Structure-Mapping vs. High-level Perception: The Mistaken Fight Over The Explanation of Analogy

Clayton T. Morrison and Eric Dietrich
Philosophy And Computers & Cognitive Science (PACCS)
State University of New York
Binghamton, NY 13902-6000
clayton@turing.pacss.binghamton.edu
dietrich@turing.pacss.binghamton.edu

Abstract

There is currently a competition between two theories that propose to explain the cognitive phenomenon of analogy: Dedre Gentner's Structure-Mapping Theory and Douglas Hofstadter's theory of Analogy as High-level Perception. We argue that the competition between the two theories is ill-founded because they are after two different aspects of analogy: structure-mapping seeks a "horizontal" view of analogy where the phenomena is examined at the level of already existing psychological representations, and where the task is to identify what processes are common to all or most analogy function; High-level Perception, on the other hand, seeks a "vertical" view of analogy in which the goal is to explain the processes that make up the construction of representations. An integrated theory of analogy should encompass both horizontal and vertical views.

Introduction

In this paper, we argue that there is a mistaken competition between two theories of analogy: Dedre Gentner's structure-mapping theory (**SMT**), and Douglas Hofstadter's theory of analogy as high-level perception (**HLP**). Proponents of either theory have developed arguments claiming that their theory captures more of analogy than the other. The task of this paper is to separate these combatants and show that their theories are after explanations of different aspects of analogy phenomena, not necessarily pitted against one another.

Summary Of The Positions

Gentner's SMT (Gentner, 1980, 1983, 1989) describes analogy as a product of *structure-mapping*. A basic assumption of SMT is that our psychological concepts have a structure to them. According to Gentner, these structures are the psychological representations of relations between perceptual and conceptual objects. According to SMT, an analogy, the ability to recognize that "one thing *is like* another," is a *mapping* of one structure onto another according to a similarity comparison based on the relations represented in the concept structures. Gentner and others have set out to empirically test the explanatory power of this conception with respect to human analogical production (Gentner, Falkenhainer & Skorstad, 1987; Gentner & Imai, 1992; Gentner & Landers, 1985; Gentner & Rattermann, 1991; Gentner, Rattermann & Forbus, 1993; Kotovsky & Gentner, 1990). SMT has two key strengths: 1) it makes a clean distinction between analogies and other types of similarity comparisons (abstraction, anomaly, literal similarity, and mere appearance), both in theory and as evidenced in psychological examination; and 2) it is generally applicable — rather than requiring a specific algorithm for each potential analogy, or even a collection of algorithms for each domain of comparison, the generalized structure of knowledge representation and the structure-mapping algorithm makes it possible for any properly constructed knowledge structure to be compared and considered for structure-mapping.

The *Structure-Mapping Engine* (SME) (Falkenhainer, Forbus & Gentner, 1986, 1989; Gentner, Falkenhainer & Skorstad, 1987) is a computer model intended to simulate the structure-mapping process of Gentner's theory. When given a properly constructed representation, SME can find a mapping between the appropriate relations for each representation. A system of analogical retrieval, called MAC/FAC (Gentner, 1989; Gentner & Forbus, 1991; Gentner, Ratterman & Forbus, 1993), provides a plausible method by which a huge database of structured knowledge representations may be searched and an item retrieved from it with little computational strain. MAC/FAC includes SME as the key component that performs the structure-mapping.

Douglas Hofstadter and several of his graduate students (Hofstadter, 1984; Hofstadter, Mitchell & French, 1987; Chalmers et al., 1992; Mitchell, 1993; Hofstadter et al., 1995) propose a different approach to the explanation of analogy by which an analogy is conceived of as the product of a more general cognitive function called *high-level perception*. HLP is the process by which an organism's representation of a situation at a conceptual level is constructed based on an interaction between high-level concepts and low-level perceptual processes: high-level concepts influence low-level perceptual processing, while what is perceived at a low level affects the activation of high-level concepts as a representation of the situation is constructed.[1] The Copycat project, designed by Hofstadter and Mitchell (1992; Mitchell, 1990, 1993; Mitchell &

[1]The conceptual level is the level at which concepts begin to play a role; a concept is anything from object recognition (e.g., recognizing an apple) to the ability to grasp complex relations and situations (e.g., that Bill Clinton is in the Democratic Party).

