Research Article

THE EFFECTS OF ALIGNABILITY ON MEMORY

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Abstract—*According to structure-mapping theory, the process of comparison is one of alignment and mapping between representational structures. This process induces a focus on commonalities and alignable differences (i.e., those related to the commonalities). Nonalignable differences (i.e., those not related to the commonalities) are held to be neglected. The theory thus predicts increased focus on the corresponding information, whether these are commonalities or differences. In this article, we explore the implications of this claim for memory: Specifically, we test the prediction that alignable differences are more likely to be processed and stored than nonalignable differences.*

We present a study in which people made similarity comparisons between pairs of pictures and then were probed for recall. The recall probes were figures taken from the pictures and were either alignable or nonalignable differences between the pairs. The alignable differences were better memory probes than the nonalignable differences, suggesting that people were more likely to encode and store the corresponding information than the noncorresponding information.

Daily experience bombards a person with a wide array of information, only some of which is worthy of further attention. In order to make sense of the world, it is necessary to filter out some aspects of the incoming information and focus on others. How does one determine which aspects to attend to and store?

One important determinant of what will be processed and remembered is consistency with prior schemas or mental models (Bransford & Johnson, 1972, 1973; Brewer & Dupree, 1983; Rumelhart, 1980). For example, Bransford and Johnson (1973) gave subjects titled paragraphs to read. Sentences that were consistent with the schema suggested by the title of the paragraph were better remembered than were sentences that were inconsistent with that schema. Anderson and Pichert (1978) asked subjects to read a description either from the perspective of a home buyer or from the perspective of a burglar and then recall the description. Each group recalled details consistent with their perspective. Bower, Black, and Turner (1979) demonstrated effects of the restaurant script (Schank & Abelson, 1977) on subjects' recall of restaurant descriptions. Thus, there is abundant evidence that the likelihood that information in a complex situation will be remembered is related to its consistency with stored knowledge. But what happens when no clear schema applies, or (perhaps more commonly) when many schemas could apply?

For example, in the scene shown in Figure 1a, there are a number of objects participating in a number of events: There is a barn, a pigsty, fences, grass, a pig spraying mud on a tractor, a farmer shouting angrily, a helicopter causing a breeze, a hayloft blowing over, and so on. When a person is presented with such a situation, how is it determined which information will be processed deeply enough to be recalled later?

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In this article, we suggest that one determinant of the information people attend to is the comparisons they make. We first review the structure-mapping theory of comparison; then, we examine the implications of this view for memory and present an experimental test of the predictions.

STRUCTURAL ALIGNMENT AND MAPPING IN SIMILARITY COMPARISON

Comparison is a core cognitive process. It has typically been studied in the context of determining the similarity between two things (Gentner & Markman, 1995; Markman & Gentner, 1993b; Medin, Goldstone, & Gentner, 1993; Tversky, 1977), or in order to examine the impact of similarity on cognitive processes such as categorization (Goldstone, 1994a; Hampton, 1995), learning (Gentner, 1989; Kotovsky & Gentner, in press), and decision making (Medin, Goldstone, & Markman, 1995). However, comparison is equally important in determining which differences people find psychologically salient. The comparison of two scenes tells you what information to pay attention to: the aligned structure and its associated alignable differences. By the *aligned structure,* we mean the system of matching predicates and matching objects; objects can be placed in correspondence either on the basis of having shared attributes or by virtue of playing similar roles in the common relational structure. By *alignable differences,* we mean nonidentical items that have been placed in correspondence (Gentner & Markman, 1994; Markman & Gentner, 1993a, 1996). Alignable differences contrast with *nonalignable differences,* which are differences that are not in correspondence: that is, elements in one scenario that have no correspondence in the other. For example, the pig in Figure 1a and the baby in Figure 1b are an alignable difference: They can be placed in correspondence because both are making a mess and are the object of another individual's anger. In contrast, the helicopter in Figure 1a has no correspondence in Figure 1b, and hence it is a nonalignable difference.

