Effects of Background Knowledge on Family Resemblance Sorting

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Abstract

Previous studies on category construction have shown that people have a strong bias of creating categories based only on a single dimension. Ahn and Medin (1989) have developed a two-stage model of category construction to explain why we have categories structured on the basis of overall similarity of members in spite of this bias. The current study investigates effects of background knowledge on category construction. The results showed that people created family resemblance categories more frequently when they had a priori knowledge on prototypes of potential family resemblance categories. It was also found that people created family resemblance categories much more frequently when they had knowledge on underlying dimensions which integrated surface features of examples. How the two-stage model should be extended is discussed.

Introduction

Generally, it has been argued that natural categories lack defining features that are true to all members in the same category (Rosch & Mervis, 1975; Smith & Medin, 1981). Instead, natural categories are considered to have family resemblance (FR) structure: members in the same category are generally similar to each other but members in different categories are dissimilar to each other. Rosch (1975) argued that FR categories might be created because people would try to achieve a compromise between maximizing within-category similarity and minimizing between-category similarity. However, previous studies showed that people rarely sort unclassified examples based on their overall similarity (Ahn, 1990; Ahn & Medin, 1989; Imai & Garner, 1965, 1968; Medin, Wattenmaker, & Hampson, 1987). Subjects in these experiments showed a strong tendency to sort examples based on values on a single dimension (uni-dimensional sorting) to create categories with defining features.

Ahn and Medin (1989) developed a two-stage model to explain why we have FR structure in spite of this strong bias for uni-dimensional sorting. Although the two-stage model has so far been successful in describing when uni-dimensional sorting and when FR sorting will be observed, the model has only been applied to domains where people do not have any background knowledge on examples to be classified. The present work investigates the effects of various types of background information on creation of FR categories. Specifically, this study is concerned with how knowledge about prototypes and underlying dimensions affect people's sorting behavior.

The first part of the paper briefly reviews previous data from free sorting tasks in knowledge-poor domains, followed by the two-stage model's explanations of these data. The second part presents an experiment in which subjects were provided with either prototypes or theories underlying categories. The final section discusses how the two-stage model should be extended to handle the data obtained in the current experiment.

Previous Results

Medin et al.'s experiments (1987) are the first systematic study showing that people rarely created FR categories even when exemplars to be classified were developed around prototypes on the basis of overall similarity. Figure 1 shows the abstract notation of stimuli used in their experiments. In this figure, the first column (E1, E2, ...) indicates each examples and the next four columns indicate each example's values on 4 dimensions (D1, D2, D3, and D4). These exemplars had characteristic features in the resulting FR categories (i.e., features that are generally true to members in the same category but can also appear in contrasting categories). The exemplars are laid out in two categories, each of which indicate one of the potential FR categories.

	D1	D2	D3	D4		D1	D2	D3	D4
E1	0	0	0	0	E6	1	1	1	1
E2	0	0	0	1	E7	1	1	1	0
E3	0	0	1	0	E8	1	1	0	1
E4	0	1	0	0	E9	1	0	1	1
E5	1	0	0	0	E10	0	1	1	1

Figure 1. Abstract Notation of Stimuli Used in Medin, Wattenmaker, & Hampson(1987)

This set consists of two prototypes (E1 and E6) and four distortions of each prototype, which were developed by replacing a value of a prototype with the value of a contrastingg prototype. Subjects in Medin et al.'s experiments were asked to create two categories from these exemplars. According to similarity-based clustering models (see Anderberg, 1973; Massart & Kaufman, 1983, for reviews), and category construction models considering predictability of categories as a critical determinant of category construction (Anderson, in press; Fisher 1989), the two categories that the subjects would create should be FR categories (see Ahn, 1990; Ahn & Medin, 1989 for more details). However, almost all subjects in Medin et al.'s experiments sorted examples based on values on a single dimension. Then why do we have FR categories?

