# A NEW MODEL OF SIMILARITY

## Finding the Essence of Similarity: The Four Way Variance Model

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## Abstract

The purpose of the present meta-analysis is to cross traditional discipline boundaries in order to integrate their findings and explore a new approach to the study of similarity. Previous research findings show that similarity judgments are complex and highly variable. With previous models, the understanding of similarity is as complex and variable as similarity itself. The author incorporates previous research findings from the disciplines of neuropsychology, developmental psychology, and cognitive psychology to develop a new model of similarity called the Four Way Variance Model. The paper concludes with an application of the model.

There is a constantly changing, infinite amount of perceptual information in the world. organisms who actively interact with and within this environment need to be able not only to perceive these perceptual cues, but they also need to be able to organize the infinite amount of information in some way. We live in a world where stimuli that are encountered once are likely to be encountered again (Zarate & Sanders, 1999), and often in a slightly different form. Human evolution has equipped us with the ability to both perceive our environments and to organize and remember past stimuli. The question of how we are able to do these things and thereby behave effectively in the world has intrigued many psychologists and cognitive scientists, sparking extensive research on the topic. Although these disciplines have developed a strong understanding of how our five senses perceive the world, an answer to how we organize and store the knowledge our senses bring to us is far less conclusive.

The initial goal of this paper was to develop an understanding of how humans use similarity to create categories and organize information from the external world. The first step in developing this understanding was an investigation of similarity. With established models of similarity, it became clear that this is an incredibly convoluted task. Rather than abandon the construct of similarity, the purpose shifted to an integration of previous research findings and the development of an alternate model for understanding similarity called the Four Way Variance Model.

## VARIABILITY IN PAST SIMILARITY FINDINGS

It is currently believed that we organize knowledge into concepts, each one being a representation of a category in our mind. Concepts function to make sense of the huge amount of information that surrounds us by guiding our attention and by facilitating

generalization, classification, inference, interpretation, and communication (Kunda, 1999). Specifically, classification allows us to make inferences on the basis of partial information (Medin & Coley, 1998). A category is defined by Medin and Coley (1998) as the set of entities picked out by the concept in a nonarbitrary manner. It is plausible that similarity, the degree of overlap between the respective properties of two stimuli, is the organizing principle for categories and categorization since "entities within the same category tend to be more similar to each other than they are to examples from contrasting categories"(Medin & Coley, 1998). This sentence fits with the natural understanding of similarity that everyone holds and uses in daily conversation. However, when you look beyond intuitive understanding, similarity quickly becomes too flexible to explain categorization and is better seen as its by-product rather than its cause (Medin & Ross, 1992).

Once you venture beyond intuitive understanding, the complex nature of similarity becomes apparent. It has been found that, depending on the level of analysis, any two things can be judged as arbitrarily similar or dissimilar (Medin & Coley, 1998). Formal models of similarity need to afford it great flexibility in order to account for the variability found in the research. To begin with, similarity judgments vary according to the goal of the categorization. Items will hold similarity insofar as there is a uniting purpose between them. The most well known example of this is Barsalou's (1991, cited in Ross and Murphy, 1999) work showing that children, money, and photo-albums are similar in that they are all items you would take out of a fire. Likewise, Medin, Lynch, Coley and Atran (1997) found that while taxonomists categorized trees according to morphological similarities, landscape workers categorized trees according to

their similar functions in landscaping. The goals of both these groups, taxonomists and landscapers, influenced their respective similarity judgments.

Secondly, an individual's prior knowledge and area of expertise will vary the similarity judgments reached. Referring once more to the work of Medin et al. (1997), the differences in similarity judgments made by the taxonomists and the landscape workers can be attributed to the differences in expertise between each group. Furthermore, a dichotomy can be seen when novices or experts are given the task of sorting physics problems. Where novices group according to superficial similarity, experts group according to underlying physical principles (Chi, Feltovich, and Glaser 1981, cited in Kunda 1999).

