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Analogical Mapping During Similarity Judgments*

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Abstract

We propose that carrying out a similarity comparison of two objects or scenes requires that their components be aligned in a manner akin to analogical mapping. We present an experiment which supports this claim and then examine a computer simulation of these results which is consistent with the idea that a process of mapping and alignment occurs during similarity judgments.

Introduction

A process for calculating the similarity of two things has been assumed by nearly every model of categorization (Medin and Shaffer, 1978, Smith and Medin, 1981) and problem solving (Ross, 1984, Gick and Holyoak, 1985). A better comprehension of the processes which govern similarity would result in a deeper understanding of the mechanisms which control many other cognitive processes.

The pioneering work of Tversky (1977) established that the similarity between two items is a function of the elements which the two items have in common (common features) and the elements possessed by one item but not by the other (distinctive features). In addition to outlining the importance of common and distinctive features, Tversky and his colleagues have set out a number of ways in which the salience of common and distinctive features can be determined (Tversky, 1977, Gati and Tversky, 1984).

Although the importance of common and distinctive features cannot be overstated, Tversky's work has not addressed the problem of how the representations of the objects are compared in order to determine which elements are common and which elements are distinctive. However, some recent work has begun to address this issue (Markman, Medin and Gentner, under revision, Goldstone, Gentner and Medin, 1989). This work suggests that object representations are aligned through a process akin to the mapping processes which have been proposed for analogical reasoning (Gentner, 1983, 1989, Holyoak and Thagard, 1989 and Hall, 1989).

In this paper we first outline how analogical mapping may be applicable to similarity. We then present an experiment designed to test whether mapping is a part of similarity judgments. Finally, we will examine the results of a computer simulation of this experiment.

Similarity and Structure Mapping

We will discuss the applicability of mapping to similarity with respect to Gentner's structure-mapping theory (SMT) (Gentner, 1983, 1989) specifically, but the general points are compatible with many current theories of analogical mapping (cf. Hall, 1989 for a review). According to SMT, the comparison of two scenes requires that their relational structures be

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aligned. Thus, objects which play a common role in both scenes are likely to be placed in correspondence, while identical objects which play different roles in their respective scenes are unlikely to be placed in correspondence. In addition, Gentner's systematicity and structural consistency principles reflect subjects' tendency to preserve relational structure (e.g. causal relations, goals, or other higher order relations) even when the objects themselves are dissimilar.

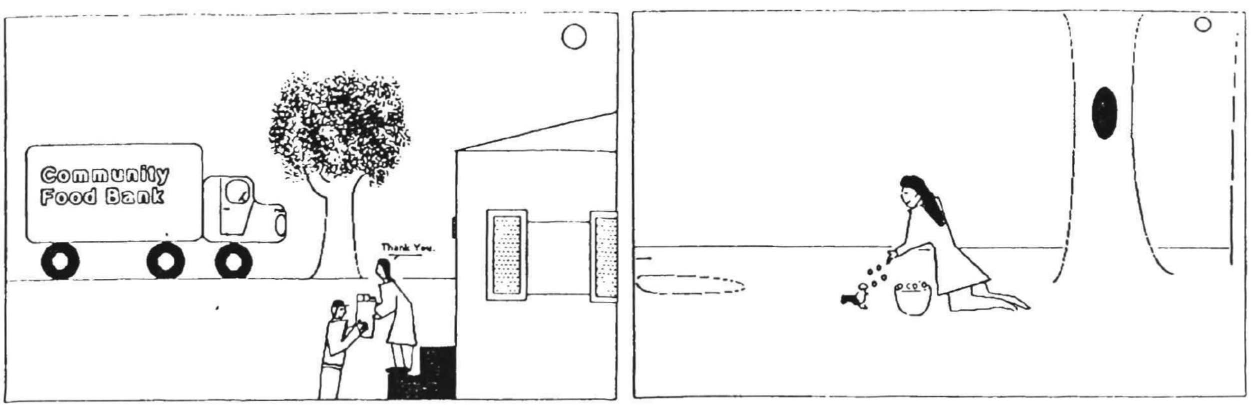
Recent research has shown that similarity judgments are sensitive to the relational structure of the stimuli (Markman, Medin and Gentner, submitted, Goldstone, Medin and Gentner, 1989, Rattermann and Gentner, 1987). For example, Rattermann and Gentner found that subjects considered pairs of stories that had similar relational structure and different characters to be more similar than pairs that had similar characters and a different relational structure. However, sensitivity to relations yields only indirect evidence that an analogical mapping process takes place during similarity judgments. The following experiment will address this question more directly.

