Dynamic Use of Multiple Analogies in the AMBR Model Causing Re-Representation of the Target

Georgi Petkov (gpetkov@cogs.nbu.bg)
Ivan Vankov (i.i.vankov@cogs.nbu.bg)
Boicho Kokinov (bkokinov@nbu.bg)

Central and East European Center for Cognitive Science, Department of Cognitive Science and Psychology,
New Bulgarian University, 21 Montevideo Street
Sofia 1618, Bulgaria

Abstract

This paper describes how the AMBR model explains multiple analogies and more specifically how the use of a superficially similar analogical base, that turns out to be inappropriate (we call it a bridge analogy), may actually lead to the re-representation of the target and the activation of a more appropriate remote analogical source. A simulation is described that demonstrates this capability of the model. A specific prediction of the model about the re-representation that the presence of the bridge analogical source is causing is tested in a psychological experiment.

Introduction

Analogy-making is considered to be a basic cognitive process that underlies much of human cognition (Hofstadter, 2001; Holyoak, Gentner, Kokinov, 2001). That is why of lot of efforts have been put to investigate this fundamental cognitive ability (Holyoak, Gentner, Kokinov, 1998; Gentner, Holyoak, Kokinov, 2001; Kokinov, Holyoak, Gentner, 2009).

Most of this research, however, is devoted to understanding single analogies, i.e. analogies between a target and a single source. While this is certainly a very wide spread phenomena, *multiple analogies* (i.e. analogies between a target and multiple sources) do play an important role as well. There are two reasons for the use of multiple analogies. The first reason is that it is not always the case that in our previous experience we do have a case close enough to the target that can help us cope completely with the new situation. We can, however, combine several previous cases each of which partially maps to the target to collectively help to solve the problem. In the early days of analogy research there were some interesting studies of multiple analogies in physics (Collins & Gentner, 1987, Clement, 1993), in astronomy (Gentner & Markman, 1997, Gentner, et al. 1997), in medicine (Spiro et al., 1989), in biology, archeology and philosophy (Shelly, 1998, 1999, 2003), in computer science (Burstein, 1986, 1988), in transportation (Veloso & Carbonell, 1993). There were even some initial computational models of multiple analogies that were trying to explain how the information from different sources is being integrated – CARL (Burstein, 1986, 1988) and a special version of the Multiple Constraint Theory (Holyoak & Thagard, 1989) suggested by Shelly (1999). However, later on the mainstream research in the field of analogy has concentrated on the single analogy case (Gentner, 1983, 1989, Falkenheiner at al., 1989, Holyoak & Thagard, 1989, Hummel & Holyoak, 1997, Kokinov & Petrov, 2001).

This paper is returning us to the study of multiple analogies from a new perspective following the second reason to use multiple analogies: the first analogy that comes to our mind is not necessarily the best one and we may reject it and search for a better one. Thus this first analogy may play the role of facilitator that invites the second one. Some call it "*bridging analogy*". We are interested in the dynamics of the re-representation processes that such bridging analogies trigger and how they facilitate the multiple analogies production.

The concept of bridging analogies was first introduced by John Clement and then used by Stella Vosniadou and others (Clement, 1993, 2009, Vamvakoussi, & Vosniadou, in press, Vosniadou & Skopeliti, in press). The idea is that the teacher can provide an intermediate analogical base that will be in-between the target and the desired remote analogical source. They have experimentally shown that children, students and even experts make the desired remote analogy easier if there is such a bridging analogy provided by the teacher of physics or mathematics.

In contrast, we are interested in the mechanisms of *spontaneously self-generating* of such *bridging analogies* and what their effect could be on the *re-representation of the target* and subsequent *search for better analogies*. The next section describes a simulation experiment which demonstrates the capability of the AMBR model to spontaneously come up with bridging analogies and use them in further search of a better remote analogy. Then we present the results of a psychological experiment which tests what are the influences of this bridging analogy on the evaluation of the desired remote analogy.

Simulation

The AMBR Model

We have used the AMBR model for simulating the process of spontaneous multiple analogy-making including the generation of bridging and remote analogical sources. The general AMBR model is described elsewhere (Kokinov, 1994, Kokinov & Petrov, 2000, 2001) and for the lack of space it will not be presented here again. Crucial features of AMBR are the *decentralised representation* of episodes

which allows for context-sensitive construction of the episode descriptions (past episodes are not stable static structures but are dynamically constructed on the fly); the *continuous change of the relevance* of the various representational elements which allows for dynamic processes of representation building and re-representation; the *emergent computation processes* which are based on local information processing only and depend on the computed relevance of the memory elements which allows for exhibiting context-sensitive computation.

