second set was generated by re-pairing the high similarity pairs from the first set to form low similarity pairs and re-pairing the low similarity pairs from the first set to form high similarity pairs. A group of 40 undergraduates at Northwestern University (who did not participate in either experiment) rated the similarity of these pairs on a scale ranging from 1 (low similarity) to 9 (high similarity). Significantly higher similarity ratings were given to the high similarity pairs (mean=7.00) than to the low similarity pairs (mean=1.65) validating the intuitions that led to our pairings, $t(78)=39.60$, $p<.001$.

The structural alignment view predicts that more differences should be listed for similar pairs than for dissimilar pairs. Furthermore, since similarity focuses on matching information, more alignable differences should be listed for similar pairs than for dissimilar pairs. In contrast, the number of nonalignable differences listed for high and low similarity pairs is not expected to differ. Finally, in keeping with previous results, we would expect more alignable differences to be listed overall in this study. These predictions differ from those of a simple featural view, which would suggest that more differences should be listed for low similarity pairs than for high similarity pairs, and no systematic differences should be observed between alignable differences and nonalignable differences (since this distinction is actually illusory on a featural account).

Method

Subjects. Subjects were 32 undergraduates at Northwestern University who received course credit for their participation.

Materials. Two sets of 20 high similarity and 20 low similarity word pairs were constructed subject to the constraint that words in high similarity pairs in one set were placed in pairs of low similarity in the other set. All eighty words were nouns naming concrete objects.

The 40 pairs in a set were placed in an arbitrary order in two columns on a single sheet of paper. Spaces between pairs were provided for subjects to write a difference. Four orders were generated for each stimulus set.

Procedure. Subjects were given five minutes to write down one difference for as many different pairs as they could. As described above, subjects were told to skip around the page, doing the easiest pairs first. Subjects were run in small groups, and the experimenter timed the study with a watch.

Design. Pair Similarity (Low or High) was run within subjects. The two stimulus sets were run between subjects. Because the results did not differ for the sets, the data are collapsed across stimulus set in the analyses in this paper.

Scoring. The sheets were scored for the number of alignable differences, nonalignable differences and total number of differences listed. A difference was considered an alignable difference if the subject listed a property for both objects that suggested how they differed (e.g. Cars have 4 wheels, motorcycles have 2 wheels), or if they listed a dimension along which the items differed (e.g. number of wheels). All other differences were considered nonalignable differences (e.g. Motorcycles have kickstands). The number of alignable and nonalignable differences were then added to get the total number of differences.

Results and Discussion

As predicted by structural alignment, subjects listed significantly more differences for the high similarity pairs (mean=11.38) than for the low similarity pairs (mean=5.88), $t(31)=5.68$, $p<.001$.[2] Furthermore, this difference was due to subjects listing alignable differences for more high similarity pairs (mean=9.09) than low similarity pairs (mean=3.88), $t(31)=5.62$, $p<.001$. In contrast, subjects listed nonalignable differences for roughly the same number of high similarity (mean=2.28) and low similarity pairs (mean=2.00), $t(31)=0.70$, $p>.10$. Finally, for both high and low similarity pairs, significantly more alignable differences were listed than nonalignable differences ($t(31)=1.80$, Low similarity; $t(31)=6.35$, High similarity, $p<.05$).

These findings clearly support the predictions of structural alignment. Subjects found it easier to list differences for similar pairs than for dissimilar pairs. Further, this difference resulted primarily from the number of alignable differences listed, suggesting that the ease of comparison determines the ease with which differences are found. Finally, the finding that more alignable differences were listed than nonalignable differences suggests that comparisons focus on matching information.

An alternative explanation for these results is that subjects may have found the similar pairs to be more interesting than the dissimilar pairs. If so, the

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[2]All t-tests reported for both studies use one-tailed probabilities.

results of Experiment 1 might reflect that subjects spent more time with the similar pairs than with the dissimilar pairs. To test this possibility, we repeated the timed difference-listing methodology, but presented one group of subjects with only high similarity pairs and a second group of subjects with only low similarity pairs. According to the structural alignment view, subjects presented with high similarity pairs should list differences for more pairs than subjects presented with low similarity pairs. In contrast, according to the 'sub optimal strategy' view, subjects presented only with low similarity pairs should now list more differences than subjects presented only with high similarity pairs.