These distinctions emerge within the framework of structure-mapping theory. Structure mapping casts similarity as a process of alignment and mapping of structured representations (Falkenhainer, Forbus, & Gentner, 1989; Gentner, 1983, 1989; Gentner & Markman, 1995, 1997; Gentner & Toupin, 1986; see also Holyoak & Thagard, 1989; Keane, Ledgeway, & Duff, 1994). On this account, similarity is processed much as analogy is (Gentner & Markman, 1995, 1997; Markman & Gentner, 1993a, 1993b; Medin et al., 1993). This approach presupposes structured mental representations that contain explicit relations between their elements: for example, in Figure 1a, CAUSE [MESS (pig, tractor), ANGRY (man, pig)]. To compare representations of this type, one carries out a process of *structural alignment* to find the maximal structurally consistent match. A match is structurally consistent when it observes both *parallel connectivity* and *one-to-one mapping.* Parallel connectivity states that the arguments to corresponding representational elements must also be placed in correspondence. For example, the pig in Figure 1a corresponds to the baby in Figure 1b, because both are making a mess. Likewise, the

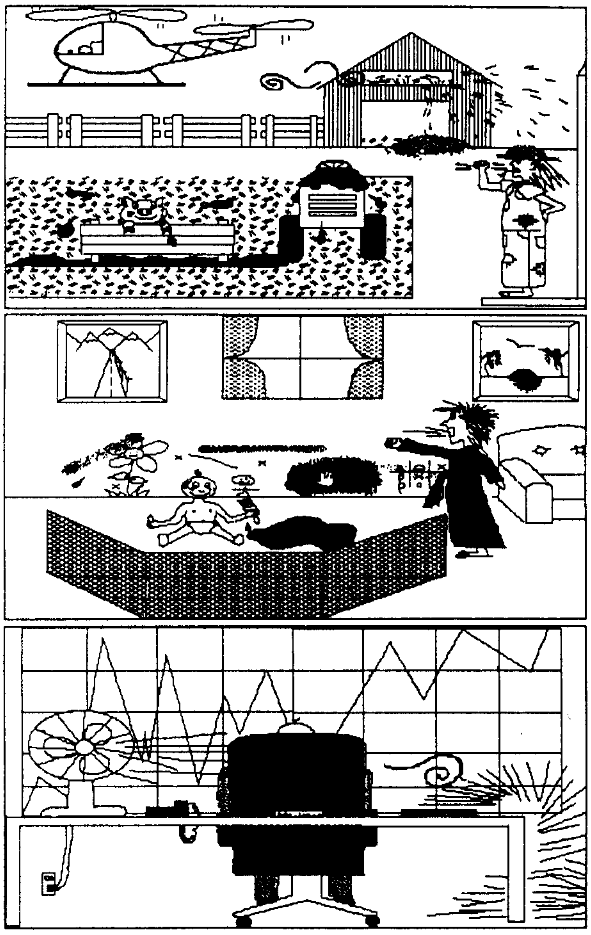

Fig. 1. Sample triad of stimuli used in the experiment. The base picture (a) could be compared with one of two other pictures (b or c). Each comparison changes which objects are alignable differences and which are nonalignable differences.

tractor in Figure 1a corresponds to the wall in Figure 1b, because both are the receivers of this mess making. One-to-one mapping requires that each element in one representation match with at most one element in the other. For example, if the pig in Figure 1a is placed in correspondence with the baby in Figure 1b, he cannot also be placed in correspondence with the mother.[1]

The distinction between alignable and nonalignable differences is a result of this comparison process. Alignable differences arise when nonidentical elements are placed in correspondence (by virtue of playing the same role in a matching relational structure). In contrast, nonalignable differences are those that either are not related to the commonalities or are related in different ways. Nonalignable differences may be different elements that occupy different roles or that lack assignable roles (because they are not connected to the common structure); or (in a frequent operationalization) they may be elements in one scenario that have no correspondence in the other. Alignable differences are connected to the common system; therefore, whether a difference is considered to be alignable or nonalignable depends on which two scenarios are aligned and on how they are aligned. Thus, what is considered to be an alignable or a nonalignable difference will vary across comparisons. In the comparison of Figures 1a and 1b, the pig in Figure 1a and the baby in Figure 1b are an alignable difference, whereas the helicopter in Figure 1a is a nonalignable difference. In contrast, Figures 1a and 1c share a different set of relations. In this case, the pig has no correspondence at all in Figure 1c, and hence is a nonalignable difference. The helicopter in Figure 1a and the fan in Figure 1c are placed in correspondence because they are both blowing something over, and so they form an alignable difference.

