Analogical versus Rule-based Classification[1]

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Abstract

Classification models have implicitly assumed that the nature of the representation that emerges from encoding will determine the type of classification strategy that will be used. These experiments, however, demonstrate that differences in classification performance can occur even when different transfer strategies operate on identical representations. Specifically, a series of examples was presented under incidental concept learning conditions. When the encoding task was completed, subjects were induced to make transfer decisions by analogy to stored information or to search for and apply rules. Across four experiments, an analogical transfer mode was found to be more effective than a rule-based transfer mode for preserving co-occurring features in classification decisions. This result held across a variety of category structures and stimulus materials. It was difficult for subjects who adopted an analytic transfer strategy to test hypotheses and identify regularities that were embedded in stored instances. Alternatively, subjects who adopted an analogical strategy preserved feature covariations as an indirect result of similarity-based retrieval and comparison processes.

Introduction

There are a variety of different strategies that people can use to learn concepts. Research that has examined the influences of learning strategies has found that different strategies produce clear differences in classification performance (e.g., Medin & Smith, 1981; Nosofsky, Clark, & Shin, 1989; Wattenmaker, 1991). Although this research has examined influences of alternative encoding strategies, it seems likely that there are also a variety of transfer or *postencoding* classification strategies that can be adopted. All research that has investigated relationships between strategies and classification performance, however, has only manipulated encoding strategies. In contrast, the present experiments investigated the influences that different transfer strategies have on classification performance.

In particular, the contrast between analytic and nonanalytic encoding strategies (e.g., Brooks, 1978; 1987) was extended to transfer strategies. In *nonanalytic transfer* conditions subjects were encouraged to make decisions by analogy to known instances (e.g., Medin & Edelson, 1988; Gentner, 1983; Holyoak & Koh, 1987). In *analytic transfer* conditions, however, subjects were encouraged to make transfer decisions by developing and applying rules. There is evidence that analogy can be effective for preserving complex regularities in decisions (e.g., Brooks, 1978, 1987; Wattenmaker, 1991), but there is very little research that has examined the ability of people to detect regularities that are embedded in stored information.

The general procedure in the experiments was to have subjects memorize a set of instances (short descriptions of hypothetical people) under incidental

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concept learning conditions. After the examples had been memorized, the subjects were induced to make decisions by analogy to stored instances or to analyze the stored examples and develop rules. The analogy and analytic tasks were concealed until memorization had been completed. Thus all comparisons and analyses were heavily dependent on retrieval processes. Many features co-occurred in the memorized examples, and the central question was whether these co-occurrences would be preserved in classification judgments in the analogical and rule-based transfer conditions.

One possibility was that an analogical transfer mode would preserve co-occurrences as an indirect result of similarity-based retrieval mechanisms (Medin, Altom, Edelson, & Freko, 1982; Medin, 1983; Ross, 1989; Wattenmaker, Nakamura, & Medin, 1988), but that limitations associated with retrieving and analyzing stored information would make it difficult to recover co-occurrences in the rule condition (Wattenmaker, in press). In this case, an analogical transfer mode would be more effective than a rule-based transfer mode for preserving co-occurrences. A major way that encoding strategies influence classification performance, however, is by influencing *what* information is encoded (Medin & Smith, 1981; Medin, 1986). Thus, it is not clear that any differences in classification should be expected when different transfer strategies operate on identical representations.

Experiment 1

To examine the ability of analogical and rule-based transfer strategies to preserve correlated features, subjects in both conditions initially memorized descriptions of hypothetical people that had co-occurring features. When the descriptions had been memorized, a set of transfer tests was presented, and subjects were induced (through instructional manipulations) to make decisions by analogy to stored examples or to analyze the stored examples and develop rules. Performance on the transfer tests was examined to determine the extent to which decisions preserved the feature co-occurrences.

Method

Subjects. The subjects were 50 undergraduates from the University of Pittsburgh who participated in the experiment to fulfill course requirements.

