Analogical Transfer Through Comprehension and Priming

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Abstract

An unexplored means by which analogical transfer might take place is through indirect priming through the interaction of text comprehension and memory retrieval processes. REMIND is a structured spreading-activation model of language understanding and reminding in which simple transfer can result from indirect priming from previously processed source analogs. This paper describes two experiments based on REMIND's priming-based transfer framework. In Experiment 1, subjects (1) summarized analogous source stories' common plot; (2) rated the comprehensibility of targets related to sources by similar themes, contexts, or themes and contexts; then (3) described any sources incidentally recalled during target rating. Source/target similarity influenced comprehensibility and reminding without any explicit mapping or problem-solving. In Experiment 2, subjects (1) rated each story's comprehensibility in source/target pairs having similar relationships to each other as in Experiment 1; then (2) rated source/target similarity. Analogous targets were rated as more comprehensible than non-analogous targets. Both experiments imply that transfer can be caused by activation of abstract knowledge representations without explicit mapping.

Introduction

Analogical transfer allowing inferences from a source to a target representation has important status in cognitive science because it allows people (and programs) to reason and benefit from experience. Understanding the psychological mechanisms underlying transfer is therefore critical to models of comprehension, problem solving, explanation, case-based reasoning, theory formation, and metaphor.

Most computational systems of analogical transfer (e.g., ARCS & ACME, Thagard, Holyoak, Nelson, & Gochfeld, 1990; Holyoak & Thagard, 1989; MAC/FAC & SME, Forbus & Gentner, in press; Falkenhainer, Forbus, & Gentner, 1989) posit that, first, source episodes are provided in advance or retrieved from memory. Transfer then proceeds via a complex mapping process to elucidate the analogy and allow appropriate causal predicates (e.g., explanations, plans) to be transferred from the source to the target.

We believe that there is another, relatively unexplored form of analogical transfer that is much simpler and more common — *analogical transfer through comprehension and priming*. These predictions are derived from the interaction of comprehension and analogical retrieval in REMIND (Lange & Wharton, in press), a structured spreading-activation model of language understanding and reminding embodying many of the ideas originally proposed in Schank's (1982) *Dynamic Memory*. In REMIND, text comprehension uses abstract knowledge representations, causing them to become activated while inferences are made to understand a target. Activation feedback between the shared abstract knowledge structures of the target and analogous source episodes in memory strongly influences and primes the comprehension process — a ubiquitous but nearly computationally costless form of analogical transfer. This paper presents two experiments that explore the psychological reality of such priming-based analogical transfer.

Analogical Transfer

As seen in two influential works on the topic of analogical transfer, Holyoak and Thagard (1989, p. 296) and Gentner, Rattermann, and Forbus (1993, p. 527), the general consensus is that the *process* of analogical transfer takes place as follows: (1) A source analog is provided or accessed from memory (retrieval); (2) Matching relations in source and target representations are placed into correspondence (mapping); (3) Higher order relations (e.g., goals, plans, explanations, etc.) are transferred from the source analog to the target analog (transfer). This process has been used to model creation of difficult analogies, such as Rutherford's analogy of atoms to the solar system and of the tragedy in *Romeo and Juliet* to that of *West Side Story*.

For example, in Forbus and Gentner's (in press) model, MAC/FAC, a source analog would initially be retrieved from memory by MAC. The retrieved source analog, along with the probe that cued it, would be passed to a separate mapping program, FAC (SME in its literal similarity mode, Falkenhainer et al., 1989). FAC first maps corresponding higher order relations between the source and target analogs, and then reports systems of relations that can be mapped from the source to the target. Similarly, Thagard et al.'s (1990) ARCS model retrieves a source analog, which can be passed to ACME (Holyoak & Thagard, 1989) for analogical mapping with and transfer to the target. Most case-based reasoning models (cf. Riesbeck & Schank, 1989) perform transfer in a similar manner.

Analogical mapping models such as SME and ACME and case-based reasoning models provide powerful mechanisms for creating complete analogies and transferring potentially large amounts of information between a source and target. They therefore serve as useful models of the creation and understanding of analogies that often occurs in explicit problem-solving and argumentation.

This great power of explicit analogical mapping and case-based reasoning models, however, comes at a relatively high computational cost. More importantly, it is questionable whether people use such large-scale mapping processes in everyday comprehension and conversation. Clearly, people

spend very little of their time *consciously* creating new analogies and mappings. Yet they are able to benefit from past experience of analogically-similar episodes during comprehension, even when they are not consciously performing analogical retrieval and mapping.

