Analogy as a mechanism of comparison

Andrew Lovett (andrew-lovett@northwestern.edu)
Qualitative Reasoning Group, Northwestern University
2133 Sheridan Road, Evanston, IL 60201 USA

Eyal Sagi (ermon@northwestern.edu)
Department of Psychology, Northwestern University
2029 Sheridan Road, Evanston, IL 60208 USA

Dedre Gentner (gentner@northwestern.edu)
Department of Psychology, Northwestern University
2029 Sheridan Road, Evanston, IL 60208 USA

When we think of analogies, we often imagine cases where drawing on complex concepts from one domain helps to extend our comprehension of concepts from a different domain. As such, the use of analogies is often associated with creativity and problem-solving. However, there is evidence that the inferences derived through processes of analogical thinking are applicable in other contexts that might not at first appear to involve analogies. For instance, there is evidence that analogical thinking might play an important role in language acquisition (cf. Gentner & Namy, 2006). Furthermore, as discussed below, there is evidence that the processes underlying comparison and the identification of differences are supported by the same framework that is used for drawing analogical inferences.

It appears then that the usefulness of analogical processes extends beyond the boundaries of creativity and inferences derived out of complex representations. We suggest that the theories of analogical thinking are useful not only in explaining creativity and problem solving, but also as a tool for understanding the processes underlying comparison, both conceptual and perceptual (Gentner & Markman, 1997). Specifically, we will suggest that one such theory of analogies, Structure-mapping Theory (Falkenhainer, Forbus, & Gentner, 1989; Gentner, 1983, 2003; Gentner & Markman, 1993, 1994; Markman & Gentner, 1993) can be used to describe not only the processes of analogical reasoning but also those involved in comparison.

According to Structure-mapping Theory, analogies are understood via process of *structural alignment.* The alignment of two representations is assumed to proceed via a local-to-global process that begins by placing identical elements (attributes and relations that exist in both representations) into potential correspondences. These correspondences form an initial set of *local matches*. These local matches are coalesced into structurally consistent connected clusters (called *kernels*), which are merged together to form one or a few structurally consistent global interpretations. This global alignment facilitates the generation of analogical inferences, but also reveals structural commonalities between the two representations as well as *alignable differences*.

Therefore this process can be used for the identification of specific differences between representations as well as for the generation of analogical inferences (Gentner & Gunn, 2001; Gentner & Markman, 1994; Markman & Gentner, 1993, 1996). Furthermore, the more similar the two representations are, the easier the alignment process becomes, resulting in the faster identification of specific differences. However, in cases where the identification of specific differences is not required, such as when making simple judgments of “same” or “different”, it is possible to shortcut this process by employing a simple heuristic (Markman & Gentner, 2005). Basically, the lower the number of initial local matches, the more likely it is that the two things differ. Moreover, in order for two things to be identical, a minimum number of local matches is required – specifically, there need to be enough local matches so that the resulting mapping might cover all of the representation.

Structure-mapping theory therefore makes some substantive predictions about tasks that involve comparison (Gentner & Markman, 1997). Tasks that require the identification of specific differences should be easier for two similar images or representations than for two disparate ones because full alignment is required for the determination of such differences. In contrast, tasks that require only an overall match, such as determining whether two images are identical, can often be completed by means of a heuristic based on the quantity of local matches. This heuristic will generate faster “different” judgments when the representations are very different than when they are quite similar. Thus, saying “different” in a same-different task should be easier for two disparate images or representations than for two similar ones.

These predictions have been tested in several experiments. In one such experiment, Gentner and Markman (1994) gave participants a *speeded-difference task* in which they were asked to state one difference between as many word pairs as possible in a brief time period. As predicted, participants identified differences for many more high similarity pairs than low similarity pairs. In a related study, Gentner and Gunn (2001) asked participants to compare word pairs and write a commonality prior to completing a speeded-difference