Two-Stage Model

To explain these results, Ahn and Medin (1989) proposed a two-stage model of category construction; the first stage involves sorting examples based on one dimension and the second stage involves assigning remaining examples based on their overall similarity to the initially created categories (see also Ahn, submitted; Ahn, 1990, for more details). Ahn and Medin argued that the reason why hardly any FR sorting was observed in Medin et al.'s experiments was because their examples had characteristic features in the resulting FR categories: after subjects carried out uni-dimensional sorting in the first stage, there existed no remaining examples to be classified in the second stage, resulting in uni-dimensional categories.

The two-stage model argues that FR categories can be created as a by-product of the two stages only when the resulting categories have sufficient features. Take an example of the set used in Ahn and Medin (1989) shown in Figure 2 under the

Sufficient set. The FR categories from this set consisted only of sufficient features (i.e., 0's and 2's). Suppose a task is to create two categories and the first dimension was chosen for the most salient dimension. In the first stage, the model categorizes E1, E2, E3, and E4 into one category and E6, E7, E8, and E9 into another category. In the second stage, one of the remaining examples, E5, is grouped with E1, E2, E3, and E4, and E10 is grouped with E6, E7, E8, and E9, based on their overall similarity. As a result, the final categories have a FR structure. On the other hand, when the resulting FR categories have characteristic features such as in the set used in Medin et al.'s experiments and the Characteristic set in Figure 2, the resulting categories are always uni-dimensional.

In Ahn and Medin's experiments, as predicted by the model, no subjects given the Characteristic set created FR categories whereas more than half of those given the Sufficient set created FR categories.

Sufficient Set				Characteristic Set			
E1	0 0 0 0	E6	2 2 2 2	E1	0 0 0 0	E6	2 2 2 2
E2	0 0 0 1	E7	2 2 2 1	E2	0 0 0 1	E7	2 2 2 0
E3	0 0 1 0	E8	2 2 1 2	E3	0 0 2 0	E8	2 2 1 2
E4	0 1 0 0	E9	2 1 2 2	E4	0 1 0 0	E9	2 0 2 2
E5	1 0 0 0	E10	1 2 2 2	E5	2 0 0 0	E10	1 2 2 2

Figure 2. Abstract notation of Sufficient and Characteristic Set

Sorting in Knowledge-Rich Domains

Although existence of sufficient features is shown to be an important determinant of sorting in knowledge-poor domains, it may not be the only one in knowledge-rich domains. Results from Medin et al.'s Experiments 5 and 6 suggest that knowing interproperty relations is an important determinant of creation of FR categories. They used personality descriptions, prototypes of which are descriptions of either an introvert or an extrovert person. When all four dimensions were developed in such a way that they could be related in terms of a single underlying dimension (i.e., introvert / extrovert dimension), most of the participants created FR categories. However, these experiments relied on the background knowledge that was pre-experimentally obtained by the subjects.

To better control the background knowledge, in the current experiment, knowledge on interproperty relationship is experimentally manipulated by providing participants with information on how dimensions could be related in terms of a deeper theory[1]. Take an example used in the current experiment. There were four dimensions which were descriptions of tribes: The first dimension was whether a tribe wore cotton clothes or leather clothes. The second dimension was whether they had monotheism or polytheism. The third dimension was whether they were ruled by hierarchical leaders or by a single leader. The fourth dimension was whether they

[1] There have been debates on what theories are. Although in this paper I used the term, theory, to refer to underlying dimensions and their relationship with surface features, it may be an inappropriate use of the term.

cremated the dead or buried the dead.

At first sight, these dimensions seem to be just a list of independent features, but they can be easily integrated in terms of an agricultural / nomadic dimension. That is, agricultural tribes wore cotton clothes obtained in their farms, were monotheists because they hardly had any chance to learn other types of religion, had hierarchically organized leaders to control farmers living in their areas, and buried the dead near their farms. Nomadic tribes wore leather clothes obtained from their hunting, were polytheists because they had contacted many types of religions while travelling, had a single leader to make flexible and quick decisions in their changing environments, and cremated the dead because they were always on the move.

The underlying theories can be also used to determine prototypes of categories (or ideals, Barsalou, 1985) of the potential FR categories, each of which consists of characteristic values of each category. Therefore, even if FR sorting is observed when interproperty relationships are known, it can be simply attributed to the advantage of knowing the prototypes of the FR categories. To investigate whether there is an additional advantage of knowing theories besides knowing prototypes, it is important to have a condition in which subjects learn prototypes without knowing about interproperty relations.