Analogical Transfer Through Priming

How people are able to benefit from analogous experience without engaging in explicit source/target mapping is suggested by REMIND (Lange & Wharton, in press). REMIND is a structured connectionist model that integrates text comprehension and episodic memory retrieval within a spreading-activation network. REMIND does not address the problems of complex analogical mapping and transfer simulated by models such as SME and ACME. However, the spread of activation between semantic and episodic memory modeled in REMIND does suggest a different, simpler, form of analogical transfer — analogical transfer through priming (see Dunbar & Schunn, 1993, for a similar argument).

In REMIND, activation spreads through a semantic network that performs dynamic inferencing and disambiguation to infer a conceptual representation of the input, as in ROBIN (Lange & Dyer, 1989). Stories to be memorized are presented to the network and understood in this manner, and then stored as episodes in the network by adding units and connections to encode the abstract knowledge structures representing them. Because stored episodes are associated with concepts used to understand them, the spreading-activation process also activates any episodes in the network that share features or knowledge structures with the target being understood.

REMIND produces a simple form of analogical transfer as a side effect of how it models text comprehension. Two aspects of its text comprehension process are responsible. First, comprehension of new text input results in residual activation on the units of its semantic network that were used during processing. Second, when an analogous input target is processed, its partially activated inferences and knowledge representations activate (and sometimes retrieve) similar ("source") episodes in memory. These episodes, in turn, feed activation back to associated knowledge structures in the semantic network. Both of these aspects of REMIND influence and prime the comprehension process, causing a target to be more fully or correctly elaborated than if the previous source analogs had not been processed.

The type of analogical transfer suggested by REMIND's integrated knowledge representation framework requires little attention. It is a nearly costless emergent property of the spreading-activation process in which comprehension and retrieval are integrated within a single mechanism.

Materials

Table 1 shows the four relations (besides *unrelated*) that source and target stories could have to each other in these experiments. Table 2 is an example of one story theme group containing six stories involving two related themes ("sour grapes" and "self blame"). (The stories are shortened from their actual length.) Note that our materials consisted of 14 theme groups similar to that shown in Table 2. *Analog* stories, which appear in the same column, have similar themes (cf. Dyer, 1983). For example, the stories in the first column all instantiate some form of "sour grapes." The main characters fail to attain some goal and then try to make that failure seem less important by disparaging the goal. *Disanalog* stories, which appear in opposite columns, invoke different, but partially related, themes. For example, the source target of Theme 1 (the "John" story) and the within-context target of Theme 2 (the "Jennifer" story) are disanalogs because they describe different themes that both describe characters striving for a goal that then fails, but who attribute the failures very differently.

The materials also vary on their common contextual similarity. *Within-context* targets share similar event and situation descriptions with the source stories (e.g., MOPs, Schank, 1982), even though they have few similar surface features or words. *Cross-context* targets do not share event or situation descriptions. For example, all four main characters in the source and within-context targets (rows 1 and 2) are portrayed as hard-working people who are trying to advance their careers. The cross-context targets in row 3, however, are in a totally different world than the sources (enchanted animals in fantasy worlds).

Unrelated stories (not shown here) share neither contextual nor thematic similarity. Such pairings are created by using sources and targets from different theme groups (see Table having totally unrelated contexts and themes.

Note that in both experiments, all 28 source stories from the 14 theme groups appeared in all conditions, and that all 56 target stories appeared in analog, disanalog, and unrelated pairings. Thus, what is particular to each condition is not the stories themselves but the relation *between* stories.

Experiment 1: The Relation of Priming and Reminding to Transfer

We tested REMIND's predictions about analogical transfer through comprehension and priming in an experiment which measured both reminding and transfer. The goal of the experiment was to see whether previously studied source episodes could positively influence subjects' comprehension of targets, even when subjects were not instructed or biased to perform any explicit mapping or problem-solving.

Subjects initially summarized the common plots of two pairs of analogous stories. Subjects then saw four other stories, one to a page. Subjects rated each of these stories for its comprehensibility, defined as "how easy it is to understand what is being described by the story." The first two rated stories were unrelated to any of the previous stories. The third and fourth rated stories were related to the first and second pair of summarized source stories, respectively.