In previous work we have demonstrated how perception and analogy-making interact in AMBR thus allowing for dynamic re-representation of ambiguous input stimuli under the pressure of the analogy-making process (Kokinov, Bliznashki, Kosev, Hristova, 2007; Kokinov, Vankov, Bliznashki, 2009). In the following simulation we are exploring AMBR's capability to produce several analogies one after another and exhibit dynamic re-representation of the target as result of these intermediate analogies.

Overview of the Simulation

The goal of the system is to find an appropriate remote analogy for the case of "a suicidal terrorist act, made by a single terrorist"; and if possible, to transfer additional knowledge or even a proposal for how to prevent further similar acts. One superficially similar potential base is the suicidal act of a kamikaze during the World War II. We expect the system easily to activate this base and to launch the analogy. However, this analogy is not good and will fail later on. The reason is that one vivid aspect of the kamikaze is their motivation: the kamikaze is typically coming from a wealth family; they are proud of their origin and culture, of their country; they perform their suicide act with pride and for the prosperity and safety of their country.

Once activated, the motivational aspect of the kamikaze situations will try to map with its analog in the terrorist situation. Thus, the question about the deep psychological motivation of the terrorist's act will "cross the mind", i.e. the system will activate it.

However, the encoded knowledge about the terrorist's motivation is that he is an immigrant for several years already; and although he has good educational and relatively good professional successes, he is not happy. He has never overcome the cultural differences; the guilty that he has left his country; and the nostalgia.

Once activated, this aspect of the target situation should activate completely different base. Namely, the base of a Bulgarian emigrant in Ireland who has the same problems to adapt himself to a different culture and, as a consequence, he beats his wife. Nevertheless that this base seems quite different from the terrorist's one, we expect it to win the analogy because of the deep structural analogy according to the motivation.

The last step for the system is to make a transfer. The story for the Bulgarian emigrant in Ireland has a happy continuation. This man has found a solution and has solved his problems. Actually, he has opened a Bulgarian restaurant and a small shop for traditional Bulgarian souvenirs. Thus, from one side, he has never uprooted fully from his country and, from other side, has deserved a respect from the Ireland people. Spreading of his traditional culture allows to the immigrant to stop beating his wife.

Dynamic of the simulation

The target situation is represented with eight instance AMBR-agents (fig. 1). Two of them stand for the terrorist himself and for the suicidal act.

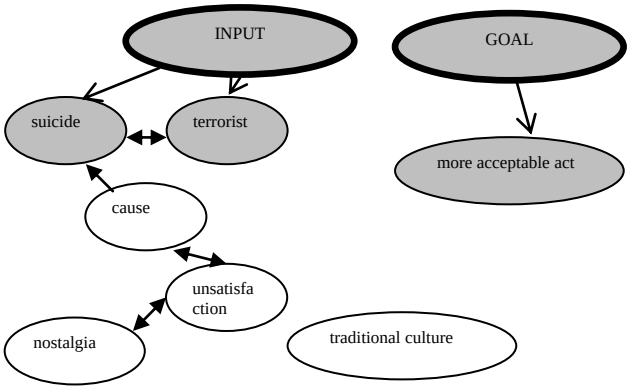

Figure 1. Schematic representation of the knowledge about the terrorist. The activation is represented with the level of gray.

These two nodes are directly attached to the INPUT and the activation spreads to the respective concepts and then back to some other known instances.

The other agents (in white on the picture) from the terrorist situations represent different aspects that the system 'knows' about the terrorists but these aspects cannot be activated easily. For example, a coalition of agents represents the deep motivation for the suicidal act of the terrorist – he is unsatisfied because of nostalgia or no acceptance of the cultural differences. However, there are not any links from the active elements to this aspect and as a consequence, the system does not 'think' about this at the beginning.

The agent 'more acceptable act' is attached to the GOAL node. Its purpose is an eventual solution to be transferred from somewhere around this agent. This agent is not connected to any other agent except its respective concept-agent.

Some other marginal pieces of knowledge are represented – for example the fact that the Arabic traditional culture is very rich and interesting for the foreigners.