Stimuli and procedure. Eight descriptions of hypothetical people (e.g., *likes diet pepsi, has a blue car, was born in July, likes apples, and has dark hair*) were memorized by subjects in both conditions. Four of the examples belonged to one category (Category A) and four of the examples belonged to another category (Category B). Each example had one feature on each of the following dimensions: beverage preference (diet coke or diet pepsi), color of car (blue or green), month of birth (July or August), fruit preference (apples or peaches), and hair color (light or dark). In terms of an abstract binary notation, the Category A examples were 11111, 11010, 00111, and 00001, whereas the Category B examples were 10100, 10010, 01100, and 01001. To construct the examples from this notation, the five stimulus dimensions (e.g., beverage preference) and features (e.g., diet coke vs. diet pepsi) were randomly assigned to the 1's and 0's. Thus, for one subject the pattern 11111 might have been represented by a description such as: *green car, July, apples, diet coke, and dark hair*. For another subject, however, this pattern might have been represented by the description: *diet pepsi, blue car, July, dark hair, and apples.*

The values on the first two dimensions were perfectly correlated in that the feature combinations 11--- and 00--- only occurred in Category A, whereas the feature combinations 10--- and 01--- only occurred in Category B. The assignment of features to values was counterbalanced, but if drink preference was on the first dimension and car preference was on the second dimension, then in Category A whenever *diet pepsi* occurred *blue car* also occurred, but whenever *diet coke* occurred *green car* occurred. Alternatively, in Category B, *diet pepsi* always occurred with *green car*, and *diet coke* always occurred with *blue car*. On the fourth and fifth dimensions, the value 1 was typical of Category A whereas the value 0 was typical of Category B.

After the eight examples had been memorized, subjects in the rule condition were instructed to analyze the stored examples and attempt to develop a rule or set of rules that would separate the descriptions in Category A from the descriptions in Category B. Subjects in the analogy condition, however, were discouraged from looking for rules. Instead of searching for rules, these subjects were instructed to make classification decisions by attempting to decide if the transfer items seemed more like the descriptions in Category A or the descriptions in Category B. The category assignments of the examples were not revealed until after the

memorization phase of the experiment. Thus, all analyses of the categories were based on stored information.

The transfer tests also consisted of descriptions of hypothetical people (e.g., likes diet pepsi, has a blue car, born in August, likes apples, and has dark hair). Twenty-four different transfer test were presented. All of the transfer tests were new items but the values on the correlated dimensions were either consistent with Category A or Category B. With the transfer test 11011, for example, the values on the correlated dimensions (i.e., 11---) favored a Category A response. The results were analyzed in terms of the proportion of responses that were consistent with the correlated features. Classifying 11011 as a member of Category A, for example, would be consistent with the correlated features (see Wattenmaker, McQuaid, & Schwertz, 1992, for additional details).

Results and Discussion

Across the twenty-four transfer tests, there were significantly more decisions that were consistent with the co-occurring features in the analogy than the rule condition (.65 vs. .54), $F(1,38) = 4.71$, $p<.05$, $MSe=14.93$. Examination of the pattern of errors across the transfer tests revealed that subjects in the analogy condition preserved co-occurrences as a by-product of using similarity relations. The transfer items appeared to be placed in the category that had learning examples that were perceived to be highly similar to the transfer items. This process of retrieving similar learning examples, and making classification decisions by analogy to the retrieved examples, indirectly preserved the correlations. Subjects in the rule condition, however, had difficulty identifying the co-occurrences. Instead, they developed simple rules that were either inaccurate or had little generality. The retrieval and computational processes that are required with postencoding analyses appeared to make it difficult to develop accurate rules that involved features from multiple dimensions.