Previously, prototypes have been considered as a collection of average or the most frequent values on each dimension used to represent members in the same category. In these types of prototype representations, interproperty relations are not necessarily preserved. In the case of agricultural / nomadic examples, knowing that a prototype of one category have values of "monotheism, cotton clothes, burying the dead, hierarchical leaders" does not indicate how these values are related to each other. Therefore, if subjects who receive only prototype information can be compared to those who receive underlying theories, we can examine whether there is an additional advantage of knowing interproperty relations.

Another rationale for having the prototype condition is as follows. People may learn the most typical examples first and then construct categories around the prototypes. One can argue that in the previous experiments, people might have failed to produce FR categories simply because they could not find prototypes. According to this argument, subjects may be more likely to create FR categories if prototypes are given before free sorting tasks. Therefore, introducing the prototype condition allows us to investigate whether the failure to construct FR categories was simply due to failure to identify prototypes.

Method

Basically, subjects received a set of exemplars and were asked to sort them into two groups of any size. There were two groups of subjects depending on whether they received the Characteristic set or the Sufficient set in Figure 2. Half of the subjects in each group received the set instantiated in pictures of flowers and the other half received the set instantiated in descriptions of tribes.

For the flower stimuli, the four dimensions and the values corresponding to 0 and 2 for each dimension were as follows. The first dimension was color with 0 being bright color and 2 being dark color. The second dimension was whether flowers bloomed at night or during daytime. The third dimension was whether flowers bloomed on trees or on grass. The fourth dimension was whether flowers were located near water or distant from water. (Parts of these stimuli were taken from Nakamura, 1985.) The subjects who received the flower stimuli were explicitly instructed about the four dimensions and their values. For the tribe stimuli, the four dimensions and the values were described in the earlier section. For both types of stimuli, the value 1 was absence of any value on the dimension. The subjects were told that if a certain dimension was not shown in an example, it meant that the information on the dimension was not available.

Within each stimulus set and within each stimulus type, there were three groups depending on types of background knowledge they received before sorting. The types of background knowledge that the subjects received were either none (Control group), prototypes (Prototype group), or underlying theories (Theory group).

The control group who did not receive any information about prototypes was simply asked to sort ten cards in a way that seemed natural to them. There were 78 subjects in the control group who were evenly distributed across the Characteristic and the Sufficient set conditions and across the two types of stimuli.

The Prototype group received eight non-prototype examples and was asked to sort them into two categories in a way that seemed natural to them. With these instructions, they received two prototypes of the potential FR categories (i.e., 0 0 0 0 and 2 2 2 2 in both the Characteristic and Sufficient set) and were told that these were the most typical exemplars of the two categories that they were to create. There were 80 subjects in the prototype group who were also evenly distributed across the various conditions.

The theory group received only the eight non-prototype examples coupled with theories underlying each category they were to create. For the flower stimuli, they were told that one group of flowers attracted a hypothetical class of birds called "champin" and the other attracted a hypothetical class of bees called "trood." They were also told that the champin birds liked bright color, were active at night, flew high, and laid eggs near water and that the trood bees liked dark color, were active during daytime, hovered low, and laid eggs distant from water. For the tribe stimuli, they were told about the theories on the agricultural / nomadic distinction mentioned in the earlier section. Although they could presumably determine the prototypes of the potential FR categories based on the theories, they did not see the actual prototypes during the experiment. There were 77 subjects in the theory group who were evenly distributed to the various conditions.

Results

The results are summarized in Table 1. Numbers in the table indicate percentages of FR sorting within each group within each set. Responses other than creation of FR categories were mostly uni-dimensional sorting.

Comparison between the Characteristic and the Sufficient sets

As in Ahn and Medin (1989), across all groups and across both kinds of stimuli, the Sufficient set led to more FR sortings than the Characteristic set. Chi-square and Fisher's exact tests indicated all the differences between the Sufficient set and the Characteristic set within each group were significant at $p=.05$ except for the theory group with the tribe stimuli (i.e., the difference between 78.9% and 100%).