The central point of computational models of analogical reasoning is that higher-order relations are transferred from one representation to another. There are several ways to measure this relational transfer (e.g., reading time, problem solution rate). We choose comprehensibility as our measure both because of its implementational simplicity and its relatively direct relation to transfer: Up to some asymptote, the more appropriate causal relations transferred to a target repre-

Table 1. Relations of target stories to summarized source stories.

		thematic similarity	
		high	partial
contextual similarity	high	within-context analog	within-context disanalog
	low	cross-context analog	cross-context disanalog

Table 2. Example of stories in Within-Context and Cross-Context conditions.

Theme 1: "Sour Grapes."	**Theme 2:** "Self-Doubt."
Source: John did a lot of homework in order to get good marks. Earlier, a counselor had arranged for him to meet with the recruiter from Yale. When he got home from class, he opened the thin rejection letter from Yale. Later, that night he mentioned to his father how he believed that people from Ivy League schools were pretentious.	**Source:** Derrick practiced to make the team. His PE teacher had gotten him a try out with the gymnastics coach. The gymnastics team coach watched him perform and then told his PE teacher that he didn't want him on the team. Derrick confessed that the coach undoubtedly thought that he didn't have the talent for gymnastics.
Within-context target: Lisa spent long hours trying to make her corporation successful. A coworker set her up to go out with someone he knew. She waited at the restaurant until 8:30 and then left without ordering dinner. She told her friend that she thought that her date probably wasn't that handsome and that investment bankers are really boring, anyway.	**Within-context target:** Jennifer worked hard attempting to create a new business venture. A friend fixed a blind date for her with one of his friends, Henry, from work. She waited alone at the entrance of the museum for two hours. She confessed to her friend that her date thought she wasn't that attractive and that software engineers aren't interesting.
Cross-context target: Elle, a unicorn, wanted to see what was on the other side of the river. She thought the lands over there were enchanted and rich with meadows and fruit trees. One day she set out to cross the river. Elle swam as hard as she could but after 20 minutes she had to turn back, exhausted. Elle decided that the stories about the land on the other side of river were just false rumors and that there was probably nothing of worth over there.	**Cross-context target:** Jane, a unicorn, wanted to see what was on the other side of the river. She thought the lands over there were enchanted and rich with meadows and fruit trees. One day she set out to cross the river. Jane swam as hard as she could but after 20 minutes she had to turn back, exhausted. Jane decided that she wasn't worthy of being in the magic lands.

sentation, the more understandable that representation will appear to a reader or listener.

After subjects rated all four target stories, they read the following instructions: "When you rated them for comprehensibility, did any of the four stories...remind you of any of the stories you had previously summarized? If so, please turn back to that story...and write which story (or stories) you got reminded of...."

It is not clear whether analogical retrieval/mapping models would predict that subjects would perform explicit retrieval, mapping, and transfer under these conditions. The most likely prediction, however, seems to be that subjects would have no pragmatic reason for doing a detailed source/target mapping. Accordingly, normal retrieval/mapping models should predict no significant difference in comprehensibility between analog and unrelated targets.

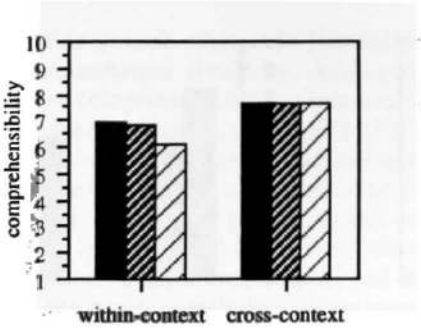
In contrast, the REMIND framework predicts that the previous summarization of the related sources will increase the activation of particular theme and contextual elements. Being reminded of analogous source stories would also increase the activation of those elements, even without a mapping process being performed. These two additional sources of priming will in turn increase the causal integration and activation of the target. Accordingly, the REMIND framework predicts that there should be increased comprehensibility for related targets compared to unrelated targets.

Method

Subjects were 168 UCLA students. Subjects saw source stories and target stories in a single booklet, the first page of which stated, "There are two brief experiments in this packet. The first experiment concerns what occurs when people create summaries of similar stories. So, on the next two pages you will see two very short stories. Below each pair of stories, please write 2-3 sentences summarizing their common plot..." On each of the next two pages were a pair of stories that were within-context analogs of each other.