A third point of variability is the context of the similarity judgment. Goldstone, Medin, and Halberstadt (1997) found that the similarity of two things depends greatly on the context of the judgment. This includes not only the alternatives available in the stimulus set, but it also includes the alternatives that had been presented on previous trials; prior alternatives will subsequently create a context for the later comparisons. They concluded that, rather than being fixed to physical properties a priori, salience of a dimension is modified "on line" at the time of the similarity judgment. Not only do the variables presented alter the context, but the way in which the question is phrased will also place a contextual constraint on the similarity judgment. Responses were found to vary with the direction of comparison required (How similar is A to B? verses How similar is B to A?) (Goldstone et al., 1991, cited in Soloman and Rips, 1998).

Ross and Murphy (1999) looked at the real world category of food in order to find how similarity judgments would be conducted for a domain that everyone had extensive

experience with and which everyone found extremely personally relevant. They found that the contexts of other foods, the time of day, the setting, and other cultural indicators will each determine the ways which foods are grouped together and the categories that are activated.

A fourth variable of similarity is that individuals will not make similarity judgments that do not make semantic sense. Bassok and Medin (1997) found that when asked to judge similarity of paired stimuli, participants would integrate the stimuli into common thematic scenarios which would make sense of the stimuli. Semantic dependencies of the stimuli affected similarity judgments by inducing participants to systematically replace the process of comparison with that of association. In earlier work by Markman and Medin (1995), it was found that justifications of similarity judgments systematically favoured comparable over noncomparable properties. Participants did not willingly judge the similarity along nonsensical dimensions.

Furthermore, Wisniewski and Bassok (1999) articulated that in cases of comparison, the scenarios were from the same taxonomic category and were alignable (e.g. "we bought the Saturn because it is safer that the Dodge Neon"). In cases of integration the scenarios played different roles in a thematic relationship and were non-alignable (e.g. "the Saturn is safer than the car key”). Wisniewski and Bassok (1999) could not alter this pattern of similarity judgments with changes in the emphasis in questioning ("goes with" verses "is similar to") leading them to conclude that stimuli primarily affected the type of processing in the similarity judgment. In contradiction to this however, Yamauchi, Takashi, and Markman (2000) have found that category membership, not the stimuli themselves, affected the processing. They found category

to influence inference even when similarity information contradicted the category label. Their findings suggest that category labels and category features are two different things

Finally, similarity is variable according to the salience of dimensions within the stimuli. Goldstone (1994, as cited by Sloman &Rips, 1998) has shown that when participants are told to make similarity judgments based on discrimination of visual patterns on one dimension, variation on an irrelevant dimension can slow them down. Likewise, Kaplan and Medin (1997) found similarity ratings to reveal a robust coincidence effect indicating that salience of a dimension varies similarity judgments. Coincidental exact matches on a salient dimension were weighed more heavily by participants than overall proximity in a similarity space. Kaplan and Medin (1997) do not, however, try to claim that coincidence is the mechanism of similarity, but rather that it is one type of similarity pattern displayed.

In conclusion, the flexibility of similarity is mediated by a number of variables including goals, prior knowledge, context, semantic coherence, and the relative salience of a dimension. This highly variable set of findings leaves the reader asking how coherence within the topic of similarity could possibly be found. The Modal Approach to similarity proposed that concepts are comprised of features and that two entities are similar to the extent that they share underlying features (Medin & Coley, 1998). This model of similarity has been criticized because it does not specify how the basis for this similarity is decided (Medin & Coley, 1998). The great variability found in the research reviewed above provides further support for this criticism. In Sloman and Rips's (1998) review of similarity they divide the views of similarity into four groups: strong similarity, weak similarity, feeble similarity, and no similarity. Each of these views vary in the

degree to which similarity plays an explanatory role in categorization, from stating that similarity judgments are automatic and impenetrable to stating that similarity judgments are so complex that understanding them would require understanding whatever we are trying to use similarity to explain. Each of these views have supporting empirical data, especially the last one; similarity judgments are complex and highly variable. It is very tempting to throw up your hands to the variability found in the research and say that similarity will not be understood. Research could then turn to investigating the mechanism of categorization and concept development which we have been trying to explain with similarity.