One *binding-node* (not shown on fig.1), represents the whole situation. All other agents point to it, but there are few opposite links and all aspects of the situation cannot be activated from a single element.

During the first 5 AMBR cycles the activation spreads through the concepts of "suicide" and "terrorist" and then back to some typical instance. As the concept of a "japan kamikaze" is assumed to be a typical instance for a suicide, it is an opposite link from the concept of "suicide" to "kamikaze". The 'kamikaze' situation is represent again with a 'kamikaze' and 'suicide' nodes and like in the target situation the action 'suicide' is a relation with one argument

– ‘kamikaze’. This allows these pairs of nodes to be mapped easy (see Figure 2).

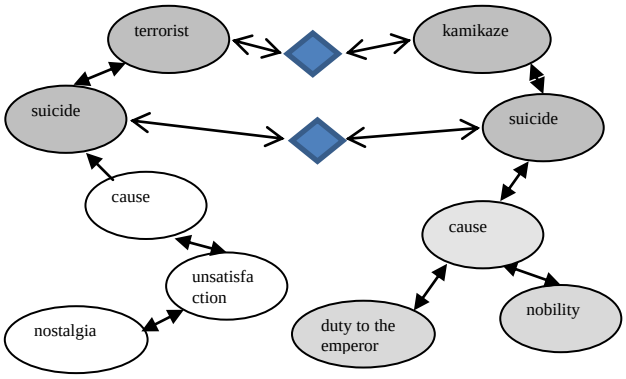

Figure 2. The mapping between the “terrorist” and “kamikaze” situations occurs at the 10th AMBR cycle. The hypothesis agents are represented with diamonds.

Once activated, the node for ‘kamikaze’ spreads activation to some other agents. The deep motivation for the kamikaze’s suicide is his honor in front of the nation, emperor and family. Thus, the activation spreads to the abstract concepts for the motivation in general, then back to the more concrete concepts and instances, and the motivational aspect of the terrorist’s act starts slowly to become active (Figure 3).

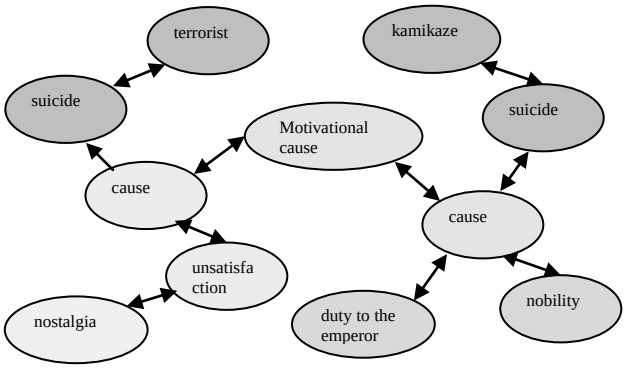

Figure 3. Between the 6th and the 19th AMBR cycles the motivational aspect of the “terrorist” story becomes active.

From other side, again from the ‘kamikaze’ base some other concepts become active because of a large number of associative links - ‘Japan’, ‘Shogun movie’, ‘England’, ‘Ireland’, etc (Figure 4).

As a result of the activation of the “immigrant” base, its elements map to the elements of the target situation. Thus, the “kamikaze” and the “immigrant” bases become competitors for the mapping with target situation.

The ‘immigrant’ base is structurally closer to the target situation, because both share the high-order relations about the motivational cause of the respective actions. Thus, nevertheless that the actions themselves are very different (the immigrant beats his wife, whereas the terrorist makes a suicidal act), they map each other because of the pressure for structural mapping.

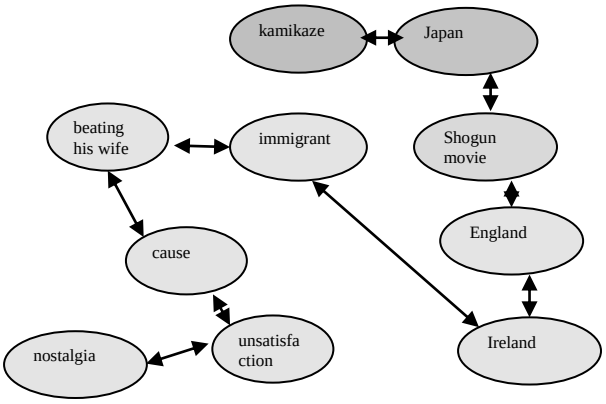

Figure 4. Between the 6th and the 17th AMBR cycles the activation spreads from the “kamikaze” base to the “immigrant” one.

