Relation priming, the lexical boost, and alignment in dialogue

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of a set of stimuli in novel relationships. Suppose, for example, in one task instance (T1) *square predicts circle*, *circle predicts triangle*, and *triangle predicts square*; in the next task instance (T2) *cross predicts star*, *star predicts bar*, and *bar predicts cross*; and so on. The transverse patterning structure and the fact *cross predicts star* (information trial) are sufficient to correctly predict the responses to *star* and *bar* in the other two trials. Even on more complex structures involving more objects and more information trials, adults reach the point of correctly predicting the responses on the remaining trials (Halford et al. 1998).

The target authors' model fails to account for this sort of abstract analogy because the system can only utilize relations between objects that have already been learned as transformation functions on the basis of prior experience. Analysis of internal representations by the authors revealed that the developed network groups objects in hidden unit activation space by the relations that transform them. The input/hidden-to-output connections effectively implement a mapping whose domain is partitioned into subdomains, one for each causal relation (e.g., *cut*, *bruised*, etc.). The input-to-hidden connections implement a mapping from object pairs to points located within the subdomain corresponding to the relationship between the two objects, effectively providing an index to the objects' relation. For example, *apple* and *cut apple* are mapped to a point in hidden unit space contained in the subdomain for the *cut* transformation function. This point provides the context for mapping the next object, say, *banana* to *cut banana* (assuming that this transformation was also learned) to complete the analogy. The same sequence of steps may also be applied to transverse patterning, assuming that the network has learned all the required mappings: For example, *cross* and *star* would map to a point in the subdomain corresponding to the task relation T2; and *star* in the context of T2 would map to *bar*. Unlike adults, however, the network must be trained on all possible transformations to make this inference.

Notice that the problem with Leech et al.'s model is not about a complete failure to generalize. Suitably configured, some degree of generalization may be achievable using a learned internal similarity space of object representations. All fruit, for example, could be represented along a common dimension, and the various causal relations could be orthogonal projections that systematically translate the representations of *fruit* to *cut fruit*, or *bruised fruit*, and so on. Learning to complete analogies for some instances of fruit and cut fruit may generalize to the other instances, assuming the number of parameters (weights) implementing the mappings is sufficiently small compared to the number of fruit examples. But the elements of a transverse patterning task may not be systematically related in any way other than via the transverse patterning structure; they need not belong to the same category of objects, and they may even contradict mappings learned from a previous task instance (e.g., *cross* may predict *bar* in a new instance of the task). Thus, there is no basis on which the needed similarity could have developed. The problem is that the capacity for abstract analogical inference transcends specific object relationships.

Despite this pessimistic assessment, perhaps an explanation for analogy could be based on transformations augmented with processes that represent and manipulate symbols. Assuming a capacity to bind/unbind representations of objects to representations of symbols, abstract analogies such as transverse patterning may be realized as the transformation of symbols (e.g., symbol *a* maps to *b*, *b* maps to *c*, and *c* maps to *a*), instead of specific object representations. However, hybrid theories are to be judged at a higher explanatory standard (Aizawa 2002). Not only are they required to explain each component (e.g., an object transformation account for concrete analogies and a symbolization account for abstract analogies), but they also need to explain why the components are split that way.

Indeed, Aizawa's detailed analysis of the systematicity problem (Fodor & Pylyshyn 1988) and its proposed "solutions" (for a review, see Phillips 2007) signpost a general developmental theory of analogy. To paraphrase, the problem is not to show how analogy is possible under particular assumptions, but to show how analogy is a necessary consequence of those assumptions. The capacity for analogy, like the property of systematicity, is a ubiquitous product of normal cognitive development. If a developmental connectionist explanation depends on a particular network configuration, then why does it get configured that way? And if the answer is an appeal to error minimization, then what preserves this configuration in the face of optimization over numerous stimulus relations that may have nothing to do with analogy? Answers to these sorts of questions without relying on what Aizawa distinguishes as ad hoc assumptions would help to shift Leech et al.'s account from one that is simply compatible with the data to one that actually explains it.

