Tensor models: a creative basis for memory retrieval and analogical mapping

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We take creativity to be a computational process, which can be understood in terms of the cognitive processes that underlie it. Analogy and memory are generally accepted as two of the most fundamental processes of cognition. However, whereas analogies have traditionally been seen as tasks requiring creativity (Johnson-Laird, 1989), memory storage and retrieval have often been viewed as relatively uncreative cataloguing or filing processes. Recent memory models based on parallel distributed processing (PDP) have shown that memory retrieval can indeed be creative (Humphreys, Bain & Pike, 1989; Humphreys, Wiles & Bain, 1990). This is achieved by the interaction of components such as cue, target and context. This approach seems capable of accounting for the kinds of creativity assessed in Mednick's (1962) remote associates task. For example, a subject might be asked to find a word that serves as an associative link between three disparate cues such as "rat, blue, cottage" (cheese). Rubin and Wallace (1989) showed that in similar tasks involving two cues, a target term could be retrieved even when the separate probabilities of eliciting the target were essentially zero; for example, name a mythical being that rhymes with post (ghost). These performances are creative in that they cannot be explained by direct memory retrieval, or addition of associative strengths; the probability of retrieving "ghost" is greater than can be predicted by summing the separate associative strengths to "mythical being" or to "post". These creative processes require an interaction between cues and targets, which can be handled by distributed memory models that
directly compute the intersection of sets of targets associated with each cue (Wiles, Humphreys, Bain & Dennis, 1991).

The fact that memory can be creative is not the only reason for linking it to analogies. A recent model of analogical reasoning (Halford, Wilson, Guo, Wiles & Stewart, 1991) has shown that analogies can be accounted for by a PDP model that has formal and procedural similarities to Humphreys, Bain and Pike’s tensor model of memory. This Tensor Analogical Reasoning (TAR) model represents relations (more generally, predicates), and their arguments, as vectors, just as the tensor model of memory represents cue, target and context as vectors. The binding of relation (predicate) to arguments is represented by the tensor product of the relevant vectors. For example, the relation LARGER_THAN(horse, rabbit) is represented by the tensor product of three vectors, representing LARGER_THAN, horse, and rabbit. This follows Smolensky’s (1990) use of tensor products to represent variable-value bindings. Thus an analogy such as whale:dolphin::horse:rabbit can be solved by representing whale and dolphin as vectors which are used to retrieve the vector representing appropriate relations, including LARGER_THAN. This vector, together with the one representing horse are presented, and the vector representing rabbit is retrieved (among other things).

The process of retrieving relations and arguments from the tensor product representation in the TAR model of analogies is the same as the retrieval of targets from the tensor product of cue, target, and context vectors in tensor memory model. The latter model provides an integrated account of a wide range of memory phenomena (Humphreys et al., 1989), such as how different control structures over the same memory can explain differences between recognition and recall tasks, and how the same memory can store both general (semantic) and specific (episodic) memories. The TAR model can account for a range of analogical reasoning tasks. For example, given a concept such as “nucleus, electron”, it can retrieve a set of relations such as ATTRACTS, MORE_MASSIVE_THAN. These can then be used to retrieve other concepts that embody the same relation, such as “planet” and “sun”, which also have the relation ORBITS_AROUND. Thus the hypothesis that the electron orbits around the nucleus, the essence of the Rutherford analogy, can be discovered.

The distributed memory model and an analogical reasoning model are similar in their use of tensor products of vectors to represent information, unbinding of tensor products as the retrieval mechanism, and computation of the dot product as a matching process. Furthermore both can account for creative processes, in memory and reasoning, and both are fully specified computational models. They therefore support the claim that creativity is a computational process that can be investigated using available techniques.

The TAR model offers a solution to the problem of how to deal with analogies in the PDP architecture. Because analogical reasoning is arguably the basic process underlying much human inference, and has the potential to explain how people understand abstractions such as variables, this increases the application of PDP models to higher cognitive processes. The TAR model is based on the same representational and process mechanisms as the tensor model of memory. This opens the way for work on distributed representations in the memory area to be utilized in the study of reasoning, and work on control processes from research on reasoning, to be applied to memory.

References