The page after the second source pair stated, "The second experiment in this packet explores various factors involved with text comprehension. Please read and rate each of the next 4 stories for its comprehensibility." Below each target story was a 10-point scale (1, low; 10, high) for rating comprehensibility. Across subjects, analogous and disanalogous stories appeared equally in the third and fourth ordinal target positions. Contextual Similarity was a between-subjects factor. The reminding instructions were placed after the last target story.

We used the min F' statistic (computed from subject and story ANOVAs) to allow simultaneous generalization over both subjects and stories. Differences between conditions were analyzed in a mixed-subjects/within-items min F' ANOVA with the following factors: (a) for comprehensibility ratings, 3 (Thematic Similarity: analog, disanalog, unrelated) x 2 (Contextual Similarity: within, cross), and (b) for reminding, 2 (Thematic Similarity: analog, disanalog) x 2 (Contextual Similarity: within, cross). The relationship between reminding and comprehensibility was measured by computing point-biserial correlations of subjects' comprehensibility ratings and reminding scores (1, if reminded at least one source story; 0, if not reminded of any).



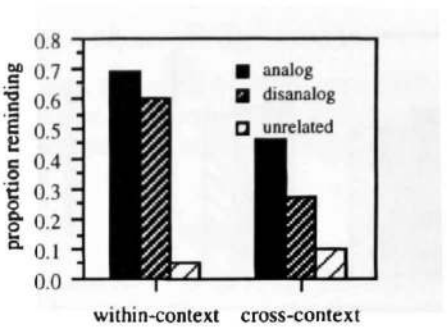


Figure 1 (left panel). Comprehensibility Ratings. Figure 2 (right panel). Reminding Proportions. Note that the y-axis shows the proportion of subjects being reminded of at least one of the related summarized stories.

Results and Discussion

Recall that the REMIND framework predicts that priming from activated source targets should increase comprehensibility of targets having related sources vs. those of targets not having related sources, even though there is no pragmatic reason for subjects to engage in mapping between sources and targets. Analyses of the comprehensibility ratings (shown in Figure 1) support this prediction. The main effect of Thematic Similarity and the omnibus interaction of Thematic Similarity and Context Similarity were not significant, min F' (1, 60) = 1.60, min F' (1, 139) = 1.09, respectively. However, planned comparisons showed that in the (single-degree of freedom) within-context condition, analog and disanalog target stories were rated as more comprehensible than unrelated stories, min F' (1, 72) = 4.70, $p < .05$ (see left side of Figure 1). In other words, targets that had within-context sources in memory had significantly higher comprehensibility than those without.

A potentially confusing fact is that cross-context analogs were rated as more comprehensible than within-context analogs, min F' (1, 54) = 4.94, $p < .05$. This is undoubtedly a consequence of the constraints necessary to construct appropriate materials. While cross-context analogs shared similar themes, within-context analogs had to share both theme and event descriptions. Accordingly, within-context targets described relatively more thematically-irrelevant events.

Reminding proportions for sources are shown in Figure 2. As is evident, subjects were reminded of more analog source stories than of disanalog sources, and more within-context sources than cross-context sources, (respectively, min F' (1, 74) = 4.72, $p < .05$, min F' (1, 96) = 12.16, $p < .001$). The interaction between Thematic Similarity and Context Similarity was not significant, min $F' < 1$.

Interestingly, the reminding/rating correlation in the within-context analog condition is significant ($r = .38$, $p < .001$), but the correlation in the within-context disanalog condition is essentially zero ($r = -.02$). While any discussions of this finding are beyond the scope of the present paper, we include this correlation as an indictation that the relation between retrieval and transfer is not simple or linear.

The basic results of this experiment support the REMIND framework's claim that a form of analogical transfer can happen even when subjects do not perform explicit mapping or problem-solving, since comprehensibility ratings were increased when subjects had previously studied contextually-similar stories.

Experiment 2: Similarity Comparison and Target Comprehension

To further explore the role of priming in analogical transfer, we examined target comprehension under conditions in which subjects performed source/target mapping. Subjects were presented with booklets of 6 pairs of stories, one pair to a page. Subjects saw one story pair from each of the following conditions: within-context analog, within-context disanalog, within-context unrelated, cross-context analog, cross-context disanalog, cross-context unrelated (see Table 2). Subjects were asked to read each story in the pairing and rate its comprehensibility. After rating each story's comprehensibility, subjects in the similarity comparison condition were also instructed to "Please reread the above two stories and then rate how similar the overall situations being described are to each other."