Experiment 2

Method

Subjects. Subjects in this study were 48 undergraduates from the same population as those in Experiment 1.
Materials. The same word pairs were used as in the first study, only now one group saw the 40 high similarity pairs, and the other group saw the 40 low similarity pairs.
Procedure and Scoring. The procedure and scoring were the same as Experiment 1.
Design. Pair Similarity (Low,High) was run between subjects in this study.

Results and Discussion

As predicted by the structural alignment view, subjects who saw high similarity pairs listed differences for more items (mean=18.42) than subjects who saw low similarity pairs (mean=13.63), $t(46)=2.75$, $p<.01$. As expected, high similarity subjects listed more alignable differences (mean=15.63) than low similarity subjects (mean=11.38), $t(46)=2.13$, $p<.05$, but roughly the same number of nonalignable differences (mean=2.79) as low similarity subjects (mean=2.25), $t(46)=0.47$, $p>.10$. Once again, more alignable differences were listed than nonalignable differences for both the high similarity items and the low similarity items ($t(24)=4.18$ for Low similarity; $t(24)=7.58$ for High similarity, both $p<.001$).

This study provides additional support for the predictions of structural alignment. Once again, subjects found it easier to list differences for similar pairs than for dissimilar pairs. Further, this difference is once again concentrated in the number of alignable differences listed. This finding suggests that subjects seek to align the representations and that differences are found more easily for pairs that align well than for pairs that align poorly.

The results of this study differ strikingly from the predictions of the intuitive featural model illustrated in Figure 2. Subjects presented with low similarity items (e.g. Hotel/Grapefruit) could have listed almost any property of either one of the objects as a difference, yet they did not adopt this strategy. Indeed, for both high similarity and low similarity pairs, subjects listed more alignable differences than nonalignable differences, suggesting that their comparisons focused on matching information even though the task called for them to list differences. Overall, these studies provide a powerful demonstration that structural alignment highlights the differences related to matching information.

General Discussion

These results (summarized in Table 1) add to a growing body of evidence suggesting that similarity comparisons involve structural alignment. On this view, representations of objects and situations include relational information. The structural alignment process takes pairs of structured representations and determines the maximal structurally consistent match between them (Falkenhainer, Forbus & Gentner, 1989). This match can be used to determine the commonalities, alignable differences and nonalignable differences of a pair. These elements can then be combined into an estimate of the overall similarity of the items.

Table 1. Summary of differences listed in both experiments.

Experiment 1			
Similarity	Total	AD	NAD
High	11.38	9.09	2.28
Low	5.88	3.88	2.00
Experiment 2			
Similarity	Total	AD	NAD
High	11.38	9.09	2.28
Low	5.88	3.88	2.00

We are currently extending the present studies using a response time methodology. In these studies, word pairs are presented to a computer screen, and subjects are asked to type one difference. We are measuring the time it takes subjects to begin typing. Pilot results suggest that subjects are faster to come up with an alignable difference for an item than a nonalignable difference for the same item. This finding is consistent with the results of the studies presented here.

A central issue to be explored is the generality of these findings. Further work must demonstrate that the distinction between alignable differences and nonalignable differences plays a role in cognitive processes more general than similarity comparisons. One area in which this distinction seems important is decision making. For example, in Tversky's (Tversky, 1972) elimination-by-aspects theory, a person faced with a decision between a number of alternatives first selects a dimension and eliminates alternatives with unsatisfactory values along that dimension. This process is continued until the person is left with a single choice. Here, alignable differences are used to explain people's choice behavior. Markman and Gentner (in press-a) provide a more comprehensive discussion of the potential importance of alignable differences to other cognitive processes. Further work will have to examine the way commonalities, alignable differences and nonalignable differences can be used in other cognitive processes that require comparisons as a subcomponent.

Conclusions

The studies presented here examined the claim: 'There are no differences without similarity.' In two studies subjects listed differences more readily for similar pairs than for dissimilar pairs. Furthermore, subjects differed in the number of alignable differences they listed for high and low similarity pairs, but not in the number of nonalignable differences they listed. These findings suggest that comparisons focus on both the commonalities of a pair and the differences that are connected to those commonalities. This connection between commonalities and alignable differences is useful in the calculation of similarity, and may also be important for other cognitive processes in which items are compared.

Acknowledgments

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