Leech et al.'s developmental approach may yield valuable insights into the early acquisition of a capacity for concrete analogical inference. But to expect that it will lead directly to higher cognition seems more like wishful thinking.

Relation priming, the lexical boost, and alignment in dialogue

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Abstract: The authors' claim that analogical reasoning is the product of relational priming is compatible with language processing work that emphasizes the role of low-level automatic processes in the alignment of situation models in dialogue. However, their model ignores recent behavioral evidence demonstrating a "lexical boost" effect on relational priming. We discuss implications of these data.

Leech et al. present a connectionist model of analogical reasoning based on relation priming, rather than on explicit structure-mapping processes. Their core idea is that priming is itself a mechanism for producing analogy, and from it ultimately emerges the relation that is critical for establishing the similarity between a pair of terms in one domain and a pair of terms in a second domain. This claim is compatible with recent work in language processing that emphasizes the role of "low-level" priming in the development of semantic representations. This is most apparent in work on dialogue, in which interlocutors prime each other to produce equivalent situation models that form the basis of mutual understanding (Pickering & Garrod 2004). For example, interlocutors tend to repeat each other's choice of reference frames or ways of interpreting complex arrays (Garrod & Anderson 1987; Schober 1993). Clearly, alignment of analogical structures constitutes an important part of such situation models.

Critically, Pickering and Garrod's (2004) framework suggests that alignment takes place at many linguistic levels, and that repetition at low levels such as words enhances alignment at higher levels, such as the situation model. It follows that lexical repetition should enhance relational priming, and therefore analogical reasoning. Raffray et al. (2007) directly addressed the issue of the effects of lexical repetition (of the head or modifier) on relation priming of noun-noun combinations such as *dog scarf*. Three expression-picture matching experiments investigated whether relation priming occurred in the context of head repetition, modifier repetition, or both, and allowed direct comparison of the effects of head and modifier repetition. Results showed that participants were more likely to interpret *dog scarf* as a scarf decorated with a picture of a dog (i.e., *dog* DESCRIBES *scarf*) than as a scarf worn by a dog (i.e., *dog* POSSESSES *scarf*) after interpreting another expression involving the description relation rather than the possession relation; but the priming was greater when one term was repeated (e.g., *dog T-shirt* or *rabbit scarf*) than if neither was repeated (e.g., *rabbit T-shirt*). In sum, while conceptual relations were independently primed, the level of activation that a given relation received was enhanced where there was repetition of lexical items between prime and target.

We propose that such "lexical boost" effects, similar to those found in syntactic priming studies (Pickering & Branigan 1998), mean that priming of analogical relations should be enhanced by any repetition of terms. In Goswami and Brown (1989), the participant infers that *lemon* is to *cut lemon* as *bread* is to *cut bread*. Importantly, the concept of a lexical boost within analogical reasoning only makes sense in the context of two- (or more) place relations. That is, to get a lexical boost we would need to consider analogies such as *boy & ball* is to *boy kicks ball* as *man & stone* is to *man kicks stone*. In this case, the lexical boost predicts that participants should find it easier to resolve analogies containing repeated terms, such as *boy & ball* is to *boy kicks ball* as *man & ball* is to *man kicks ball*, or similarly *boy & ball* is to *boy kicks ball* as *boy & stone* is to *boy kicks stone*. For more complex analogies, the prediction is that any repetition of concepts will enhance analogy. To take the authors' example, it should be easier to draw the analogy from *World War II* to *World War I* than to the *Gulf War*, because more of the objects (e.g., *Germany*) are repeated (see Table 3 of the target article, sect. 4.1.2). Whereas the analogy between *Churchill orders_attack_of Germany* and *Bush orders_attack_of Iraq* involves different Object 1s and Object 2s, the analogy between *Churchill orders_attack_of Germany* and *Lloyd George orders_attack_of Germany* involves different Object 1s but the same Object 2. If such analogy works like the priming effects we have discussed, then lexical repetition should facilitate analogical reasoning.