How then, though, could we explain the fact that people make "similarity" judgments. Even experts in the area, who are arguably very conscious of "similarity", use the mechanism in their discussions in order to connect thoughts: "... taxonomic categories we investigated. *Similarly*, it is not known whether the basic categorization can be overruled by goal directed categories..." (Ross and Murphy, 1999). It appears that there is something to similarity which is unique in and of itself, and that similarity should not be dismissed.

## A NEW THEORY: THE FOUR WAY VARIANCE MODEL

Part of the failure to develop a comprehensive theory of similarity is due to a lack of cross-disciplinary research. Sticking primarily to testing similarity by presenting semantic or visual stimuli and then coding the verbal responses has failed to break through the diverse empirical findings to form a unified theory of similarity. There is obviously something missing within the process of constructing the research and posing the questions to be investigated. In the research for this paper, neurological and

developmental psychology findings were investigated alongside cognitive psychology. These areas emphasize the difference between implicit (outside conscious awareness) and explicit (within conscious awareness) tasks. Cognitive psychology makes a differentiation between procedural (that which can not be communicated verbally) and declarative (that which can be communicated verbally) knowledge. Together these distinctions can be combined into a two by two matrix to create four distinct areas where similarity judgments take place (Appendix A). By organizing cognition in this manner, it is much easier to be methodical in accounting for the variability in similarity findings. It is also possible to pose tasks in a way that would only test one of these four quadrants allowing the complexity of similarity to be explained more succinctly. This two by two matrix forms the Four Way Variance Model of Similarity (FWVM).

Support for the dissociation of implicit and explicit similarity tasks comes from neurological research. Very interesting data comes from patient LEW, reported in the work of Robertson, Davidoff, and Braisby (1999), who suffered a left hemisphere stroke leaving him with full visual fields, normal short-term spatial memory, and intact implicit categorization judgments. Despite these normal abilities, he failed significantly in tasks testing explicit categorisation judgments. He had no difficulty recognizing and interacting with objects, rather his problems appeared to be conceptual in nature. When given a colour sort task LEW grouped the colours in ways that were considered “illogical, paradoxical, or incoherent” (pg. 27), but he had no trouble choosing which colour was the odd-one-out. The same pattern of results was found for facial expressions. LEW could not make a categorization that required more than direct perceptual similarity. His knowledge about category boundaries is implicitly available for the task of eliminating

one stimuli, but is not available for an explicit free sort task. Robertson et al. (1999) proposed that similarity is an umbrella term for two different types of similarity comparisons, some involving only perceptual attributes, and some involving category relevant information. This conclusion has been integrated into the FWVM, theorizing that implicit procedural similarity judgments would rely on perceptual attributes and explicit declarative judgments would use more category relevant information.

The selective degradation in LEW's abilities suggests that implicit similarity judgments are localized in different areas of the brain from explicit similarity judgments. Robertson et al. (1999) suggest that LEW's implicit perceptual categories are completely hard-wired into the visual system which was still intact after his stroke, and that these categories could be both acquired through experience and genetically coded from birth.

Additional neurological findings also support the theory of localization of similarity judgments within the brain. Mummery, Patterson, Hodges, and Price (1998) predicted that the processing of what an object looks like would be neuroanatomically dissociated from processing where the object is typically found. They found that the left temporo-occipito-parietal junction showed enhanced activity for similarity judgments about object location, and that the left anteromedial temporal cortex and caudate nucleus were differentially activated by colour similarity judgments. These results suggest that perceptual similarity judgments are fundamentally different from similarity judgments involving context. Later work by Price, Mummery, Moore, Frackowiak, and Friston (1999) found that the extrasylvian temporo-parietal and medial superior frontal regions are sufficient to perform semantic similarity judgments.

Recent work within cognitive psychology also supports a dissociation between implicit and explicit tasks. The research of Humphreys, Tehan, O'Shea and Bolland (2000) found proactive interference effects for cued recall tasks when the target words were "similar", but found no effect of "target similarity" on free association tasks. This research is flawed in that it uses a common understanding of similarity to choose "similar" target words without ever explaining why those words are considered similar. It is helpful, however, because it shows that implicit tasks vary from explicit tasks in that they are affected differently by proactive interference on the dimension loosely defined as "target similarity".