Thus, at time 21 AMBR cycles (Figures 5, 6), the first mappings between the ‘terrorist’ and ‘immigrant’ situations are launched. Nevertheless, the ‘kamikaze’ situation is still more active and remains leading for a long time. The continuous structural pressure from the ‘immigrant’ situation cause firstly an inversion of the activation of the two bases (time 34); and much later the ratings are inverted too (time 77).

Finally, at time 128 the rating for the ‘immigrant’ base exceeds the threshold 1.000 and wins the competition. With other words, the hypothesis that the binding-node for the ‘terrorist’ situation corresponds to the respective binding-node for the ‘immigrant’ situation becomes a winner.

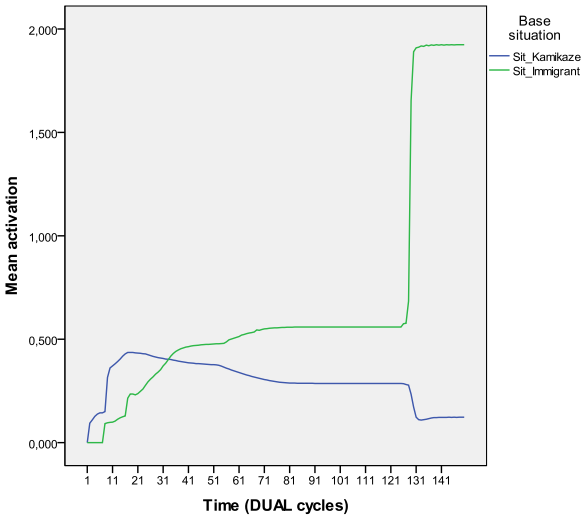

Figure 5. Activation level of the binding nodes for the two base situations (‘kamikaze’ and ‘immigrant’ as a function of time). At time 128 the mapping with the ‘Immigrant’ situation wins.

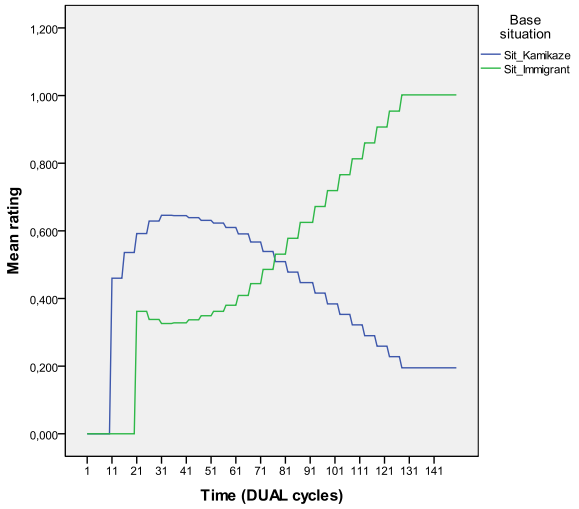

Figure 6. Rating of the hypotheses that the target situation ('terrorist') corresponds to the two base situations respectively ('kamikaze' and 'immigrant' as a function of time). At time 128 the mapping with the 'Immigrant' situation wins.

The transfer mechanism, however, does not wait for any winners. Soon after the goal-agent 'more acceptable act' from the 'terrorist' situation (see fig. 1) finds its correspondence, the system starts to transfer the respective relation. It is known from the base situation that the Bulgarian immigrant opened a Bulgarian restaurant in Ireland (which is an instance of popularization of the Bulgarian traditional culture) and this act causes stopping him beating of his wife. Thus, the most important causal relation (popularizing own culture in foreign countries causes acceptable actions) is transferred to the target situation (Figure 7). After winning of the respective analogy, these transferred agents remain in the description of the target and can be further interpreted.