A central assumption of the structural alignment approach is that comparisons focus attention on the common system. This assumption predicts both that commonalities should be more focal than differences (Markman & Gentner, 1993a; Tversky, 1977) and that alignable differences should be more focal than nonalignable differences (by virtue of their connection to the common system). To test this second claim, we (Gentner & Markman, 1994) gave subjects word pairs and asked them to list one difference each for as many pairs as possible under time pressure. Subjects produced many more alignable differences than nonalignable differences, suggesting that the comparison process made the alignable differences salient. We (Markman & Gentner, 1996) have also tested the prediction that alignable differences should have stronger effects on the perception of overall similarity than nonalignable differences. Using picture pairs, we found that a change in an item that played the role of an alignable difference in a comparison had a greater impact on rated similarity than did the same change when the item played the role of a nonalignable difference.

Thus, there is evidence that comparison of two items draws attention to the commonalities and the alignable differences of the pair. Returning to the issue of memory storage, we now draw a further implication. The structural alignment view predicts that when comparisons are available during encoding, the greater degree of attention paid to commonalities and alignable differences during the comparison process should manifest itself as greater memorability for these features of the pair than for nonalignable differences.

We tested this prediction in a straightforward experiment. Participants were asked to rate the similarity of 10 pairs of pictures. After a 30-min delay, participants were shown an item taken from one of the pictures. The item was either an alignable difference (e.g., the pig from Fig. 1a given the pair 1a and 1b) or a nonalignable difference (e.g., the helicopter from Fig. 1a given the pair 1a and 1b). The participant was then asked to remember as much as possible about the scene from which the cue came. We predicted that if the cue was an alignable difference of the scenes, subjects would be able to remember more about the scene than if the cue was a nonalignable difference. However, if comparisons do not focus on commonalities and their associated alignable differences, then there would not be a systematic advantage for alignable-difference cues over nonalignable-difference cues.

EXPERIMENT

Method

Participants

Participants in this study were 36 members of the Columbia University community. They were paid $8.00 for their participation.

1. More detailed descriptions of this process and of a computational model that can implement it can be found in Falkenhainer et al. (1989) and Markman and Gentner (1993b). Other computational models with the same general characteristics have also been developed (Goldstone, 1994b; Holyoak & Thagard, 1989; Keane et al., 1994).

Materials

Ten sets of picture triads like the one in Figure 1 were drawn. The general structure of these triads was that the base picture had two distinct relational scenes within it. Each comparison figure matched one of these relational scenes. For example, Figure 1a is a base in which there are both anger and blowing relations. Figure 1b matches the base on the anger relation, and Figure 1c matches the base on the blowing relation. One object from each relational structure in the base scene was used as a recall cue. For example, as shown in Figure 2, the pig and the helicopter from Figure 1a were used as recall cues.

For the similarity-rating booklet, pairs consisting of a base and one comparison figure were placed on sheets of paper. Beneath each pair was a similarity scale ranging from 1 (*highly dissimilar*) to 9 (*highly similar*). Each booklet contained one pair from each triad. For the cued-recall booklet, one recall cue appeared at the top of each page. Below the recall cue was a set of lines on which participants could write what they recalled about the scene the cue came from. Each booklet contained one recall cue from each base scene. The cued-recall booklets were set up so that half of the cues were alignable differences of the picture pairs in one of the similarity booklets and half were nonalignable differences. For both tasks, a different random order of pages was constructed for each booklet.

This design yielded two similarity booklets and two cued-recall booklets. Each subject was given one of the similarity booklets and one of the cued-recall booklets. Between subjects, all possible pairings of similarity booklets and cued-recall booklets were run.

Procedure

At the start of the experimental session, participants were given a similarity-rating booklet. They were asked to look at the pairs of pictures and to rate their similarity on the 9-point scale provided. They were asked to give the pair a low rating if the two scenes were not very similar, and to give it a high rating if the scenes were quite similar. Participants took approximately 5 min to complete the similarity-rating task. After completing their ratings, participants took part in an unrelated study for approximately 30 min. After completing this task (and in no case before 30 min had elapsed since the completion of the similarity-rating task), participants were given the cued-recall booklet. They were told that they would see objects that had appeared in pictures from the similarity-rating task performed earlier in the session. Participants were asked to write down as much as they could about the picture in which each object had appeared. The cued-recall portion of the study took approximately 15 min to complete.

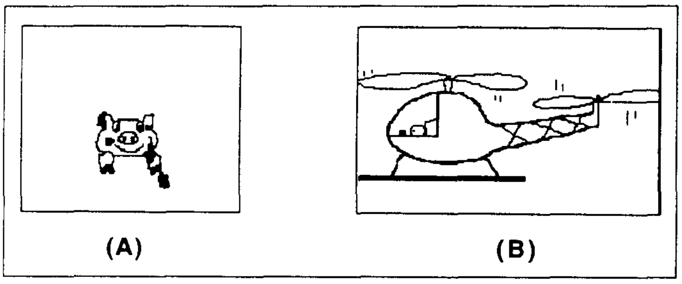

Fig. 2. Two recall cues used in the experiment. Depending on which picture the base is compared with, the cue can be either an alignable difference or a nonalignable difference.