There is also evidence for a semantic boost to syntactic priming (Cleland & Pickering 2003), so that priming is stronger when terms are semantically related than when they are not. For example, participants are more likely to describe a red sheep as *The sheep that is red* after hearing *The goat that is red* than after hearing *The door that is red*. It might similarly be the case that priming of analogical relations is enhanced by the inclusion of semantically related terms. That is, *boy & stone* is to *boy kicks stone* as *man & pebble* is to *man kicks pebble* might be easier to process than an analogy that contains semantically unrelated terms, such as *boy & stone* is to *boy kicks stone* as *man & ball* is to *man kicks ball*. Such effects should affect both the speed and the likelihood of obtaining a particular analogy.

Pickering and Garrod's (2004) model of dialogue assumes that processes by which interlocutors align their models of the situation are largely the result of automatic priming. In particular, repetition at one level of representation enhances repetition at other levels. For example, Branigan et al. (2000) showed that interlocutors are more likely to repeat each other's grammatical choices if they also repeat each other's choice of verbs. More generally, we assume that if two people start to use the same words, they start to take on board the same conceptualizations. One of the functions of analogical reasoning is to assist in the process by which interlocutors end up with equivalent situation models, and therefore we predict that lexical and other repetition will enhance this process. Therefore analogical reasoning can be seen as part of the mechanism of alignment and will be affected by the processes affecting priming.

Child versus adult analogy: The role of systematicity and abstraction in analogy models

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Abstract: The target article develops a computational connectionist model for analogy-making from a developmental perspective and evaluates this model using simple analogies. Our commentary critically reviews the advantages and limits of this approach, in particular with respect to its expressive power, its capability to generalize across analogous structure and analyze systematicity in analogies.

Leech et al. present a computational (connectionist) approach to explain analogy-making from a developmental perspective. At the outset we would like to emphasize that this is a very compelling and advanced approach: Tackling the problem from a developmental point of view enables the authors to highlight completely new aspects of analogy-making. This approach reflects the infantile learning process, from comparisons based mainly on superficial similarity to a controlled and advanced strategy of analogical comparison based on structural systematicity. So far, analogy models have always been inspired by adult analogical reasoning. Emphasizing the learning process, it makes sense to approach this problem from an infantile developmental perspective: Leech et al.'s model is based on a neural network implementing a Hebbian learning algorithm which is able to enhance bit by bit the strategy for analogy-making and explicitly model the development from superficial similarity to structural similarity. More precisely, the network can learn causal relations using a transformation of an object (e.g., "apple") by a causal agent (e.g., "knife") to achieve a representation of a transformed object (e.g., "cut apple"). The network extends this ability step by step to different domains and cross-mapping analogies; it can model the relational shift from surface similarity to relational similarity; and finally, it is trained on analogies involving multiple objects and multiple relations. There exists no other comparable analogy model modeling strategic learning – current analogy models can only model analogical learning by analogical transfer.

Another interesting capability is the creative potential of the analogy model: A trained network can creatively construct completely new objects when a relation is applied to a new (target) object. However, this capability must also be seen critically: Any relation can be applied to any (suitable or unsuitable) object and always leads to some result, which might be completely meaningless and absurd.

Inspired by research on infantile development, the authors investigate mainly analogies used in previously conducted analogy experiments with children. These are typically proportional analogies, that is, *a-is-to-b-as-c-is-to-what* analogies. All of these analogies are based only on a single, common relation, which is the same in source and target. We argue that such analogies are oversimplified – the task in these examples is applying the same relation to a new target object rather than making an analogous transfer. The target object is in fact very similar to the source object with respect to the applicability and the outcome of the relation. The "analogical" mapping required to solve the analogy is very small. We do not deny that such oversimplified analogies are necessary to investigate the initial analogical abilities of very young children; however, an analogy model (if it is not limited to modeling the analogy-making capability of 1-to-5-year-old infants, who anyway have only a very limited ability of analogy-making) must foremost have the capability to solve analogies with