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Comptuational Principles of Human Analogical Reasoning

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Artificial Intelligence and Understanding Human Cognition

Since the advent of the cognitive revolution, the information-processing paradigm has been a central organizing principle in almost all models of thought. By providing a vital framework, one that organizes and clarifies the ontology of concepts available to researchers, the cognitive revolution allows computationally-aware scientists to harness the extensive knowledge of engineering and computer science in pursuit of understanding the mind.

Analogical Reasoning

In seeking to leverage the advantages of engineering and computer science to our end goal of a computational understanding of human intelligence, we have focused on tasks and phenomena related to analogical reasoning. Analogy has long been regarded as a key process in human thought, and has been the subject of intense study by cognitive psychologists. Our overall approach to the investigation of analogy is to develop computational models that both expose computational principles and predict the results of these psychological experiments. Our framing of the process is consistent with that expressed in papers by Gentner and her colleagues (Gentner, 1983; Falkenhainer, Forbus, & Gentner, 1986), which argue that it is the mapping of high-order relations (or structure) between domains that gives an analogy its meaning. That is, what makes an analogy meaningful is not correspondences drawn between object properties, such as that an atom is small and a solar system is large, but rather correspondences drawn between relationships among the objects, such as the idea of an orbit: electrons orbit the nucleus just as planets orbit the sun. This "structure-mapping" is what makes an analogy meaningful.

Recent Work: The Goldilocks Principle

Our recent work has highlighted what we believe to be a computational principle behind certain aspects of analogical reasoning, namely, the retrieval stage of the process, where a stimuli causes the reasoner to retrieve precedents from long-term memory that might possibly be useful for analogical reasoning. In spite of the importance of structure in the process of analogy, psychological studies of retrieval indicate, surprisingly, that it is difficult for most people to recall precedents that are analogically related to probe information or useful for further analogical inference (Gick & Holyoak, 1980; Rattermann & Gentner, 1987); rather, they retrieve information that is similar in surface, or superficial, features. In contrast to these striking results, other work from the field of expert problem solving suggest that certain sorts of people, namely "experts," do consistently achieve analogical recall in particular domains (Chi, Feltovich, & Glaser, 1981). That is, experts are often able to recall precedents from memory that are structurally related to the stimulus, and therefore much more useful for analogical reasoning.

Current models of retrieval do not account for the drastic difference between novice-like and expert-like retrieval (Thagard, Holyoak, Nelson, & Gochfeld, 1990; Forbus, Gentner, & Law, 1994). As a step toward addressing this gap, we have produced a model that relies on a single mechanism to account for both types of retrieval. The mechanism is grounded in the idea of fragment matching, where a symbolic description is split into fragments and these fragments are used to find related descriptions in memory. In experiments with a set of 56 simple descriptions of wars and revolutions we show that as we increase the size of the fragments that participate in matching, retrieval performance changes in a manner that parallels the difference between human novices and human experts. With features larger than an intermediate size, we find that retrieval once again degrades to the novice level or worse. We call this an example of the *Goldilocks Principle*, because the best feature size for structural retrieval is in the middle, not too big and not too small.

References:

[1] Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5, 121-152.

[2] Falkenhainer, B., Forbus, K. D., & Gentner, D. (1986). The structure-mapping engine. In *Proceedings of the Fifth Meeting of the American Association for Artificial Intelligence* (pp. 272-277). Lawrence Erlbaum Associates, Mahwah, NJ.

[3] Forbus, K. D., Gentner, D., & Law, K. (1994). MAC/FAC: A model of similarity-based retrieval. *Cognitive Science*, 19, 141-205.

[4] Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, 7, 155-170.

[5] Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology*, 12, 306-355.

[6] Rattermann, M. J., & Gentner, D. (1987). Analogy and similarity: Determinants of accessibility and inferential soundness. In *Proceedings of the Ninth Annual Conference of the Cognitive Science Society* (pp. 23-35). Lawrence Erlbaum Associates, Mahwah, JN.

[7] Thagard, P., Holyoak, K. J., Nelson, G., & Gochfeld, D. (1990). Analog retrieval by constraint satisfaction. *Artificial Intelligence*, 46, 259-310.