Experiment 2

Although little sensitivity to co-occurrences was observed in the rule condition of Experiment 1, the presence of simple rules (i.e., typical features) might have prevented subjects from entertaining more complex hypotheses. Thus, this experiment was identical to Experiment 1, except that the category structure was altered so that there were no regularities in the categories other than the co-occurrences. (In terms of the abstract notation the Category A examples were 11100, 11011, 00001 and 00110, whereas the Category B examples were 10001, 10110, 01100, and 01011).

Results and Discussion

Again an analogical transfer mode was very effective for preserving co-occurrences, but very few subjects in the rule condition were able to detect the co-occurrences. Overall, when the co-occurrences were consistent with similarity relations, 86% of the decisions in the analogy condition preserved the co-occurrences whereas 72% of the decisions in the rule condition preserved the co-occurrences, $F(1,42) = 5.08$, $MSe = 7.52$, $p<.05$. As in Experiment 1, subjects in the analogy condition appeared to make decisions by analogy to highly similar learning examples, and the feature co-occurrences were preserved as a by-product of this process. It was still difficult to capture the co-occurrences with postencoding analyses, however, as only four subjects accurately reported the correlation. Indeed, eleven subjects in the rule condition reported that they were unable to find a rule, and ten of these subjects spontaneously adopted an analogical strategy.

Experiment 3

Experiment 3 was designed to produce conditions that would be especially conducive to rule-based transfer. Specifically, the materials in the first two experiments consisted of lengthy lists of unrelated features, and the examples were highly similar, unfamiliar, and poorly integrated (e.g., blue car, July, diet coke, light hair, and apples). Materials of this type make it difficult to retrieve examples and to keep retrieved examples active in working memory. Thus, to increase the accessibility of the examples and the features, an attempt was made to use distinct, familiar, and well-integrated examples.

As in Experiments 1 and 2, the subjects were shown exemplars from two categories, and within each of these categories specific pairs of features were perfectly correlated with each other. The following features were used to construct the examples: male vs. female, politician vs. entertainer, and active career vs. inactive career. However, rather than presenting these features in list form, a single

expression that integrated the features was presented. For example, if the underlying features of an example were *male, politician, and inactive*, then rather than presenting this list of features, the name of a well-known person who represented this combination was presented (e.g., *Winston Churchill).* Thus, the feature co-occurrences that were present in the underlying features (e.g., that male co-occurred with inactive) were preserved in the specific examples.

These familiar, well-integrated, and distinct examples should facilitate rule-based transfer by increasing the ease and accuracy of retrieval, by making it easier to keep retrieved features active in working memory, and by minimizing confusions between exemplars during retrieval and analysis. To eliminate potential problems in identifying the relevant features, participants were provided with the relevant features before the start of the transfer phase.

Method

Participants in both conditions initially memorized name-number associations (e.g., Winston Churchill-12). There were sixteen famous people (eight in each category) and the categories were distinguished by feature co-occurrences. In terms of the abstract notation, the examples in Category A were 110, 111, 111, 111, 000, 001, 001, and 001, whereas the examples in Category B were 101, 100, 100, 100, 011, 010, 010, and 010. Although some of the abstract patterns re-occurred within a category, each occurrence was represented by a different person. For instance, if the pattern 111 corresponded to the features *male, political, and inactive*, then in one case this pattern might be represented by Abraham Lincoln, in a second case by Thomas Jefferson, and in a third case by Winston Churchill.

The features on the first two dimensions co-occurred. These co-occurrences were of the same form as the co-occurrences in Experiment 1 and 2. Although the correlations were never directly presented, they were preserved in the exemplars. Consider, for example, a case where the Category A examplars were Ted Kennedy, John Adams, Thomas Jefferson, Winston Churchill, Barbra Streisand, Judy Garland, Greta Garbo, and Rita Hayworth, whereas the Category B examples were Eleanor Roosevelt, Margaret Thatcher, Geraldine Ferraro, Sandra O'Connor, Charlie Chaplin, Paul Newman, Robert DeNiro, and Michael Douglas. Notice that in Category A all the males were connected to politics whereas all the females were connected to entertainment. In Category B, however, all the females were connected to politics whereas all the males were connected to entertainment. Thus, all of the co-occurrences were implicitly represented in the exemplars.