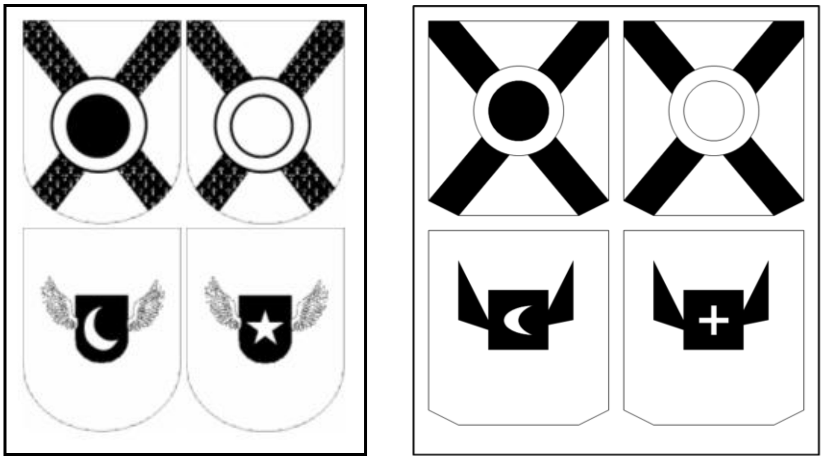

Figure 1. Sample stimuli from Sagi & Gentner (2006) Experiment 1 (Left) and the sKEA simulation (Right). Images in the same row represent high-sim pairs; images in the same column represent low-sim pairs.

task. Participants generated more differences for the previously compared pairs than for new pairs, demonstrating that prior comparison and alignment facilitated the identification of differences. Moreover, many of the differences identified by participants in this task were alignable differences. In another experiment, Markman and Gentner (1996) asked participants to list differences between pairs of images. Once again participants listed more differences for highly similar images than for less similar ones. These findings are consistent with the structure-mapping claim that participants will find it easier to note differences between concepts and images that are fairly similar (and consequently more alignable) than between concepts and images that are substantially different (and therefore difficult to align) Thus, the evidence is quite strong that tasks in which participants must identify specific differences are easier when the items are highly similar (because such tasks require alignment).

In contrast, results from tasks where participants are simply asked to judge whether pairs of images are “same” or “different” often show a reversed pattern of behavior (e.g. Farell, 1985; Goldstone & Medin, 1994; Luce, 1986; Posner & Mitchell, 1967; Tversky, 1969). Participants in such tasks take longer to say “different” to highly similar pairs than to less similar ones and are more likely to erroneously respond “same” to similar image pairs than to dissimilar ones. These findings are consistent with the prediction that overall comparisons often rely on a rough heuristic in which only the quantity of local matches is taken into account. Using such a heuristic it is possible to rapidly identify that a pair of representations differ, but only if the differences are substantial.

These two types of comparison were explicitly compared by Gentner and Sagi (2006). Gentner and Sagi asked participants either to perform a same-different judgment task or to identify a single difference between pairs of images presented on a computer screen. Participants were consistently faster to respond “different” to low-similarity pairs than to high-similarity pairs. In contrast, when identifying specific differences, participants were faster to respond when presented with a high-similarity pair than with a low-similarity pair. Furthermore, performance on the same-different task was significantly faster than performance on the difference-identification task. These results are consistent with the difference between the two tasks predicted by Structure-mapping.

Interestingly, the relative simplicity of the materials used by Gentner and Sagi (2006)’s Experiment 1 (Figure 1) makes it possible to directly compare the performance of the participants in that experiment with the performance of a computer-based implementation of structure-mapping. The system we used for simulating participants’ responses was sKEA (Forbus, et al., 2004), the sketching Knowledge Entry Associate. sKEA is the first open-domain sketch understanding system. It allows users to sketch one or more objects, or glyphs, and to assign them conceptual labels describing what they represent. It then computes a number of qualitative relationships between the glyphs in the sketch. These include topological relationships, such as whether two glyphs are overlapping , and positional relationships, which come up into play when one glyph is above, or to the right of, another glyph. The conceptual and spatial information is combine to produce a symbolic, qualitative representation of the sketch. This representation can then be used as the input to symbolic reasoning systems.