Experiment 1

This experiment was designed to test the claim that an analogical mapping process takes place during similarity judgments. Subjects were shown a base scene and a target scene (see Figure 1). One of the objects in the base scene was highlighted and the subject was asked which objects 'goes with' that object in the target scene. We call this task one-shot mapping (1map).

In each pair of scenes one object was *cross-mapped*. Gentner and Toupin (1986) define a cross-mapping as a comparison in which there are perceptually similar objects in two scenes, but the perceptually similar objects play different roles in the relational structure of each scene. For example, in Figure 1, the two women are highly similar perceptually. However, in the top scene the woman is receiving food while in the bottom scene she is giving food away. Thus, the perceptually similar objects play different roles in their respective scenes.

Using this tension between perceptual similarity and relational similarity, we examined subjects preferences in three conditions. The first group of subjects (1map), was shown the pair of scenes. The experimenter pointed to the cross-mapped and asked the subject to point to the object in the target which 'went with' the cross-mapped object. The second group of subjects (3map) was asked to give the objects that 'went with' three of the significant objects in the target scene including the cross-mapped object. Finally, the third group of subjects (sim->1map) was asked to rate the similarity of the two scenes first, and then they were asked to point to the object that 'went with' the cross-mapped object.



(a) (b)

Figure 1. Sample stimulus in Experiment 1a.

We predicted that the subjects in the 1map condition would tend to select the nearly identical object in the other scene. Since these subjects need only map a single object, they have no reason to consider the relational structure of the two scenes and thus will be guided by object similarity.

Furthermore, we predicted that subjects in the 3map condition who were asked to map three of the objects which play a role in the relational structure would tend to map objects based on the relational structure of the scenes. These subjects must consider how to make three consistent mappings. If the two cross-mapped objects are placed in correspondence, there is no justification for placing any of the other objects in correspondence. As a result, these subjects should be more likely to preserve the relational structure of the scenes, which would provide support for all three object mappings.

The key prediction, however, centers on the the sim->1map condition, where subjects first performed a similarity judgment and then perform a single mapping. We predicted that these subjects would also be likely to map objects based on the relational structure of the scenes. If, as we believe, similarity judgments require that the relational structures of the scenes be aligned, then subjects' mappings following a similarity judgment should reflect this relational structure.

Method

Stimuli. The set of stimulus pictures portrayed causal higher order relations (*causal HOR*). These pictures presented scenes with a goal structure or causal structure. For example, in the pictures shown in Figure 1 someone is giving food to someone else. Each of these pictures had a cross-mapping as well.

Procedure. Subjects were run one at a time. They were seated at a table with an experimenter seated behind them. Subjects participated in only one experimental condition. The experimenter had no knowledge of the hypothesis being tested.

Subjects in the one-shot mapping (1map) condition were shown each of the base/target pairs in turn. The experimenter pointed to the cross-mapped object and asked the subject to point to the object in the other picture that went with that object. The subject's response was recorded and the next pair of pictures was presented. After completing the mapping task, subjects rated the similarity of each pair on a scale from 1 to 9.

Subjects in the three mappings (3map) condition were also shown each of the base/target pairs. However, in this case, the experimenter pointed (one at a time) to each of the three objects which made up the central relational structure of the scene. Subjects were asked to point to the objects which went with each of those objects. The cross-mapped object was always tested first. After completing the mapping task, these subjects were also asked to rate the similarity of all of the pairs of pictures.