Hofstadter, 1990), is a model of analogy as high-level perception. Copycat is intended to embody the principles of high-level perception by building it's own representation of an analogy situation in a simplified letter-domain. In order to really get at HLP, we must now turn to Hofstadter's criticisms of Gentner, and thus the confrontation between structure-mapping and high-level perception.

The Fight

The theory of high-level perception is first introduced in print in the paper, *High-level perception: representation and analogy*, by CFH[2] (Chalmers, et al., 1992). The main thesis of their paper is that HLP is deeply interwoven with other cognitive processes. They argue that much of the work in AI has attempted to model conceptual processes independently of perceptual processes, but that this approach cannot lead to a satisfactory understanding of the human mind. Therefore, they argue, researchers in AI must integrate perceptual processing into their modeling of cognition.

As an example of high-level cognition that depends on high-level perception (and *vice versa*), CFH take up the cognitive process of analogy. They posit that, "when people make analogies, they are perceiving some aspects of the structures of two situations — the *essences* of those situations, in some sense — as identical" (Chalmers et al., 1992, p.193). The structures of the representations of these situations are, they propose, the product of high-level perception. Analogical thought also provides an illustration of the flexible nature of our perceptual abilities. For instance, making an analogy requires highlighting various aspects of a situation, and the aspects that are highlighted are often not the most obvious features from the beginning. The perception of the situation can change radically, depending on the analogy we are making.

CFH divide the processes involved in analogical thought into two basic components. One is *situation perception*, the filtering and organizing of data involved in a given situation according to a given context. And the other is *mapping*, the taking of the representations of two situations and finding appropriate correspondences between components of one representation with components of the other to produce the analogy match-up. CFH claim that, "it is by no means apparent that these processes are cleanly separable; they seem to interact in a deep way" (Chalmers et al., 1992, p.195). They propose that because perception underlies analogy, we are tempted to divide the process of analogy sequentially into situation perception, followed by mapping (as Gentner's analogy architecture suggests). However, analogy is deeply involved in the situation perception stage as well; perceptions of many situations are possible because of analogical mappings. Thus, CFH conclude that situation perception and mapping processes go hand-in-hand.

For these reasons, CFH believe that perception must be accounted for in a model of analogical thought — something they claim has not been taken into account by current models of analogy. CFH make use of three technical terms in characterizing the pitfalls of separating perception from high-level cognition. The first term is that of *hand-coding* representations. This refers to the structuring of representations by humans. Hand-coding becomes a fallacy when an implementer's representations beg all the interesting cognitive questions; i.e., when the implementer encodes all the information needed to complete the task (e.g., BACON[3]). The second term is *rigidity*, a feature of representations in which they are inflexible or unable to change. This, CFH claim, may be a result of hand-coding representations rather than having the mechanism build them through some sort of constructive process. The third term is *20-20 hindsight*, which occurs when a researcher develops a mechanism that relies on hand-coded concepts rather than a mechanism that independently arrives at a representational structure for a particular concept. The mechanism using the hand-coded representations is said to be guilty of 20-20 hindsight.[4]

CFH accuse Gentner's model of analogy of bypassing the process of perception. They say that Gentner's approach involves starting with fixed, hand-coded representations which are compared and a mapping between them is performed. CFH's criticisms are focused on the difficulties that arise out of the rigidity of SME's representations, the foremost of which is the inability to change representations as needed during processing. According to Gentner's model, CFH claim, mapping is the only process involved in analogy. In SME, representations are hand-coded, and thus building is ignored — it is assumed that "correct representations" will be available through some external process. The result of SME's dependence on rigid representations is that decisions in representation must be precisely the right one's before processing starts. But such information as to which one's are correct is not available ahead of time unless (even to some extent) the analogy to be made is known ahead of time. And this is what makes SME guilty of 20-20 hindsight.

---

[2]The authors of this paper are David J. Chalmers, Robert M. French and Douglas Hofstadter. We will refer to the authors as **CFH** for abbreviation.

[3]The creators (Langley *et al.*) of BACON, a model of scientific discovery, claim that BACON is able to make scientific discoveries, such as Kepler's third law of planetary motion. However, the model is given *precisely the data required to derive the law*, so that it's "discovery" is reduced to a rather simple deduction that any beginning physics student should be able to deduce. For this reason, Chalmers et al. accuse BACON of having *20-20 hindsight* in being given only what is needed, when in fact the actual cognitive processes involved in such scientific discoveries are faced with the much more monumental task of paring down what is relevant and making careful hypotheses paired with testing, all part of an intricate process of induction.