These results validate the need to separate the implicit tasks (like free association) from the explicit tasks (like cued recall) which have been widely used in similarity research. This differentiation may account for some of the variability found in the literature. The FWVM separates implicit and explicit tasks because they do not test the same neural pathways nor the same type of similarity judgments. At the right level of observation, future research may find that the four areas of the FWVM are each characterized by unique patterns of neural activation.

The second differentiation in the FWVM, that between procedural and declarative knowledge, was sparked by the work of Lockart, Layman, and Glick (1988) on insight problems. They differentiate between procedural and declarative knowledge in the transfer of concepts. Their research revealed that concept training within procedural knowledge, but not within declarative knowledge, facilitated future problem solving skills. There is therefore a difference between procedural concepts and declarative concepts. Since similarity is so closely tied to concepts and categorization, there may also

be a difference between procedural similarity and declarative similarity.

The research reviewed at the beginning of this paper is based heavily on declarative responses which are inherently insufficient for understanding similarity due to the ineffable nature of many similarity judgments. Although individuals can justify their similarity comparisons, they can not state why, for example, they know that apples and oranges are extremely dissimilar and can be widely used as an exemplar of a bad comparison (Wisniewski and Bassok, 1999). Research within developmental psychology was reviewed in order to investigate the declarative-procedural dichotomy. A starting point into procedural similarity is to investigate the actions of preverbal infants who can not articulate their similarity judgments but rather can simply act on them. Quine (1977, cited in Mandler and McDonough 1996) found that generalizations in infancy were based on physical similarity in areas such as colour, shape, and texture. Recent work done by Gerhardstein, Adler, and Rovee-Collier (2000) has found that three month olds represent the specific size of an object and can discriminate that particular size from other sizes twenty-four hours later. When the task does not require reaching, it has been found that even newborns include size in their mental representations of an object (Slater et al. 1990, cited in Gerhardstein et al., 2000). The proficiency of infants to perceive the physical aspects of a stimuli supports the theory that physical characteristics are the primary basis for similarity judgments. This impact of direct perceptual similarity is evident in the structure of people's naturalistic similarity theories (Medin and Ross, 1992).

Mandler and McDonough (1996) investigated categorization of perceptually similar categories in fourteen month olds. A very interesting finding from this research is

that infants can not only classify on the basis of percept, but that they are also influenced by conceptual categories. The infants generalized across the entire category of animal no matter how perceptually diverse the stimuli were. They would then attend to an aeroplane as novel stimuli even if it was extremely perceptually similar to the bird included in the animal set. The same pattern of generalization was seen across the category vehicles, with a subsequent novel response to an animal added to the vehicle stimuli set. Not only did categories influence the infant's pattern of habituation to stimuli, but they also influenced the infants imitations of actions performed by the experimenter. Infants were reluctant to cross category boundaries to perform inappropriate actions. Mandler and McDonough (1996) concluded that there was more than one type of categorization taking place in infancy. Their results support both the theory that procedural concepts differ from declarative concepts, and the theory that procedural similarity differs from declarative similarity. Florian (1994) found that adults show the same pattern similarity judgments as children aged three to five on the declarative similarity judgment tasks she administered. It is not a far leap to hypothesize from these findings that adults would also show the same pattern of procedural similarity judgments as the infants tested.

## APPLYING THE FOUR WAY VARIANCE MODEL

Now that the FWVM has been developed it should be applied to the variable findings regarding similarity. It allows for varying levels of perceptual similarity, semantic similarity, and cognitive concepts to interact when making a similarity judgment. FWVM therefore also allows for variance in the explanatory role of these factors (recall Sloman & Rips (1998) criticism that similarity shows varying levels of the explanatory role that it plays in categorization).