	Flower Stimuli		Tribe Stimuli		Total	
Group	Char	Suff	Char	Suff	Char	Suff
Control	0	25	11	68	5	47
Prototype	20	90	45	100	33	95
Theory	55	95	79	100	67	98

Table 1. Summary of Results

Comparison among groups within the Characteristic set

In the previous experiments using materials in knowledge-poor domains (Ahn, 1990; Ahn & Medin, 1989), the subjects never created FR categories from the Characteristic set. In this experiment, when the subjects received prototype information on the Characteristic set, subjects created more FR categories (33%) than the control group who did not receive any background information (5%). In the flower stimuli, the difference between the control group (0%) and the prototype group (20%) who received the Characteristic set was not significant but in the tribe stimuli, the difference between the control group (10.5%) and the prototype group (45%) was significant ($p<.001$).

More subjects who received information on underlying theories created FR categories from the Characteristic set (67%) than those who received either prototype information (33%, $p<.05$) or no information (5%, $p<.05$). Within each stimulus type, these differences were also significant.

Comparison among groups within the Sufficient set

For the Sufficient set, almost all subjects in both the prototype group (95%) and the theory group (98%) produced the FR categories. The differences between these two groups and the control group (47%) was significant ($p<.05$). Separate analyses within each type of stimuli also showed the same kind of results.

Discussion

The results of the present experiment can be summarized as follows.

First, results in knowledge-poor domains (Ahn & Medin, 1989) were replicated by the control group in the current experiment. The control group who did not have any background knowledge rarely produced FR categories when the structure of exemplars had characteristic features in the resulting FR categories but a fair amount of FR categories was produced when they had sufficient features. Therefore, the two-stage model's explanation of FR sorting in knowledge-poor domains was once again supported.

Secondly, even when the potential FR categories had characteristic features, the knowledge on the prototypes of the potential FR categories led to the creation of FR categories. However, the difference between the prototype group and the control group in producing FR categories from the Characteristic set was significant only when the tribe stimuli were used, and it was not significant when the flower stimuli were used. The reason for this difference between the two types of materials is unclear.

Third, when the examples to be classified had characteristic features in the resulting FR categories, the theory group produced much more FR categories than both the control group and the prototype group. The significant difference between the theory group and the prototype group clearly showed that knowing underlying theories is more than simply knowing prototypes that could be derived from the theories.

These results suggest two problems with the current version of the two-stage model. First, the model does not explain why knowing prototypes in advance help people create FR categories. Considering the subjects' protocols, the prototype group seemed to be able to get over the strong bias of uni-dimensional sorting and instead they seemed to try to maximize matches between members of a category and its prototype. If people learn the most typical examples first, then the two-stage model might not be an appropriate account for category construction process.

Secondly, the advantage of knowing interproperty relationships is not explained by the model in its current form. However, sorting based on an underlying theory can be considered as a type of uni-dimensional sorting and therefore, it is not inconsistent with the spirit of the two-stage model.

The current version of the two-stage model assumes that features used for sorting are only surface features used to describe examples. However, people's strong bias to create highly structured categories (i.e., categories with defining features) would make them rely on background knowledge if it can provide them with defining features of categories. In other words, if background information provide them with a way to create a new dimension which allows them to construct categories that meet the task demand and that have defining features, they would rather create the new dimension than using only the given surface dimensions. Therefore, the two-stage model should be extended to allow creation of new dimensions using background knowledge if the new dimensions are better than the surface features in creating categories with defining features.

Conclusion

Based on the series of free sorting experiments conducted so far, it can be concluded that there are at least three ways to obtain FR structure. First, FR categories can be obtained as a result of two stages in which the first stage involves uni-dimensional sorting and the second stage involves assigning exceptions based on overall similarity. Secondly, knowing prototypes of each category before category construction encourages creation of FR categories. Third, the most effective way of producing FR categories known so far is creating a new dimension which can integrate surface features and carry out uni-dimensional sorting based on this dimension.

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