Subjects in the similarity first then one-shot mapping task (sim->1map) first rated the similarity of a pair of pictures and then were shown the cross-mapped object and asked which object in the other picture went with it.

Finally, a control condition was run. It could be argued that any effects found in the sim->1map condition arise because subjects have greater exposure to the pictures in this condition before performing the one-shot mapping. In order to control for this possibility, one final group of subjects was shown the set of pictures one at a time and told to study them carefully for a later memory experiment. The subject saw each picture for five seconds, roughly the amount of time subjects see the pictures while making similarity comparisons. After examining the entire set of pictures, subjects in the control condition performed the 1-shot mapping task.

Design. There were 4 (3 mapping conditions and control) between subjects conditions in this design. Order of stimulus presentation was counterbalanced.

Subjects. Subjects were 24 undergraduates from the University of Illinois who received course credit for their participation in a single 15 minute session. Subjects were randomly assigned to one of six experimental conditions.

Results. Subjects' responses were recorded as being either object-based mappings, relation-based mappings or spurious mappings. Object-based mappings were those choices which placed the cross-mapped objects in correspondence. Relation-based mappings were those choices which preserved the relational structure of the scenes. Any other choice was considered a spurious mapping. The number of spurious mappings was less than 1% of the total number of responses and will not be considered further here. The proportion of relational responses on the cross-mapped object for each subject is shown in Figure 2.

As predicted, subjects who performed a similarity judgment prior to mapping made more relational responses than subjects who did not perform a similarity judgment prior to mapping. A one-way analysis of variance on the three experimental conditions indicates that, as predicted, there is a significant effect of mapping condition ($F(2.21)=3.76$, $p<.05$). A planned comparison indicates that significantly more relational responses were given in the sim->1map condition than in the 1map condition ($F(1,21)=7.51$, $p<.01$ one-tailed). More relational responses were given in the 3map condition than in the 1map condition, but this difference was only marginally significant ($F(1,21)=2.233$, $.05<p<.1$, one tailed). Finally, there was significantly more responding in the sim->1map condition than in the control condition ($t(14)=2.326$, $p<.05$ one tailed).

Proportion of relational responses by condition in experiment 1.