Following the paired-associate learning procedure, the numbers (but not the names) were used to reveal the categories, and participants were induced to make transfer decisions by analogy or to search for rules. Before the transfer tests were presented, subjects in all conditions were given the features that had been used to construct the names. Unlike the learning examples, the transfer items consisted of lists of relevant features (e.g., male, political, active), and the task was to place the items in Category A or B. Again the results were analyzed in terms of the proportions of the responses that were consistent with the correlation. In terms of the categories that were illustrated above, for example, classifying the description *political, male, active* as a member of Category A would be consistent with the correlation. Ratings were collected to ensure that the famous people were perceived to have the correct combinations of underlying features.

Results and Discussion

Although very different stimulus materials were used in this experiment, exactly the same results that were observed in Experiments 1 and 2 were obtained: participants who used an analogical transfer mode were significantly more likely to make classification decisions that were consistent with the co-occurring features than subjects who used a rule-based transfer mode (.78 vs .64), $F(1,62) = 5.02$, $p<.05$, $MSe=3.81$. Even though the stimulus materials were designed to facilitate hypothesis testing in the rule condition, very few subjects in the rule condition were able to detect the co-occurrences. Instead, these subjects tended to develop rules that were inaccurate or that had very little generality.

Experiment 4

The feature co-occurrences were implicitly represented in the examples that were presented in Experiment 3. Although these materials were designed to facilitate postencoding rule abstraction, materials of this type have rarely been used and it is possible that intra-dimensional correlations of the type used in Experiment 3 are difficult to detect. To

examine this possibility, the same materials that were used in Experiment 3 were presented to subjects under rule-based *encoding* conditions rather than rule-based memory conditions (i.e., the examples were visible rather than stored in memory during analysis).

Results and Discussion

When the names were visible during rule-seeking activity the vast majority of subjects detected the co-occurrences. Indeed, 90% of the classification decisions in the on-line rule condition preserved the co-occurrences. Thus, the failure of subjects in the rule condition of Experiment 3 to detect the co-occurrences appears to reflect basic limitations associated with analyzing information in memory.

Experiment 5

An analogical transfer mode was very effective for preserving co-occurrences in the first three experiments. In these experiments, however, the transfer tests were lists of features, the co-occurring features were expressed directly in this list, and no irrelevant properties were included in the transfer items. For example, although the learning examples in Experiment 3 were unique (e.g., Winston Churchill), the transfer tests consisted of lists of features that included the co-occurrences (e.g., "male, political, and inactive" where the co-occurrence was between male and inactive). To see if correlated features would be preserved as a by-product of analogy in noisier retrieval environments, the same materials and category structures that were used in Experiment 3 were used in this experiment but rather than presenting the underlying features on the transfer tests, new names of famous people (e.g., *Abraham Lincoln*) were used as transfer items. These names contained implicit correlations that were either associated with Category A or Category B. Clearly, when learning and test items both possess unique or irrelevant features, there are a multitude of idiosyncratic properties that can be ascribed to the items (nationality, political views, personality attributes, etc.). Thus, to see if an analogical transfer mode would still be effective under these conditions, learning and transfer items that possessed a wealth of irrelevant properties were presented. The procedure in this experiment was identical to Experiment 3, except that only an analogical condition was tested.

Results and Discussion

Even under more difficult retrieval conditions, an analogical transfer mode was effective for preserving co-occurring properties. Indeed, for those subjects who used analogy, 73% of the time they selected the category that was consistent with the co-occurring features, $t(39)= 2.23$, $p< .05$. The co-occurrences appeared to constrain retrieval and similarity calculations, and the influence of these implicit co-occurrences was strong enough to override possible influences of irrelevant features.