Design

The main independent variable in this study is cue type (alignable vs. nonalignable). This variable was run within subjects, but between items. The primary dependent variable is the amount of information recalled.

Results

The data were scored by two raters, neither of whom knew the hypothesis under study. Each rater scored the entire data set, and the two raters agreed on 95% of their scorings. Differences were resolved via discussion. In the scoring, each new proposition about a picture was counted as a piece of information. In general, this information consisted of objects that appeared in the pictures and relations between the objects. At times, the recall protocols also contained descriptive information (e.g., "the dirty pig"). Each new piece of information (including descriptive information) was counted as a piece of information recalled.

The data are summarized by item in Table 1. As expected, more information was recalled on average for each cue when the cue was an alignable difference of the pair ($m = 2.35$) than when it was a nonalignable difference of the pair ($m = 1.32$). There are two ways to assess the statistical reliability of this difference by item. One is to compare the amount of information recalled when a subject saw a particular base-comparison figure combination (i.e., Pair A or Pair B) when the cue was an alignable difference or a nonalignable difference. In this case, the cues are different, but the original pair of scenes seen by the subjects is the same. Done this way, a paired t test reveals that the difference between alignable and nonalignable cues is statistically significant, $t(19) = 3.79$, $SD = 1.22$, $p < .005$. A second way to assess reliability is to compare the amount recalled for the same cue following the pair for which it was an alignable difference and following the pair for which it was a nonalignable difference. In this case, the cue is the same, but the original pair of scenes differs. Again, the difference between alignable and nonalignable cues is significant, $t(19) = 4.17$, $SD = 1.11$, $p < .005$. Overall, participants remembered at least one piece of information about a picture in memory on a higher proportion of trials when the cue was an alignable difference ($m = 0.55$) than when the cue was a nonalignable difference ($m = 0.37$), $t(9) = 5.04$, $SD = 0.11$, $p < .005$.[2]

In contrast to the data for correct recall, on average more information was recalled incorrectly given a nonalignable cue ($m = 0.64$) than given an alignable cue ($m = 0.40$). Information incorrectly recalled came from pictures other than the one containing the cue. As for the data on correct recall, these means can be analyzed holding the pair seen or the cue constant. With the pair held constant, the difference in incorrect recall is statistically significant, $t(19) = 2.09$, $SD = 0.52$, $p = .05$. Likewise, with the cue held constant, the difference in incorrect recall is statistically significant, $t(19) = 2.13$, $SD = 0.50$, $p < .05$. Thus, not only were subjects able to recall more information about the scenes correctly given an alignable cue than given a nonalignable cue, they were also less likely to recall information incorrectly given an alignable cue than given a nonalignable cue. However,

2. For this analysis, the proportion of items for which something was remembered was compared for the alignable and nonalignable cues. Because only 36 subjects were run in this study, there were not enough data to meaningfully separate the proportions by the pair and cue.

Table 1. *Amount of information recalled in the cued-recall task*

	Alignable cue		Nonalignable cue	
Picture triad	Pair A	Pair B	Pair A	Pair B
Army	2.78	1.67	0.56	2.00
Bedroom	3.33	2.11	1.00	1.78
Parade	2.56	0.44	0.44	0.00
Park, picnic	2.44	3.00	0.22	1.44
Farmer	4.67	2.89	1.00	2.44
Painter	1.22	1.78	1.67	0.00
Bicyclist	1.44	0.89	0.56	2.00
Fisherman	3.11	2.44	1.56	3.11
Baseball	3.67	1.22	2.33	1.33
Camping	3.44	1.89	1.89	1.00
Mean	2.35		1.32	

for both cues, the amount of information recalled incorrectly was small.

Finally, no systematic relationship between the rated similarity of the pair and recall was observed. The rated similarity was no higher for pairs for which at least one piece of information was recalled (m = 4.84) than for pairs for which nothing was recalled (m = 4.86).