In analogical retrieval/mapping frameworks, analogical transfer should not take place until *after* both stories are explicitly compared. Therefore, comprehensibility ratings for the analog targets should not be any different than for the disanalog or unrelated targets here, since subjects make comprehensibility ratings before they make similarity ratings. However, in the REMIND framework, transfer can result from priming of knowledge representations in working and episodic memory, and so comprehensibility ratings for analog targets should be higher than for disanalog and unrelated targets even though mapping is performed second.

It could be argued that in this paradigm that subjects might be comparing sources and targets while they are performing similarity ratings. However, in systematically debriefing subjects in a timed reading version of this task we have just completed, no subject has ever reported doing this or guessed at the relation between the comprehensibility and similarity ratings. All subjects' descriptions of their strategies for comprehensibility ratings focused on qualities of individual stories, whereas their strategies for similarity ratings focused on features shared between stories.

Note that half of the subjects did *not* perform similarity ratings on the sources and targets they were rating for comprehensibility. We included this condition in order to explore the limiting encoding conditions under which semantic memory priming occurs.

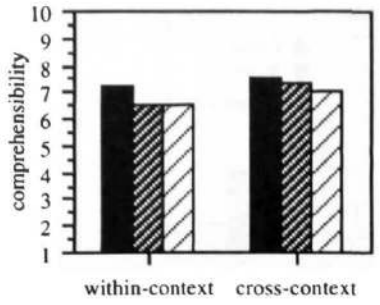


Figure 3. Comprehensibility ratings when making similarity ratings.

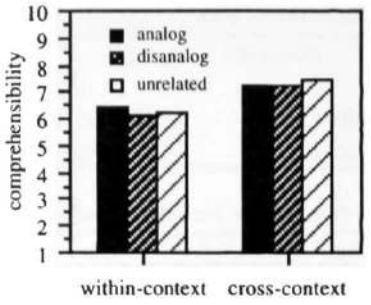


Figure 4. Comprehensibility ratings when not making similarity ratings.

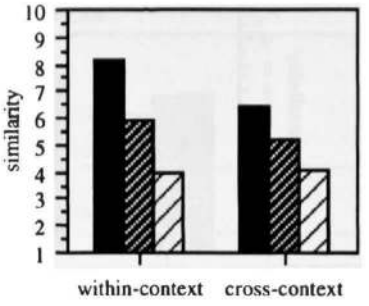


Figure 5. Similarity ratings.

Method

Subjects were 168 UCLA students. Subjects were given 6-page booklets which on each page contained a pair of stories. Underneath each story was a rating scale for comprehensibility. Subjects in the similarity conditions also saw at the bottom of each page a scale for rating the similarity of the two stories (range: 1, completely dissimilar, to 10, completely identical).

Results and Discussion

Comprehensibility and similarity rating condition. Recall that analogical retrieval/mapping frameworks posit that subjects have to explicitly compare source and target stories before transfer occurs. Accordingly, analog target comprehensibility ratings should be no different than disanalog and unrelated ratings. In contrast, REMIND's priming/transfer framework claims that subjects will activate thematic knowledge representations especially while processing source stories. Therefore, analog target comprehensibility ratings should be higher than disanalog and unrelated comprehensibility ratings even before explicit source/target mapping is begun.

Figure 3 displays the target comprehensibility ratings. These results appear to show priming occurring before explicit mapping occurs (cf. Seifert, McKoon, Abelson, & Ratcliff, 1986). Across both within- and cross-context conditions, there was a main effect of Thematic Similarity (i.e., analog > disanalog > unrelated), min F' (2, 36) = 3.20, p <.05. (In our current reading time version of this experiment, subjects are also fastest to read analogous targets.) The interaction between Contextual and Thematic Similarity was not significant, min $F' < 1$.

Though not of particular theoretical interest, the similarity ratings are important because they do validate our materials and show that subjects were indeed sensitive to our manipulation of thematic and contextual similarity. As shown in Figure 5, there was a main effect of Thematic Similarity (i.e., analog > disanalog > unrelated), and within-context pairs were rated as more similar than cross-context pairs (respectively, min F' (2, 72)= 10.42, $p < .001$, min F' (1, 66)= 15.51, $p < .0001$).