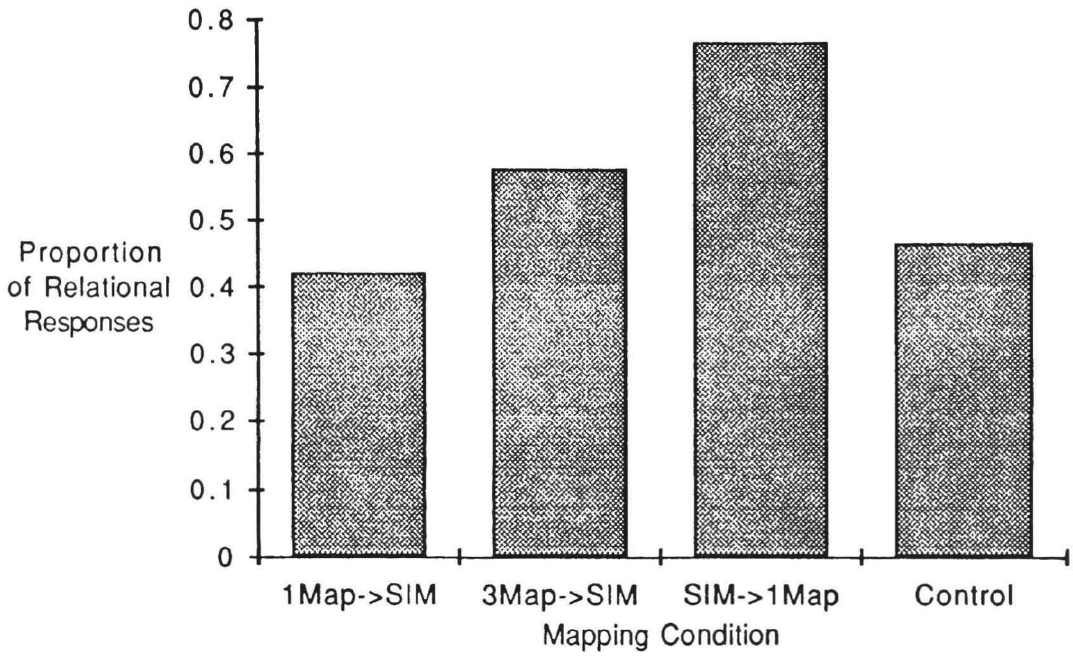


Figure 2. Graph of proportion of relational responses made by subjects in each of the mapping conditions in Experiment 1.

A correlation was done between the mean similarity judgments for each stimulus pair in each condition and the total number of relational responses given to that stimulus pair. This correlation was performed to ensure that subjects in the sim->1map condition did not simply find the stimulus pairs more similar than subjects in other conditions and thus gave more relational responses to stimuli in this condition. As expected, the correlation between similarity and number of relational responses across all mapping conditions is not significant ($r(22)=.35$, $p>.05$). Separate correlations between mean similarity and number of relational responses were also determined for each mapping condition. The correlation in the sim->1map condition were significant. ($r(6)=.64$ $p<.05$ one tailed). The correlations were not significant for any of the other conditions.

Discussion

As predicted, subjects in the sim->1map condition made more relational responses than subjects in either the 1map or control conditions. This means that, given a task that ostensibly requires object alignment, subjects prefer to preserve the relations between objects. These results support the claim that an alignment process similar to analogical mapping takes place during similarity judgments.

Furthermore, the correlation between number of relational responses given to an item and the mean similarity rating is only significant in the sim->1map condition. Since prior research indicates that similarity judgments are highly sensitive to relational structure (Markman, Medin and Gentner, under revision, Goldstone, Medin and Gentner, 1989), we interpret this correlation to indicate that, when subjects were aware of the common relational structure, they placed objects in correspondence based on their role within the relational structure. Furthermore, the non significant correlation in the 1map case indicates that, although subjects may have chosen their mapping based on the similarity between the objects, their global similarity judgments were still based on the relational similarity of the scenes.

A simulation using the Structure Mapping Engine (SME)

A computer simulation of the mapping process for the causal HOR stimulus was performed using the structure mapping engine (SME) program which was designed to implement the structure mapping theory of analogical mapping (Falkenhainer, Forbus and Gentner, 1986, 1989). The stimulus pictured in Figure 1 was encoded into a propositional representation used by SME. The representation of the scene in Figure 1a is depicted graphically in Figure 3.[1] In order to capture the cross-mapping the cross-mapped objects were given identical descriptions including a number of shared attributes, but the objects played different roles in their respective relational structures.

SME generates all possible interpretations of the match between two scenes. SME begins by proposing local matches between identical predicates in the base and target. These local matches are then connected into larger mappings provided that these matches fit into a consistent relational structure. Next, these larger matches are combined together into maximal sets with the proviso that they are structurally consistent. These maximal sets, called <u>GMAPs</u>, are then evaluated for their systematicity (see Falkenhainer, et. al. 1989 and Forbus and Gentner, 1989 for a discussion of the evaluation procedure). For these simulations, SME was configured using literal similarity rules which allow the system to map both attributes and relations. This configuration allows both object similarity and relational similarity to play a role in the generation of GMAPS.

For the causal HOR stimulus pair, the relational interpretation was clearly preferred. The GMAP with the highest evaluation score placed the woman receiving food and the squirrel receiving food in correspondence, as well as the man giving food and the woman giving food. The

[1]The representation of the causal HOR in Figure 4a is slightly simplified. All of the objects shown in the scene were included in the representation and various relations were placed between these stimuli. In order to conserve space, only two of those objects were included in the figure.

mapping preferred by SME is the same mapping preferred by subjects in the sim->1map condition where 7/8 (88%) of the subjects chose the relational interpretation.