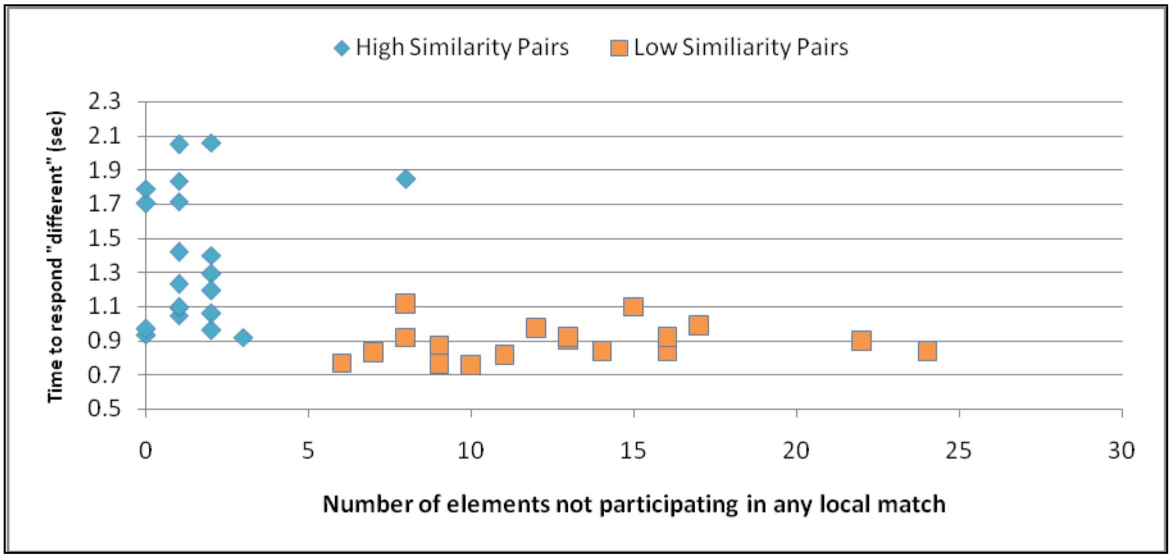

Figure 2. Response times for 'different' judgments in the same-different task as a function of number of elements NOT participating in any local match (Each data point represents a pair of images.)

For this simulation, we drew simplified versions of the stimuli from Experiment 1 of Gentner and Sagi (2006). Because sKEA can perform automatic shape matching across sketches, it was not necessary to use any conceptual labels. Pairs of stimuli were compared using an implementation of the structure-mapping theory, the Structure Mapping Engine (SME, Falkenhainer, Forbus, & Gentner, 1989). We then compared the output of the comparison to participants' response times across the two tasks. Since we expected the two tasks to involve different stages of processing in SME, we correlated the performance of participants to measures of correspondence derived out of these two levels. In the case of same-different judgments, we predicted that when there were too few local matches for the two images to be identical response times would be faster than when there were sufficiently many matches for such an identity relation to be possible (i.e., when each element participated in at least one local match). In contrast, for the difference-identification task we predicted that the appropriate measure should be related to the number of matches actually used as part of the global interpretation produced by SME – the greater the number of local matches incorporated into the global interpretation, the faster participants should be at identifying specific differences.

Overall, the correlations between the simulation and participants' response times are in line with our predictions. In the same-different judgment task, there is a significant negative correlation between participants' response times and the difference between the number of local matches and the minimum number required for an identity match. Participants are faster to respond "different" the greater the difference between the actual number of local matches and the number required for the images to be identical.

Also as predicted, in the difference-identification task there is a significant negative correlation between participants' response times and the number of local matches incorporated into the final mapping between the images. Or to put it more simply, the larger the matching structure identified by SME, the faster participants are at identifying a specific difference between the images.

An interesting way to look at these results is to consider the distribution of response times for 'different' judgments in the same-different judgment task (Figure 2) according to the number of elements that did NOT participate in local matches, which should serve as a measure of dissimilarity. (Reassuringly, we see that the pairs we constructed to be high-similarity pairs are clustered towards the left side of the graph, and the low-similarity pairs are on the right side. That is, for high-similarity pairs, there were very few elements that did *not* participate in local matches; whereas, for low-similarity pairs there were many elements that did not participate in local matches.) The key finding here is that the overall pattern of response times fits with the claim that a quick heuristic can account for the faster response times for low-similarity than for high-similarity items in this task. That is, response times are low and fairly uniform when there are many non-matching elements, but jump sharply when there are very few such non-matching elements (that is, when most of the elements have local matches).

The evidence presented here supports Structure-mapping Theory as a framework that is applicable not only for explaining the processes underlying analogical reasoning, but also those that underlie comparison more generally. They further suggest a strong link between analogical thinking and comparison – analogies can often be conceptualized as comparisons, while the identification of specific differences might be facilitated by the ease with which the compared representations are aligned. Comparison is a fundamental cognitive process. The current results add to evidence suggesting that theories of analogy and analogical reasoning have widespread application in domains such as categorization and object recognition.

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