Comprehensibility rating only condition. An important goal is to find the limiting conditions under which semantic memory priming occurs. To explore these limits, half of the subjects we tested did not perform similarity ratings after rating targets for comprehensibility. Figure 4 shows the target comprehensibility ratings for these subjects. As is evident, there were no significant effects in this condition except that cross-context stories were rated as more comprehensible than within-context stories, min F' (1, 47) = 11.25, p <.001.

The fact that no priming effects were shown in this condition but were when subjects had to make similarity ratings supports two very different interpretations of Experiment 2. One possibility, of course, is that the priming effects shown in the similarity condition were due to subjects subconsciously mapping sources and targets at the same time as they were rating targets for comprehensibility. A second possibility is that for thematic priming to occur, relevant knowledge representations have to be kept relative accessible while the target is processed. By this view, subjects in the similarity condition kept the source analog and the knowledge needed to understand it relatively active while rating the target, because they knew they would later need to compare the source and target. If this view is correct, similarity comparisons are not necessary for analogical transfer. Analogical transfer effects should be shown in any task in which (a) the source analog and its knowledge representations have to be kept active, or (b) the source analog and its knowledge representations reach a very high level of activation from extended processing (e.g., Experiment 1). We are currently performing experiments to explore this second explanation.

Discussion

Experiment 1 provided evidence for the REMIND framework's prediction that a simple form of analogical transfer can occur even when explicit analogical reasoning is not performed. In that experiment, subjects (1) summarized analogous source stories' common plot; (2) rated the comprehensibility of targets related to sources by similar themes, contexts, or themes and contexts; and then (3) described any sources reminded of while rating targets. Source/target similarity influenced comprehensibility and reminding even though there was no need for subjects to explicitly map or otherwise compare sources and targets. Similarly, Experiment 2 provided evidence for the REMIND framework's prediction that analogical transfer can take place before explicit analogical mapping occurs. Subjects (1) rated each story's comprehensibility in source/target pairs having

similar relationships to each other as in Experiment 1; and then (2) rated source/target similarity. Analogous targets were rated as more comprehensible than non-analogous targets. Retrieval/mapping theories, unlike REMIND's knowledge representation framework, predict that analogous targets will not be influenced by sources until *after* comparison.

It is impossible to rule out the possibility that subjects in fact *did* perform a complex analogical retrieval, mapping, and reasoning process in these experiments, and that this is the actual reason the comprehensibility ratings were affected by previously-read similar sources. However, we believe that this is unlikely, because there was little pragmatic reason for subjects to do so given their instructions. Moreover, we believe that the form of analogical priming in REMIND resulting from the interaction of the comprehension and memory retrieval processes provides a simpler and more coherent explanation of our results. As opposed to the relatively computationally costly process of a full-blown analogical mapping and transfer, REMIND's analogical priming emerges naturally and without cost from the encoding process.

It is important to note that we do not deny the psychological reality of complex analogical reasoning simulated by retrieval/mapping systems such as SME, ACME, and some case-based reasoning models. Clearly people do sometimes undertake conscious and explicit mapping and transfer (in difficult problem-solving tasks, for example). However, we do believe that future generations of mapping models should take into greater account how memory and encoding affects transfer, as in REMIND. Hofstadter & Mitchell's (in press) COPYCAT model shows one intriguing way this can be done by the interaction of spreading-activation through a long-term and working memory.

Much research remains to be done to explore this phenomenon. We are currently running several experiments to elucidate the encoding conditions under which it occurs. Another potentially interesting line of attack is shown in experiments by Ross and Bradshaw (in press), which seem to show a subconscious effect of long-term memory on disambiguation and interpretation of the targets, albeit only for surface (and not analogical) reminding. REMIND itself needs to be significantly extended, because like all current connectionist models, it does not yet have the capacity to perform the inferences to comprehend complex, thematic stories such as those of Table 2, though it can make abstract plan and goal-based inferences for shorter stories (see discussion in Lange & Wharton, in press).

Both experiments in this paper imply that transfer can be caused by activation of abstract knowledge representations without explicit retrieval or mapping. The implication for transfer models with no ability to represent differential activation in their semantic memory (or no semantic memory at all) seems obvious. A highly structured semantic memory that can represent differential activation among its components appears to be necessary to model our findings. Furthermore, these results suggest that in order to accurately simulate some psychologically important tasks, processes previously thought of as separate and serial are going to have to be modeled as interacting in parallel within the same general system.

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