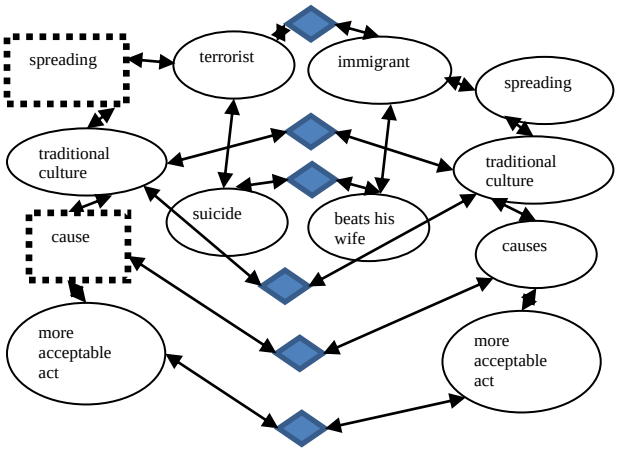

Figure 7. According to the transfer mechanism, if all arguments of a certain relation are mapped but the relation itself is not, then a copy of the respective relation is created. (The transferred elements are represented as dashed rectangles)

Experiment

The experiment is designed to test the model's prediction that a losing base for analogy may play role in highlighting specific aspects of the target that will improve the mapping between the target and another, appropriate base.

Design:

We performed an one-factorial between-group experiment. The independent variable was the group with two levels: control and experimental. The dependent variables were the judgments of the people on 7-point scales to four questions about how similar the stories and some of their aspects are.

Procedure:

Each participant received a sheet of paper with three short stories written on them. The instruction to the people was to read carefully all three stories and to prepare for answering some questions on them. There were no time limits for reading. Everybody worked alone, with the presence of the experimenter in the room only.

People from the control group received the stories "Terrorist", "Tsunami", and "Emigrant" (in this order); whereas people from the experimental group received "Terrorist", "Kamikaze", and "Emigrant" (see more about the stories in the section Stimuli below).

After that, the participants from the both groups received another sheet of paper with eight statements on each. The instruction was to evaluate on a 7-point scale how confident they feel each of the statements. The last four statements were equal for the both groups and concern the similarity between the "Terrorist" and "Emigrant" stories, as well the similarity between some of their aspects. The first four statements differed for both groups and concerned the similarity between the "Terrorist" and, respectively, "Tsunami" or "Kamikaze" stories. The subjects of analysis were the answers of the people to the four equal for both groups questions.

Stimuli

The four stories "Terrorist", "Kamikaze", "Tsunami", and "Emigrant" consisted of 120-170 words each. The first three stories were described as journalistic coverage, the fourth one – as a letter to a friend. The "Terrorist" coverage was about a lonely man who had crashed with a car-bomb in a market in New Jersey. The "kamikaze" report was about the grandson of a kamikaze, hero from the war. The grandson has been just nominated as an ambassador of Japan in US. The story for the tsunami (a control story for the participants from the control group only) was about a japan farmer who had lost his business because of a tsunami. The "Immigrant" story was a letter from the wife of the immigrant to her friend.

The questionnaire consisted of eight statements. The first four statements differed between the two groups. For the control group they served evaluating the similarity between the "Terrorist" and "Tsunami" stories; for the experimental group – respectively between the "Terrorist" and "Kamikaze" stories. People should evaluate how similar they feel the stories as a whole; the actions of the main heroes; the motives for their actions, and the nature of the persons as a whole.

The second group of four questions served for evaluating the similarity between the "Terrorist" and "Immigrant" stories according to the same criteria. These four questions were the same for both groups and were an object of analysis.

Participants:

42 students from New Bulgarian University participated in the experiment for course credits. They were randomly assigned to both groups. 24 of them fell in the control group; the other 18 – in the experimental group.

Results:

The main rating for how similar the stories for the terrorist and the kamikaze was 2.25 (st. dev. 1.225) for the control group, and 3.83 (st. dev. 1.79) for the experimental group. The difference turned to be significant: $t(40) = -3.404$, $p = 0.002$.

The respective differences for the three aspects of the stories, (whether the actions of the characters are similar; whether the motives for the actions of the characters are similar; whether the characters are similar in their nature) were not significant: respectively, $t(40) = -1.184$, $p = 0.243$; $t(40) = -0.798$, $p = 0.430$; $t(40) = -1.033$, $p = 0.308$.

Thus, the difference of the ratings for the overall similarity cannot be caused just by a simple assimilation effect. Instead, looking to each aspect of the stories separately, people from both groups do not differ in their ratings. However, it seems that people from both groups weight the different aspects of the stories differently because of the context of the third story. With other words, people weight the different aspects of the mapped stories differently because of the context. This means that they have different representations of the target situation.