[4]This fallacy is close to the fallacy of *begging the question*: for example, claiming that a program has independently arrived at a "discovery," when the "discovery" was already coded by the programmer into the program. For an excellent discussion of this sort of fallacy concerning two other programs, AM and EURISKO, see Koza 1992, pp.232-236.

Talking Cross Purposes

While these characterizations are true, CFH may have inaccurately construed what Gentner et al. claim SME can do. CFH claim that, "the SME program is said to *discover* an analogy between an atom and the solar system" (Chalmers et al., 1992, p.196; emphasis added). This is not true. SME is intended to explain what happens *in the comprehension of* an analogy between an atom and the solar system (Gentner, 1983; Gentner, 1989). It is not being proposed as a model of discovery through analogy (unlike BACON, where CFH's criticisms do seem apt).

It seems there is an important distinction which both Gentner and CFH have missed. It begins with an approach that is not made explicit by Gentner concerning what the structure-mapping theory is an explanation of. First outlined in Gentner 1983, the Structure-Mapping Theory is described as an explanation of how analogies are *produced*. In order to get this explanation, however, Gentner claims that the theory is aimed at answering the following question: how is it that one *derives meaning* from an analogy? (Gentner, 1983, p.155) This latter characterization makes structure-mapping an explanation of how analogies are *understood* or *comprehended* — the analogy has already been given, but the agent must produce a mapping in order to interpret the analogy. It is not clear that the processes of production and comprehension are the same. On the one hand, there are the situations where one may hear an analogy or be presented with one and then come to understand it. In most examples of how structure-mapping works, and especially in the operation of SME, the theory is presented as explaining this kind of situation. Production, on the other hand, seems to involve a different kind of situation: an agent observes events or situations and is able, on its own, to construct a similarity comparison between two situations (one observed and one recalled) and thus produce a novel analogy. While both understanding and production situations may share the common aspect of structure mapping, the conditions that lead to and influence the comparison are very different. All the conditions that surround the mapping are vital to understanding whether an analogy is being understood or whether a novel analogy is being produced —to leave the conditions of the mapping ambiguous seems to be a mistake. To claim that they are the same process is a profound statement about cognition. Whether structure-mapping is claiming this, or if it is only a model of analogy comprehension, is not made clear in Gentner's central papers (1980, 1983, 1989).

Gentner's theory is a theory of understanding (specifically, for good analogies) but she doesn't have a theory of how analogies are created in the first place. For example, she has a theory of what happened when Rutherford thought "the atom is like that solar system" and of what may go on when we are given this information, but she does not have a theory of how he managed to create this analogy in the first place. In other words, she doesn't have a theory of where structures come from (but she is working on it; see her treatment of *unpacking* in Kotovsky & Gentner, 1990). However, she does have a theory of what analogies are, given already existing structures. Thus, it appears that it is an explanation of analogy comprehension that structure-mapping is ultimately after. The situation Gentner is explaining is consistently presented as an agent being given an analogy and the agent then performs the mapping to create a new representation, thus high-lighting how the two situations are analogous. This is to be distinguished from the case of novel, independent, and unprompted analogy creation.

It seems that CFH may have gotten their mistaken impression of Gentner from this ambiguity between analogy comprehension and production. This also demonstrates that CFH probably don't make a distinction between the two. A model may exist in which these two are in one-and-the-same mechanism, but as Gentner's model appears to demonstrate, in not accounting for representation construction, analogy comprehension might be separated from analogy production. SME is a model of analogy *understanding* or *comprehension*, where the cognitive agent is given the analogy and must understand it given its current knowledge database (i.e., construct a representation from existing ones). In this case, there may be no need for construction of novel representations, and this limits its capacity to capture the dynamic aspects of natural analogy production. Any model that doesn't take this into account will be dependent on someone (or some module) to organize the information in a suitable manner so that a mapping can take place. So the dependence on hand-coding representations has severely limited the ability of SME to capture creative analogical production in the wild. However, as SME is a model of analogy understanding, it is immune to CFH's criticisms based on creating an analogy because in understanding, the hand-codings they look for (hand-coding the representations) may be legitimate.