General Discussion

In all of the experiments, an analogical transfer mode was more effective than a rule-based transfer mode for preserving feature co-occurrences. This result held across a variety of category structures and stimulus materials and was highly consistent within as well as between condition: whenever subjects adopted a rule-based transfer mode they were significantly less likely to preserve correlated features in classification decisions than subjects who relied on analogy.

Although there was no direct awareness of the co-occurrences in the analogy condition, the process of making decisions by analogy to retrieved examples indirectly preserved the co-occurrences. This mechanism was effective even when the co-occurrences were not explicitly presented in the examples, and when both learning and transfer items had irrelevant features.

Subjects who used an analytic transfer mode, however, had difficulty detecting feature co-occurrences. Even when the category structures (Experiment 2) and stimulus materials (Experiment 3) were designed to facilitate postencoding analyses, little sensitivity to correlated features was observed. Results that are very similar to the current pattern of results have been observed with memory-based category construction tasks (Wattenmaker, in press). The results of these two sets of experiments suggest that when people attempt to induce rules from stored instances they will have a tendency to develop simplistic or inaccurate generalizations at the cost of missing more complex regularities that exist in stored information. In general, the retrieval and computational processes that are required with postencoding analyses appear to make it difficult to develop accurate rules that involve features from multiple dimensions. Many of these difficulties appear to be due to limitations in working memory

capacity. An analogical transfer mode is adaptive because it provides a way for relational properties such as co-occurrences to be retrieved and to influence classification decisions without overwhelming processing and memorial capacities.

References

Brooks, L. (1978). Nonanalytic concept formation and memory for instances. In E. Rosch and B. C. Lloyd (Eds.), *Cognition and Categorization* (pp. 169-215). New York: Lawrence Erlbaum Associates.

Brooks, L. (1987). Decentralized control of categorization: The role of prior processing episodes. In U. Neisser (Ed.), *Concepts and Conceptual Development: Ecological and Intellectual Factors in Categorization* (pp. 141-174). Cambridge: Cambridge University Press.

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

Holyoak, K. J. & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory & Cognition, 15*, 332-440.

Medin, D. L., & Smith, E. E. (1981). Strategies and classification learning. *Journal of Experimental Psychology: Human Learning and Memory, 7*, 241-253.

Medin, D. L., Altom, M. W., Edelson, S. M. & Freko, D. (1982). Correlated symptoms and simulated medical classification. *Journal of Experimental Psychology: Human Learning and Memory, 8*, 37-50.

Medin, D. L. (1983). Structural principles in categorization. In Tighe, T. J. & Shepp, B. E. (Eds.). *Perception, Cognition, and Development: Interactional Analyses*, (pp. 203-230). Hillsdale, NJ: Lawrence Erlbaum.

Medin, D. L. (1986). Comment on "Memory storage and retrieval processes in category learning." *Journal of Experimental Psychology: General, 115*, 373-381.

Medin, D. L., & Edelson, S. (1988). Problem structure and the use of base rate information from experience. *Journal of Experimental Psychology: General, 1*, 68-85.

Nosofsky, R. M., Clark, S. E., & Shin, H. J. (1989). Rules and exemplars in categorization, identification and recognition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 15*, 282-304.

Ross, B. H. (1989). Remindings in learning and instruction. In S. Vosniadou & A. Ortony (Eds.). *Similarity and Analogical Reasoning* (pp. 438-469). Cambridge: Cambridge University Press.

Wattenmaker, W. D., Nakamura, G. N., & Medin, D. L. (1988). Relationships between similarity- based and explanation-based categorization. In D. Hilton (Ed.), *Science and Natural Explanation: Common Sense Conceptions of Causality* (pp. 204-240). Brighton, England: Harvester Press.

Wattenmaker, W. D. (1991). Learning modes, feature correlations, and memory-based categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 908-923.

Wattenmaker, W. D. (In press). Relational properties and memory-based category construction. *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

Wattenmaker, W. D., McQuaid, H. L., & Schwertz, S J. (1992). Rules, analogy, and memory-based classification. Under review.