Conclusions

Analogy-making is a powerful human ability for decision-making and evaluation. However, retrieval of the most appropriate base for analogy is a very difficult task both for humans and for the most of the models for analogy-making. It is relatively easy to retrieve situations that share the same superficial properties with the target, but it is very hard to retrieve a situation that shares the same high-level relations. In addition, the problem becomes even more difficult if the most important for the appropriate mapping aspects of the target story are not vivid.

We proposed an idea how both problems may be attacked via exploring the dynamics of multiple analogies. Instead of trying to retrieve the appropriate base directly, one may use one or more intermediate superficial analogies that slowly converge the system to the right solution. From one side, the intermediate analogies may help for the retrieval of a better structurally but less superficially similar episodes. From the other side, the intermediate analogies may cause a re-representation of the target and may highlight different aspects of it.

We used the AMBR model for analogy making to simulate this idea. One aspect of the representation of the target situation was left inactivated. The system easily extracts from its memory one superficially similar base and launched the mapping process. It was impossible for it at the beginning to activate one more appropriate base for the analogy because of its remoteness.

However, we propose at least two ways of how this remote base may be activated indirectly:

First, the initial mapping with the superficial base may cause a re-representation of the target, highlighting the non-vivid aspects of it.

Second, the superficial base may help for the further spreading of the activation to close and far associations.

The mechanisms for structural correspondence of the MABR model allow it to support and maintain the structurally well-organized mappings. Thus, nevertheless that the activation may spread to very different basis and many different initial mappings may be launched, AMBR behaves stable enough. Once it founds the most appropriate base, the consistent mappings cause additional activation of the respective appropriate base.

The hypothesis that a third, structurally not good base, may facilitate the analogy between two situations was tested with a psychological experiment. People judged with higher ratings the similarity between two situations in the context of a carefully chosen third one, in comparison with the same judgments in the context of an arbitrary third story. The context was chosen in a way to initiate some mappings between the target and the contextual stories. These initial mappings should make the important aspects of the target story on which the two stories differ more vivid. As a consequence, people weight these aspects higher.

At the same time, if people focus on the similarity of a certain aspect of the stories, there is no reason the context to influence their ratings. This was confirmed by the experimental results – people's ratings differ depending on the context only when the similarity of the whole stories should be evaluated; not when the respective similarity between concrete aspects of the stories should be rated.

Acknowledgements

This research was supported financially by the European Office for Aerospace Research and Development under grant FA8655-10-1-3061 (Adaptive Problem Solving by Analogy).

References

Burstein, M. (1988). Incremental Learning from Multiple Analogies. In: Prieditis, A. (ed.) *ANALOGICA*, Pitman, London.

Burstein, M. (1988). Combining Analogies in Mental Models. In: D. Helman (ed.), *Analogical Reasoning*, Kluwer Academic Publishers, pp. 179-203.

Burstein, M. (1986). Concept Formation by Incremental Analogical Reasoning and Debugging. In: *Machine Learning: An Artificial Intelligence Approach*, Volume II, Michalski, R. S., Carbonell, J. G., and Mitchell, T. M., eds., Morgan Kaufmann Publishers, Inc., Los Altos, Ca., pp. 351-370.

Burstein, M. (1986). Analogical Learning with Multiple Models. In: Mitchell, T. & Carbonell, J. (eds.) Machine learning: a guide to current research. Kluwer,

Clement, J. (1993). Using Bridging Analogies and Anchoring Intuitions to Deal with Students' Preconceptions in Physics. Journal of Research on Science Teaching, vol. 30, pp. 1241-1257

Clement, J. (2009). Creative Model Construction in Scientists and Students: The Role of Imagery, Analogy, and Mental Simulation. Springer

Collins, A., Gentner, D. (1987). How people construct mental models. In D. Holland & N. Quinn (Eds.), Cultural models in language and thought (pp. 243-265). England: Cambridge University Press.

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

Gentner, D. (1989). Mechanisms of analogical learning. In S. Vosniadou and A. Ortony, (Eds.), Similarity and Analogical Reasoning, 199-241. London: Cambridge University Press.

Gentner, D., Holyoak, K., Kokinov, B., eds. (2001). The Analogical Mind: Perspectives from Cognitive Science. Cambridge, MA: MIT Press.

Gentner, D., Markman, A. (1997). Structure Mapping in Analogy and Similarity. In: *American Psychologist*, vol. 52, pp. 45-56

Gentner, D. at al. (1997). Analogical Reasoning and Conceptual Change: A Case Study of Johannes Kepler. The Journal of Learning science, vol. 4, pp. 3-40.