In light of this, it is no surprise that SME doesn't do what CFH would like to see — they have mistaken what SME is explaining. This mistaken accusation as to what Gentner ultimately claims SME can do is very telling. The key criticisms that CFH bring to bear, with respect to what is missed in not accounting for representation construction, depend on SME being intended to explain how representations are constructed. HLP seems to be after the an explanation of novel analogy *production*. Their explanatory task, from which their criticisms against structure-mapping are derived, are aimed at how the analogy situation is perceived, and thus, how representations are constructed in the first place. But this seems to be something that SME isn't trying to do. CFH and the SME researchers are talking at cross purposes.

The View Of Analogy From The Horizontal And The Vertical

The fight between Hofstadter and Gentner appears unwarranted, particularly in light of the fact that they are after different aspects of analogical reasoning. And CFH have in some sense been unfair in their criticisms of SME. Their 1992 paper is written as though SMT and approaches like it had completely missed what analogy was about. Instead, they addressed a new issue in analogy, and likewise failed to appreciate the perspective SMT addresses.

But what has happened here? Both explanations seem important to an understanding of analogy, yet we are arguing that they are talking past one another. We claim that this a result of the two different sets of perspectives and goals in considering analogy phenomena. This is best described using a spatial metaphor of horizontal and vertical perspectives. On the one hand, we have SMT, which looks at analogy from a horizontal perspective: SMT views analogy in it's variety of forms and psychological manifestations, over a variety of different comparison domains, and searches for the common mechanism(s) involved in all these cases. This perspective is likewise seen in SME, which embodies the positive aspects of SMT by employing explicit structure-mapping and being a general mechanism for all kinds of possible comparison domains. HLP, on the other hand, looks at analogy from a vertical perspective: HLP views analogy as a process from the bottom up; as a representation-building process based on low-level perceptual processes interacting with high-level concepts. Copycat embodies the positive aspects of HLP by demonstrating how representations might be constructed, and by not depending on human hand-coding once set up in it's micro-domain.

This metaphor also helps to make sense out of the criticisms that each theory has of the other in that we can now see what questions they don't answer. First, SME does not have an answer for the hand-coding problem. CFH and Mitchell are correct in that SME does not account for a very compelling problem: where do the representations upon which mapping is performed come from? In light of this question, SME appears artificial. Copycat, on the other hand, is constrained by domain specificity: it can only produce analogies in a limited letter-domain. And it is unclear as to how the Copycat-style architecture can be extended to other, more psychologically plausible domains (Morrison, 1994). Thus, a similarly compelling problem is left unanswered with Copycat: How do we account for the ability to produce analogies between practically any domain? Both of these are daunting problems, and while each theory proposes to answer one, it has failed to captured the other. Table 1 is a summary comparison of SME and Copycat to highlight the two perspectives, what they are successful in explaining, and where they don't.

Conclusion

We are left with a key question: can the two problems above be solved and in a unified way? As things stand now, it seems as though we are in a dilemma in that the attempts of SMT and HLP to model one aspect of analogy resulted in missing another. And this is particularly compelling when one considers the extent and complexity of each — these models and the theories behind them are among the most respectable cognitive science has to offer. And while they may not have gotten the whole picture, they do offer important perspectives of analogy phenomena. In spite of this dilemma, we do wish to keep the faith and continue to believe that a comprehensive theory of analogy does exist. A comprehensive theory of analogy should be able to view analogy from all sides; it should be able to tell a complete story using both horizontal and vertical perspectives; and it should be able to explain how analogies are produced as well as understood, according to the same model (this issue is addressed in Morrison, 1994). While we do not have a theory to offer, we do think that we have added perspective to the "fight" that is taking place — perspective that gives us a deeper understanding of the theoretical terrain to be covered in a comprehensive theory of analogy, and what current approaches have to offer to such theory.