DISCUSSION

As predicted, people were more likely to recall pictures when probed with an alignable difference than when probed with a nonalignable difference. Further, subjects were less likely to recall information incorrectly given an alignable probe than given a nonalignable one. These results are consistent with prior findings that the comparison process creates a focus on matching systems of knowledge. The new aspect of these findings is the extension to memory: It appears that the focus induced by the comparison process improves memory for the common system of information and for differences connected to it. Because the scenes were designed so that both the alignable and the nonalignable cues belonged to rich relational systems in the base scene, the superiority of the alignable information reflects the importance of shared coherent knowledge.

This finding suggests one way in which the cognitive system deals with rich environments. By focusing on commonalities and differences between the current scene and other comparable scenes, the cognitive system can direct its processing efficiently toward information most likely to be relevant (Gentner & Markman, 1994; Markman & Gentner, 1993a, 1996). Further, alignable-difference cues selectively increased the rate of correct recall (and not the rate of incorrect recall), suggesting that the effect is not merely some sort of bias but rather the effect of a better articulated representation of the common structure. We conjecture that this focus on common systems may promote expertise in two ways. First, it may lead a learner to form more detailed relational representations of the common systems (Gick & Holyoak, 1983). Second, it may lead to increased uniformity of systems that are common across domain exemplars and thus contribute to the ability of experts to retrieve prior cases that share relational structure with the current case (Forbus, Gentner, & Law, 1995).

Is this focus on alignable differences limited to cases of explicit comparisons? We think not. Previous research on other cognitive processes that involve comparisons has also revealed a focus on matching structure. In one study of judgment, Slovic and MacPhillamy (1974) asked people to decide which of a pair of students would have a higher grade-point average. Both students were described by pairs of test scores. One of the tests was taken by both students (i.e., it was an alignable difference), and the other was unique (i.e., nonalignable). People gave more weight to the common test than to the unique test in their judgments. In a related study (Markman & Medin, 1995), people made choices between pairs of video games. Some of the properties of the games were alignable differences (e.g., one game had multiple levels, and another game had many different scenarios to be mastered). Other properties were nonalignable differences (e.g., one game had a practice session, and the other did not). People were asked to say which game would sell better and to justify their decision. The justifications were much more likely to refer to alignable differences than to nonalignable differences. In a study of category acquisition (Wisniewski & Markman, 1997), people learned categories in which some features were values along a common dimension (i.e., they were alignable) and other features were values along unique dimensions (i.e., they were nonalignable). Following a brief delay, the subjects were better able to recall alignable features in a free-recall test than to recall nonalignable features, demonstrating another advantage for alignable differences over nonalignable differences in memory. In a related study (Zhang & Markman, 1997), alignable differences of newly learned consumer products were better remembered than nonalignable differences after a 1-week delay.

The impact of alignment on memory also has developmental implications. Kotovsky and Gentner (in press; Gentner, Rattermann, Markman, & Kotovsky, 1995) showed 4-year-olds pairs of arrays displaying higher order perceptual relations, such as symmetry or monotonic increase; the relations were defined on different dimensions for the arrays in a pair. The 4-year-olds were better able to match these cross-dimensional higher order similarities when they were first given repeated experience aligning within-dimension comparisons of the same higher order relations. We conjecture that the close within-dimension comparisons served to focus the children on the common higher order pattern. Structural comparison has also been implicated in the development of taxonomic categories. In one study (Gentner & Imai, 1995), preschool children who had been taught a novel word (e.g., the experimenter pointed to an apple and said, "This is a dax") were given a sequence of new items and asked which ones the new word could be applied to. When an item from this set was both taxonomically similar and shape-similar to the original, so that the pair aligned extremely well, children's subsequent extensions to other items were far more taxonomic than in their baseline performance. These data suggest that comparisons that are facilitated by the presence of easily alignable perceptual information can promote the acquisition of more abstract categorical commonalities (see also Markman & Wisniewski, 1997; Namy, Smith, & Gershkoff-Stowe, in press).

A focus on commonalities and differences among the available exemplars may provide a way for the cognitive system to filter information from the environment and to direct processing toward information likely to be useful across a range of experiences. Our findings suggest that this focus on alignable systems influences what is stored in memory as well as what is salient in current processing. Although such a connection is to be expected, it cannot be taken for granted.

Further, these findings invite new questions. Do comparisons between a present exemplar and past exemplars stored in memory have focusing effects similar to those we found for comparisons between two simultaneously presented exemplars? Do comparisons among multiple parallel exemplars create heightened focusing effects? Are there differences between relational comparisons and attribute comparisons? Further research should illuminate these issues.

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