Implicit Procedural Similarity (IPS) accounts for results of perceptual similarity judgments, variance due to the salience of a dimension, and variance due to context. Since salience of a dimension and context are closely tied to perception they are included in the same quadrant. It should be noted, however, that Mummery et al. (1998) found that the percept of an object was processed separately from the context of the object. There is therefore more than one mechanism working in context analysis and context may also play a role in Explicit Procedural Similarity. IPS has the highest reliance on perceptual cues, and the lowest reliance on semantic similarity and higher cognitive concepts. These similarity judgments are quick and automatically acted upon without higher cognitive analysis.

Implicit Declarative Similarity accounts for the ineffable nature of many similarity judgment and categories. It is in this quadrant that prior knowledge and expertise plays a large role along with other high order cognitive concepts. These variables are included under implicit similarity because, for example, the physics expert categorizes based on underlying principles outside of conscious awareness. He would have to put cognitive effort into not categorizing in this manner, but he can easily articulate the final categorization.

Explicit Procedural Similarity is the least well defined category because the two terms generally contradict each other. It is not obvious how a similarity judgment could be made at a conscious level without then being vocalizable. An emphasis on procedural aspects needs to be made in that similarity judgments within this quadrant would result in actions not simply answers. It is in this quadrant that the variable of semantic coherence fits. Like infants who will not imitate actions inappropriate to the category (Mandler et

al., 1996), adults will not make comparisons which are inappropriate to the coherent schema (Wisniewski & Bassok, 1999). Both these findings are procedural in nature.

Explicit Declarative Similarity is the most straightforward quadrant. If one were to be perfectly strict in categorizing the research findings most current results, aside from the developmental psychology results, would have to be placed within this quadrant. The vast majority of findings have been taken from verbal declaration of similarity comparisons which are within conscious awareness. The variance due to the goals of the individual is included here. Goals are the explicit uniting purpose to the similarity judgment and are used to answer questions like “What will I eat for breakfast?” (Ross et al., 1999). This quadrant contains the most variance due to cognitive concepts applied to the stimuli, and the smallest effects of perceptual and semantic similarity.

In both procedural quadrants, stimuli would primarily affect the similarity judgment as was found in the work of Wisniewski and Bassok (1999). On the other hand, in both declarative quadrants category structure would override similarity judgments as found by Yamauchi, Takashi, and Markman (2000). For a summary of how results fit into the FWVM please refer to Appendix B.

Although similarity has been intimately connected with research on categorization and it is this research which was focused on in this paper, similarity has also been connected with a wide range of theories including theories of reasoning, decision making, problem solving, and memory searches. Similarity has not yet offered insight to any of these theories, but rather has opened them to the criticisms which similarity receives. Without an accurate understanding of similarity, one can not provide further understanding to subsequent theories (Vervaeke, 2000). Going beyond intuitive

understanding of similarity to find its essence is the challenge presented to researchers on the topic. Previous findings do not fit perfectly into the FWVM in part because the methodology of those experiments did not test one quadrant specifically, and in part because the model is not perfect. The model does however provide a framework through which research on similarity could become more methodical and thereby have more power to account for the variance in findings. The ability to account for the flexible nature of similarity would bring cognitive psychology closer to the essence of similarity.

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# Appendix A

| | Procedural | Declarative |
|---|---|---|
| Implicit | Implicit Procedural Similarity | Implicit Declarative Similarity |
| Explicit | Explicit Procedural Similarity | Explicit Declarative Similarity |

# APPENDIX B

The Four Way Variance Model of Similarity Judgements

| | Procedural | Declarative |
|---|---|---|
| Implicit | -highly guided by perceptual similarity<br>-**salience of a dimension**<br>-**context**<br>-stimuli would primarily affect the similarity judgement | -**prior knowledge**: answers where the process to the answer is ineffable<br>-where the knowledge is so well learnt that it now is activated automatically<br>-category structure would override similarity judgements |
| Explicit | -**semantic coherence**<br>-**context**<br>-stimuli would primarily affect the similarity judgement | -**goals**: the explicit uniting purpose to the similarity judgement<br>-highly guided by cognitive manipulation to apply category relevant information<br>-answering questions like "What will I eat for breakfast?"<br>-category structure would override similarity judgements |