Table 1: Summary Comparison of SME and Copycat:Pros and Cons

SME
PROS:
Employs explicit and well-defined structure-mapping - if knowledge is structured (and we believe it is), then there *must* be some sort of structure-mapping that takes place to link up base-knowledge to target-knowledge
Based solidly on a robust psychological theory developed over almost two decades of empirical investigation
Generally applicable to all domains of analogical comparison
CONS:
Hand-coding - can' t produce it's own representations. Thus, depends on work done by humans (or implausible separate representation module).
Copycat
PROS:
In a vague way, captures the notion of representation construction - closer to novel representation production
Once set up by humans in a specific domain (the letter-domain), it operates independently of humans
CONS:
Domain specificity - can only produce analogies in limited letter-domain

References

Chalmers, D. J., French, R. M., & Hofstadter, D. R. (1992). High-level perception, representation, and analogy: A critique of artificial intelligence methodology. *Journal of Experimental & Theoretical Artificial Intelligence* 4:185--211.

Falkenhainer, B., Forbus, K. D., & Gentner, D. (1986). The structure-mapping engine. In *Proceedings of the American Association for Artificial Intelligence* (pp. 272--277), Philadelphia.

Falkenhainer, B., Forbus, K. D., & Gentner, D. (1989). The Structure-Mapping Engine: algorithm and examples. *Artificial Intelligence* 41:1-63.

Gentner, D. (1980). The Structure of analogical models in science (BBN Tech. Rep. 4451). Cambridge, MA: Bolt, Beranek & Newman.

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

Gentner, D. (1989). The mechanisms of analogical learning. In Vosniadou, S. & Ortony, A. (Eds.), *Similarity and Analogical Reasoning* (pp. 199--241). Cambridge: Cambridge University Press.

Gentner, D., Falkenhainer, B., & Skorstad, J. (1987, January). Metaphor: The good, the bad, and the ugly. In *Proceedings of the Third Conference on Theoretical Issues in Natural Language Processing* (pp. 155--159). Las Cruces, NM.

Gentner, D. & Forbus, K. (1991). MAC/FAC: A model of similarity-based retrieval. In *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Earlbaum Associates.

Gentner, D., & Imai, M. (1992). Is the future always ahead? Evidence for system-mappings in understanding space-time metaphors. In *Proceedings of the Fourteenth Annual Conference of the Cognitive Science Society*. Chicago, IL.

Gentner, D. & Landers, R. (1985, November). Analogical remindings: A good match is hard to find. In *Proceedings of the International Conference on Systems, Man, and Cybernetics*. Tucson, AZ.

Gentner, D., & Rattermann, M. J. (1991). Language and the career of similarity. In Gelman, S. A. & Byrnes, J. P. (Eds.), *Perspectives on thought and language: Interrelations in development*. London: Cambridge University Press.

Gentner, D., Ratterman, M., & Forbus, K. (1993). The roles of similarity in transfer: Separating retrievability from inferential soundness. *Cognitive Psychology* 25: 524--575.

Hofstadter, D. R. (1984). The Copycat project: An experiment in nondeterministic and creative analogies (Memo 755). Cambridge, MA: MIT, Artificial Intelligence Laboratory.

Hofstadter, D. R. & Mitchell, M. (1992). An overview of the Copycat project. In Holyoak, K.J. & Barnden, J. (Eds.) *Connectionist Approaches to Analogy, Metaphor, and Case-Based Reasoning* (Norwood, NJ: Ablex).

Hofstadter, D. R. & Mitchell, M., & French, R. M. (1987). Fluid concepts and creative analogies: A theory and its computer implementation. Technical report 10, Cognitive Science and Machine Intelligence Laboratory, University of Michigan, Ann Arbor.

Hofstadter, D. R. et al. (1995). *Fluid Concepts and Creative Analogies*. New York: Basic Books.

Kotovsky, L. & Gentner, D. (1990). Pack Light: You will go farther. In *Proceedings of the Second Midwest Artificial Intelligence and Cognitive Science Society Conference*. (pp.60--72).

Mitchell, M. (1990). Copycat: A computer model of high-level perception and conceptual slippage in analogy-making. Doctoral dissertation, University of Michigan.

Mitchell, M. (1993). *Analogy-Making as Perception: A Computer Model*. Cambridge: The MIT Press.

Mitchell, M. & Hofstadter, D. R. (1990). The emergence of understanding in a computer model of concepts and analogy-making. *Physica D* 42:322--334.

Morrison, C. T. (1994). Analogy and Constructive Representation. Master's Thesis. Dept. of Philosophy, SUNY Binghamton, Binghamton, NY.