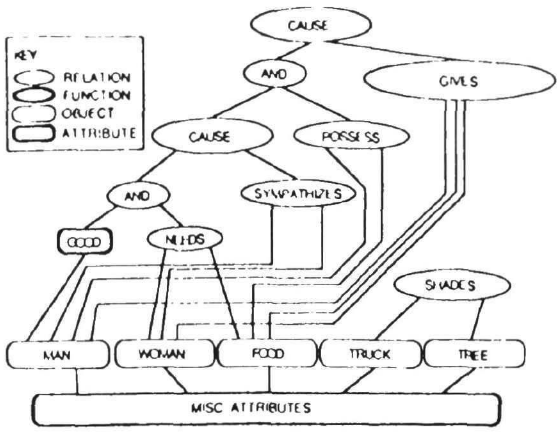


Figure 3. Propositional representation of scene in Figure 1a. This representation was used in the SME simulation of Experiment 1.

SME was also able to generate the object match interpretation of the scenes. This GMAP was given a lower evaluation score than the relational interpretation, but was given a higher evaluation score than any of the other interpretations. The simulation results are consistent with subjects' data here as well. Recall that subjects rarely (less than 1% of all trials) gave a response other than an object match or a relational match. Like human subjects, SME did not generate any highly-rated GMAPS corresponding to a spurious match.

Conclusion

The results of the experiment performed here support the claim that, in order to compute similarity, subjects must perform a relational mapping to achieve a structural alignment between the two scenes. This pattern of results is consistent with an SME simulation of the data. Thus, structure-mapping theory predicts that subjects will place objects in correspondence based on their position within the representational structure. The consistency of the predictions of structure-mapping theory with the data obtained from this similarity study demonstrate the degree to which the processes of analogical mapping and similarity judgments are alike.

References

Falkenhainer, B, Forbus, K. D., and Gentner, D. (1989). The Structure Mapping Engine: Algorithm and Examples. Artificial Intelligence. 41(1), 1-63.

Forbus, K. D. and Gentner, D. (1989). Structural Evaluation of Analogies: What Counts? in the proceedings of the 11th Annual Conference of the Cognitive Science Society. Ann Arbor, MI.

Gati, I. and Tversky, A. (1984). Weighting Common and Distinctive Features in Perceptual and Conceptual Judgments. Cognitive Psychology. 16, 341-370.

Gentner, D. (1983). Structure Mapping: A theoretical framework for analogy. Cognitive Science. 7, 155-170.

Gentner, D. and Toupin, C. (1986). Systematicity and Surface Similarity in the Development of Analogy. Cognitive Science. 10, 277-300.

Gick, M. L. and Holyoak, K. J. (1983). Schema Induction and Analogical Transfer. Cognitive Psychology. 15, 1-38.

Goldstone, R. L., Medin, D. L., and Gentner, D. (1989). Relations Relating Relations. in the proceedings of the11th Annual Conference of the Cognitive Science Society. Ann Arbor, MI.

Hall, R. P. (1989). Computational Approaches to Analogical Reasoning: A comparative analysis. Artificial Intelligence. 39, 39-120.

Holyoak, K. J. and Thagard, P. (1989). Analogical Mapping by Constraint Satisfaction. Cognitive Science. 13, 295-355.

Markman, A. B., Medin, D. L., and Gentner, D. (in revision). An analysis of the Perceptual-Verbal Distinction in Similarity Judgments.

Ross, B. (1984). Remindings and their Effects in Learning a Cognitive Skill. Cognitive Psychology. 16, 371-416.

Smith, E. and Medin, D. L. (1981). Concepts and Categories. Cambridge, MA: Harvard University Press.

Tversky, A. (1977). Features of Similarity. Psychological Review. 84(4), 327-352.