Falkenhainer B., Forbus K., & Gentner D. (1989). The structure mapping engine: Algorithm and examples. *Artificial Intelligence, 41* (1), 1-63

Hofstadter, D. & the Fluid Analogies Research Group (1995). *Fluid concepts and creative analogies*. New York: Basic Books

Hofstadter, D. (2001). Analogy as the Core of Cognition. In: Gentner, D., Holyoak, K., Kokinov, B. (eds.) *The Analogical Mind: Perspectives from Cognitive Science*. Cambridge, MA: MIT Press

Holyoak K. & Thagard P. (1989). Analogical mapping by constraint satisfaction. Cognitive Science, 13, 295-355

Holyoak, K., Gentner, D., Kokinov, B., eds., (1998). Advances in Analogy Research: Integration of Theory and Data from the Cognitive, Computational, and Neural Sciences. Sofia: NBU Press

Holyoak, K., Gentner, D., Kokinov, B. (2001). The Place of Analogy in Cognition. In: Holyoak, K., Gentner, D., Kokinov, B. (eds.) *The Analogical Mind: Perspectives from Cognitive Science*. Cambridge, MA: MIT Press.

Hummel, J. & Holyoak, K. (1997). Distributed representation of structure: A theory of analogical access and mapping. Psychological Review, 104, 427-466.

Kokinov, B. (1994). A Hybrid Model of Reasoning by Analogy. Chapter 5. in: K. Holyoak & J. Barnden (eds.) *Analogical Connections, Advances in Connectionist and Neural Computation Theory*, vol.2, Ablex Publ. Corp.

Kokinov, B. Petrov, A. (2000). Dynamic Extension of Episode Representation in Analogy-Making in AMBR. In: *Proceedings of the 22nd Annual Conference of the Cognitive Science Society*. Erlbaum, Hillsdale, NJ.

Kokinov, B., Petrov, A. (2001). Integration of Memory and Reasoning in Analogy-Making: The AMBR Model. In: Gentner, D., Holyoak, K., Kokinov, B. (eds.) The Analogical Mind: Perspectives from Cognitive Science, Cambridge, MA: MIT Press.

Kokinov, B., Vankov, I., Bliznashki, S. (2009). How Analogy Could Force Re-representation of the Target and Inhibition of the Alternative Interpretation. In: Kokinov, B., Holyoak, K., Gentner, D. (eds.). New Frontiers in Analogy Research. Sofia: NBU Press

Kokinov, B., Bliznashki, S., Kosev, S., Hristova, P. (2007). Analogical Mapping and Perception: Can Mapping Cause a Re-Representation of the Target Stimulus? In: Proceedings of the 29th Annual Conference of the Cognitive Science Society. Erlbaum, Hillsdale, NJ.

Kokinov, B., Holyoak, K., Gentner, D. eds. (2009). New Frontiers in Analogy Research. Sofia: NBU Press

Shelley, C. (1998). Multiple analogies in evolutionary biology. In: Holyoak, K., Gentner, D., Kokinov, B. (eds.) Advances in Analogy Research: Integration of Theory and Data from the Cognitive, Computational, and Neural Sciences. Sofia: NBU Press.

Shelley, C. (1999). Multiple Analogies in Archeology. Philosophy of Science, vol. 66, pp. 579-605

Shelley, C. (1999). Reasoning by Multiple Analogies. PhD dissertation. U. Waterloo.

Shelley, C. (2003). Multiple Analogies in Science and Philosophy. John Benjamins Publishing

Spiro, R., Feltovich, P., Coulson, R., and Anderson, D. (1989). Multiple analogies for complex concepts: antidotes for analogy-induced misconception in advanced knowledge acquisition. In: Vosniadou & Ortony (eds.) Similarity and Analogical Reasoning. Cambridge Univ. Press, pp. 498-531

Vamvakoussi, X. & Vosniadou, S. (in press). Bridging the gap between the dense and the discrete: The number line and the 'rubber line' bridging analogy. *Mathematical Thinking and Learning*.

Veloso, M.M. & Carbonell, J.G.(1993). Derivational Analogy in PRODIGY: Automating Case Acquisition, Storage, and Utilization. *Machine Learning*, 10, 249-278

Vosniadou, S., & Skopeliti, I.. (in press). Instructional Analogies in Conceptual Restructuring Processes. *Cognitive Psychology.*